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Reuse of Excreta and Discharge of Effluents

HUMAN EXCRETA should be regarded as a natural resource to be conserved and reused as night soil, as sewage, or as the effluent or sludge from a sewage treatment works rather than discarded. Excreta may also be composted with organic material (such as urban refuse), which provides the carbon necessary for the composting process (discussed in chapter 5).

In all forms, excreta can provide a rich source of nitrogen and other nutrients necessary for the growth of terrestial and aquatic plants. If excreta are reused as sewage or as sewage effluent, recycling simultaneously provides valuable water, an added agricultural benefit in arid regions. When excreta are broken down anaerobically by microbial action, methane is produced and can be used as energy for heating, lighting, and other purposes.

There are, however, situations in which sewage effluents should be discharged without reuse. These may occur when there are no appropriate opportunities for reuse, when there is no local demand for the product of the reuse process, or when discharge is economically the most attractive option.

The purpose of this chapter is to explore the health implications of excreta reuse and effluent discharge. For a literature review and technical assessment of the subject, the reader should consult Rybczynski, Polprasert and McGarry (1978) and Kalbermatten and others (1982). The practices considered below are agricultural reuse, aquacultural reuse, biogas generation, and effluent discharge.

Reuse in Agriculture

The common, and in some ways most attractive, form of waste reuse is agricultural—the application of sewage, sludge, or night soil to the land. The method of application depends in part upon the solids content of the material, and each of these fecal products may be used raw or after varying degrees of treatment. These materials, when applied to farming land, are important soil conditioners and often provide additional plant nutrients. Sewage and sewage effluents will also provide water, which may be a very scarce resource in arid areas. The health hazards associated with reuse are of two kinds: the occupational hazard to those employed to work on the land being fertilized, and the risk that contaminated products from reuse may subsequently infect humans or animals through consumption or handling. The occupational hazard is described in a separate section below, and it is only the risk from contaminated products that will be considered here. Such risk depends largely on the type of product, three categories of which are examined: foodstuffs for human consumption, foodstuffs for animal consumption, and agricultural products put to other uses.

Foodstuffs for human consumption

The direct, agricultural application of raw night soil to food crops has been widely practised in many countries for centuries. There is no doubt that this reuse contributes significantly to the transmission of a broad variety of human infections. It is therefore condemned by most, if not all, health authorities and advisory agencies, and attention is now being directed to the reuse of treated effluents, sludges, and night soil to enhance agricultural production.

HEALTH ISSUES. The health problems associated with waste reuse in the production of human food may be broken down into a series of questions:

- How many pathogens and of what kind reach the field or crop?
- Are pathogens likely to survive in sufficient numbers and for sufficient time to cause subsequent infection?

- How significant is this infection route compared with all other potential infection routes?

The concern here is with the health risks to those who handle, prepare, or eat the crop after it has been harvested.

PATHOGENS REACHING THE FIELD. All pathogens in the reused waste may reach the field. Different treatment technologies will remove different pathogens to varying degrees, as discussed in chapters 5 and 6. Where effluent is used, the only treatment processes that will produce an effluent free or almost free of pathogens are waste stabilization ponds or conventional treatment followed by maturation ponds, land application, or sand filtration. Where sludge or night soil are used, the only processes which will yield a totally pathogen-free product are batch thermophilic digestion, thermophilic composting, or drying for at least 1 year.

PATHOGEN SURVIVAL. If pathogens are not removed by these processes, they will arrive at the field. Survival times of excreted pathogens in soil are summarized in table 4-5 and extensively reviewed in Part Two.

Whether or not the pathogens become attached to the surface of the crops depends upon the method of application and the crop. Crops grown on or near the ground are almost certain to become contaminated. Where wastes are sprayed or poured on fields with growing crops, contamination is also certain. Crops may be protected by subsurface irrigation, by drip or trickle irrigation where crops are not on the ground, by irrigation in furrows not immediately adjacent to the crops, or by similar techniques. Alternatively, wastes may only be applied prior to planting, or application may be discontinued one month before harvesting (with the hope that all pathogens will die before the harvest). All these methods may be effective in preventing crop contamination when the waste applied has been treated. When a waste rich in pathogens is used, however, pathogens are likely to reach the crops despite these protective strategies.

Once pathogens are on the crop, their survival is not long compared with survival in soil (table 4-6). The factors most lethal to pathogens are desiccation and direct sunlight. Survival may be expected to be much shorter in dry, sunny climates than in humid, cloudy ones.

Survival rates are quite sufficient, however, for viable pathogens (except, perhaps, protozoa) to be transported into markets, factories, and homes and subsequently to infect those who handle, process, prepare, or eat the contaminated crops. A distinction is sometimes made between crops eaten raw (tomatoes, for instance) and those normally cooked (such as cabbage). Conservative and appropriate public health policy regards these similarly because, even if a food crop is eventually cooked, those who handle and prepare it are still at risk.

PATHOGEN TRANSMISSION. The epidemiological literature reviewed in Part Two indicates that, wherever an infection is highly endemic in a community wherein poverty and squalor are also found, the introduction of the particular pathogen into the home on contaminated vegetables or other crops may have a negligible effect on transmission. In contrast, wherever an infection is not widespread in a community that has improved its standards of hygiene and housing, the introduction of contaminated crops into the home may be the major transmission route for some excreted pathogens. Thus, the significance of contaminated crops in disease transmission has mainly been emphasized in countries such as Japan, Israel, South Africa, or Germany in postwar periods, when use of sewage or excreta on crops was combined with a relatively high level of hygiene and housing.

This state of affairs can be illustrated by a hypothetical example. Imagine a town of moderately wealthy people who live in houses with water connections and flush toilets. Outside this town is a village where people are extremely poor, houses have earth floors, water is drawn from an open well, and no adequate excreta disposal system exists. The main source of income for the village is the cultivation of vegetables for sale to the town; vegetables are also used by the villagers as subsistence crops. These vegetables are fertilized by night soil collected in the village and by sewage sludge obtained free of charge from the treatment works on the outskirts of the town. The prevalence of roundworm (*Ascaris lumbricoides*) infection in the town is only 8 percent, and the principal means of entry to the home of viable *Ascaris* eggs is on the vegetables bought from the villagers. Transmission among the wealthy townsfolk does not take place because their excreta are flushed away and high standards of hygiene prevail. The prevalence of ascariasis in the village, however, is 68 percent, and transmission occurs intensively, particularly in the home. The floors and yards of the village houses are contaminated with viable eggs from the feces of infected children. Most transmission is quite unrelated to the contaminated vegetables that the villagers eat. If the supply of contaminated vegetables from the village suddenly ended, the transmission of ascariasis in the town would be reduced very substantially, but transmission in the village would be unaffected.

Ascariasis was selected for this example because as an infection with high persistence it illustrates the point most effectively. For other pathogens, transmission may be more complex but the same principles may apply. For instance, if cholera were introduced to the area envisioned above and the crops were contaminated with *Vibrio cholerae*, the contaminated vegetables might cause an epidemic in the town and might be the major route of transmission. The village would, in all probability, experience a cholera outbreak in any case, and the vegetables might be only a slight contributing factor. An outbreak of cholera in Jerusalem in 1970 manifested epidemiological characteristics similar to this hypothetical example (Cohen and others 1971).

Foodstuffs for animal consumption

A widespread use of sewage effluents, sludge, and night soil is in application to pastures or fodder crops subsequently fed to animals. In the United Kingdom, for instance, 74 percent of all sewage works sludge is disposed of on land, the remainder dumped at sea. Of the sludge disposed of on land, 21 percent is spread on grazing land, 35 percent on general arable land, 33 percent is dumped, and the remainder is used in horticulture, forestry, and land reclamation. Of the sludge applied to grazing land, 29 percent is applied raw and 71 percent is applied following digestion (Standing Committee on the Disposal of Sewage Sludge 1978). A wide variety of animal pathogens may be encountered in sewage sludge, and night soil, including:

Viruses causing:	*Bacteria causing:*	*Helminths causing:*
Foot and mouth disease	Anthrax	Beef tapeworm infection
Porcine encephalomyelitis	Brucellosis	Pork tapeworm infection
Rabies	Leptospirosis	
Rinderpest	Salmonellosis	
Swine fever	Tuberculosis	

HEALTH ISSUES. Despite this alarming array of infections, it is clear that, in most cases, the sewage or sludge will contain an insignificant number of these pathogens and will have a negligible effect in transmitting these diseases. There are three exceptions, however, in which the use of human wastes on pastures or fodder crops may promote the transmission of diseases of significant human or veterinary importance: beef tapeworm infection, salmonellosis, and tuberculosis.[1]

BEEF TAPEWORM INFECTION. Beef tapeworm (*Taenia saginata*) is by far the most important of these exceptions (it is described in detail in chapter 34). This helminth circulates between humans and cattle, but infection only continues when cattle eat *Taenia* eggs excreted by humans. Any treatment, disposal, or reuse technology that brings cattle into direct contact with human excreta may therefore promote the transmission of the disease unless adequate waste treatment is provided. *Taenia* eggs are hardy and are surpassed only by *Ascaris* eggs in their ability to survive outside the host (they may survive in soil or on pasture for > 6 months). Their removal from effluent will require either the use of waste stabilization ponds or tertiary treatment in the form of sand filtration, land application, or lagooning. Removal of *Taenia* eggs from sludge requires either a thermophilic process or retention for over a year. *T. saginata* infection in humans is not a major public health problem in most countries. The importance of controlling the infection lies in its consequences for the beef industry. Carcasses found to contain the cysts of *T. saginata* are condemned in whole or in part and the economic loss is substantial in areas of high transmission.

SALMONELLOSIS. Sewage effluents, sludges, and night soil from all large communities in both rich and poor countries will contain substantial numbers of salmonellae. Figures of 10^4 organisms per liter of raw sewage and of raw sludge are not uncommon in Europe. These salmonellae may reach pastures or fodder crops and may infect animals and animals may subsequently infect people. The infective doses required are high, however, and *Salmonella* infections are transmitted among cattle by many ways other than contaminated fodder. There is no clear evidence that cattle grazed on pastures fertilized with wastes are at more risk from salmonelloses than other cattle (see chapter 15).

TUBERCULOSIS. Wastes from institutions treating tuberculosis patients, or from industries such as dairies and abattoirs that handle tuberculous animals, will almost certainly contain *Mycobacterium tuberculosis*. Studies in Denmark (Jensen 1954) showed tubercle

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[1] Pork tapeworm (*Taenia solium*) infection has been omitted from this discussion because, although the use of human wastes on fodder crops fed to pigs would undoubtedly promote the transmission of this helminth, in practice its life cycle usually depends on pigs gaining direct access to human feces, which they eagerly eat.

bacilli in the sewage produced by 5 towns with tuberculosis sanatoria. Tubercle bacilli were also demonstrated in the effluent, digested sludge, and 5-week-old dried sludge from the treatment plants of these towns.

Chlorination will remove tubercle bacilli from sewage effluent, although they are more resistant than *Escherichia coli.* In one experiment an applied dose of 10 milligrams per liter of chlorine removed tubercle bacilli from an effluent having a BOD_5 of 11–63 milligrams per liter (Jensen 1954). Greenberg and Kupka (1957) concluded, however, that a chlorine dose of 20 milligrams per liter and a contact time of at least 2 hours were required to remove tubercle bacilli from a well-oxidized effluent. Sludge has been recorded as containing at least 7×10^5 tubercle bacilli per gram of dry matter (Heukelekian and Albanese 1956), and 15 months on a drying bed were required to remove these in Denmark (Jensen 1954). Sludge may also be disinfected by thermophilic processes, in which tubercle bacilli are killed after 20 minutes at 66°C.

In summary, tubercle bacilli may be numerous in sewage, sludge, and night soil, and they are more persistent and resistant to disinfection than the enteric bacteria. The epidemiological significance of this is unclear. There is a case reported of tuberculosis in children who fell into a river polluted by sanatorium wastes (Jensen 1954). It remains most doubtful, however, that transmission of either human or bovine tuberculosis is significantly affected by exposure to wastes or polluted water.[2]

Other agricultural products

Fecal wastes may also be used to produce crops not intended for consumption by animals or humans. Examples are tree cultivation for timber production, beautification, or the control of desertification; the irrigation of parks; and the cultivation of commercial crops such as cotton or coconuts (Sundaresan, Muthuswamy and Govindan 1978). These reuse technologies pose health hazards mainly of an occupational kind. Workers in the fields and in the factories where the crops are processed are at risk (see the next section).

One reuse system worth special mention is the practice, now widespread in the Middle East and elsewhere, of using effluents to irrigate parks, lawns, central concourses or medians of highways, and other open amenity areas. Effluents are sometimes brought in tankers from the treatment works to the city center for this purpose. Where conventional treatment works without tertiary processes are operating, this practice involves great risk to the public health and should be condemned. It is only acceptable to use the effluents from waste stabilization pond or tertiary treatment processes and, even then, very careful monitoring of the pathogen content in these effluents is required. Compared with other reuses described in this chapter, the irrigation of amenity areas is a high-risk activity.

Occupational hazards

A health hazard common to all the agricultural reuse practices considered above is the risk to those who actually work in the fields. Although there is very limited epidemiological evidence to demonstrate the fact, it is likely that those who work in fields contaminated by excreted pathogens are at greater risk than others. If fieldworkers bring these infections back into their homes and subsequently infect their families, then a measurable difference in their health compared with that of nonagricultural workers and the whole community may not be apparent. Moreover, in many agricultural communities practically the whole population works in the fields at some time of the year, and so all may be exposed to the risk (although not equally).

The only sure way to protect the health of the agricultural workers is to use only wastes that are pathogen free or nearly so.[3] Once again this means only effluents that have undergone waste stabilization pond or conventional treatment followed by land application, sand filtration, or lagooning. Similarly, sludges or night soil require batch thermophilic processing, protracted drying, or storage for over 1 year.

A special problem affecting the health of agricultural workers is spray irrigation using sewage effluent. Aerosol droplets containing excreted viruses and bacteria may travel several hundred meters downwind, and excreted bacteria may be more infective (that is, have a lower infective dose) when inhaled than when

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[2] Tuberculosis has not been considered in Part Two. Those wishing to read further may consult Greenberg and Kupka (1957); Heukelekien and Albanese (1956); Jensen (1954); Maddock (1933); Pramer, Heukelekien and Ragotzkie (1950); Viraraghavan and Raman (1967); and Williams and Hoy (1930).

[3] This recommendation, with some others in Part One of this book, concerns ideal practice and is directed to those contemplating the establishment of new waste treatment and reuse projects. For those trying to upgrade existing systems, it should be noted that any measurable reduction in the pathogen content of a waste is likely to improve public health.

otherwise ingested.[4] There is therefore some cause for concern that aerosol-disseminated excreted viruses and bacteria can infect, by inhalation, those who work in, or live near to, spray-irrigated fields. A quite different potential hazard of spray irrigation is that it often causes ponding of effluent, and this might lead to increased populations of *Culex pipiens*, and other mosquitoes breeding in dirty water (Sorber and Guter 1975).

A study in Israel (Katzenelson, Buium, and Shuval 1976) showed that people in kibbutzim (cooperative agricultural settlements) practising spray irrigation with waste stabilization pond effluent had a higher incidence of shigellosis, salmonellosis, typhoid, and infectious hepatitis than people in kibbutzim practising no form of wastewater irrigation. This could be attributed either to the agricultural use of wastewater or specifically to the spray technique promoting aerosol transmission. Subsequent debate, and new studies in Israel (Shuval and Fattal 1980), have cast doubt on these findings. There is no conclusive epidemiological evidence of adverse health effects caused by exposure to wastewater aerosols at spray irrigation sites or sewage treatment plants (Pahren and Jakubowski 1980). Such health effects, if they do exist, are less likely in dry, sunny climates than in temperate climates because viruses and bacteria in aerosols are rapidly inactivated by warm temperatures, low humidity and bright sunlight.[5]

A specific occupational hazard in the agricultural reuse of excreta is schistosomiasis. Of the various species, the one whose transmission has been related to deliberate reuse rather than incidental pollution is *Schistosoma japonicum*. The eggs survive in feces for over a week, so that when excreta are applied fresh to irrigated rice fields containing the amphibious snail hosts, the snails may become infected. This occurs in several parts of Southeast Asia and, most notably, in China. After the schistosomes have developed within the snails, larvae that can bore through the human skin are shed into the water, thus creating the occupational risk to farmers. The snail-transmitted larvae of other flatworms encyst on vegetables or in fish and crabs, so that they infect the consumer rather than the agricultural worker. Excreta can be rendered free of live schistosome eggs by suitable treatment (see chapter 32).

Pathogen control in agricultural reuse

There is now a substantial literature on the health implications of the agricultural reuse of excreta, much of which is reviewed in Part Two. Several reviews of the topic, which some readers may find of additional value, are also available.[6]

It is clear from the discussion above that a desirable public health policy would be to require the highest quality standards for all wastes reused in agriculture. For effluents, this standard might be expressed in terms of a fecal coliform count of less than 100 per 100 milliliters (World Health Organization 1973). Such a standard, however, may tell little about the effluent content of viruses, protozoa, and helminth eggs, especially following the chlorination of the effluent, a process considerably more lethal to excreted bacteia than to other excreted pathogens (see the previous chapter). As discussed in chapter 4, *E. coli* is also an inappropriate indicator for the quality of treated sludges or night soil. For these materials the concentration of *Ascaris* eggs is a better guide to overall pathogen content.[7] Criteria for *Ascaris* have been adopted in China (McGarry and Stainforth 1978).

The imposition of stringent quality standards on effluents (for example, <100 fecal coliforms and fecal streptococci per 100 milliliters) restricts the range of treatment technologies considerably. It is fortunate that waste stabilization ponds are able to meet these standards and are a low-cost, appropriate form of waste treatment in hot climates (see chapters 4 and 6). Irrigation with waste stabilization pond effluent is therefore recommended.

The imposition of strict quality standards on sludges or night soil (<10 viable *Ascaris* eggs per 100 grams, for example) poses greater problems. Such standards can only be achieved by well-managed thermophilic digestion or composting, or by retention times of >1 year. A second-best choice, as indicated in figure 6-6, would be batch mesophilic digestion followed by several months on drying beds. An alternative for night soil reuse is its deposit in a facultative stabilization pond to produce a small effluent flow for irrigation or fish farming.

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[4] Enteroviruses and fecal indicator bacteria in aerosol droplets are discussed fully in the relevant sections of chapters 9 and 13.

[5] The costs of alternative methods of reducing any health hazards associated with spray irrigation are reviewed by Young (1980).

[6] See, for instance Benarde (1973); Bryan (1977); Burge and Marsh (1978); Crook (1978); Engelbrecht (1978); Gerba, Wallis and Melnick (1975); Goldberg (1979); Hickey and Reist (1975); Pahren and others (1979); Petrik (1954); Rudolfs, Falk and Ragotzkie (1950 and 1951 *a–f*); Shuval (1977); Sorber and Guter (1975); Sorber and Sagik (1978); Wiley (1962); Wiley and Westerberg (1969) and World Health Organization (1973).

[7] See Chapter 4, the section "Pathogen Indicators."

In conclusion, stringent quality standards may be set upon waste intended for agricultural reuse, and these standards can be achieved by relatively simple and low-cost technologies. Major problems in pathogen removal will only be encountered where conventional sewage treatment plants are in use. Such plants produce both an effluent and a sludge that are rich in pathogens and that require expensive additional treatment (see the previous chapter) before they can be recommended for unrestricted agricultural reuse.

Reuse in Aquaculture

Human excreta may be reused to promote the growth of aquatic flora and fauna, a practice known as aquaculture. Three principal kinds of aquaculture are common: fish farming, algae production, and macrophyte (macroscopic aquatic plant) production.

Fish farming

The raising of fish in ponds enriched with human and animal excreta has a long tradition. In China and elsewhere in Asia it has been operating continuously for centuries; it was practised in ancient Egypt and was widely used by European monasteries in the Middle Ages.

The controlled addition of wastes to ponds causes a large population of bacteria to thrive; these organisms in turn promote communities of phytoplankton (algae) and zooplankton, which then graze on the algae. With this rich food chain available, some fish, notably carp and tilapia, grow rapidly. Different fish species occupy different ecological niches—some feeding on large algae, some on small algae, some on zooplankton, some in the bottom layers, and some nearer the surface. For this reason, polyculture (the growing of several species in the same pond) is widely practiced (Muthuswamy and others 1978) because it greatly increases the total fish yield.

Fish may be grown in ponds enriched with sewage or night soil. Where sewage is used, it is usually pretreated, diluted, or both. An appropriate system is to grow fish in the maturation ponds of a chain of waste stabilization ponds (see figure 6-10); fish (except the air-breathing varieties) cannot be grown in facultative ponds because the biochemical oxygen demand (BOD) may exceed the oxygen supply, with the result that the water becomes deoxygenated, and the fish die. Night soil is commonly added to ponds either by locating latrines directly over them or by delivering night soil to them in carts or trucks.

In addition to promoting productivity, growing fish in waste-enriched ponds has other advantages. With reference to sewage treatment, nutrient removal is improved because nitrates and phosphates concentrate in the food chain and are thus removed during harvesting of the fish (Wert and Henderson 1978). The bacteriological quality of the sewage may also improve because the presence of fish appears to raise the oxygen levels and the pH (generally, to over 8.5) of the ponds, and both of these effects increase the death rate of enteric bacteria. Furthermore, there is some evidence that fish reared in sewage are less prone to disease than others.

HEALTH ISSUES. There are three distinct health problems associated with fish farming in excreta-enriched ponds:

- Passive transference of animal pathogens by fish contaminated by polluted water.
- Transmission of helminths whose life cycles involve fish as intermediate host.
- Transmission of other helminths with life cycles involving other pond fauna, such as the snail intermediate hosts of schistosomes.

The first of these problems is a cause for concern throughout the world, whereas the second and third apply only in areas where particular eating habits are found, where the helminths concerned are endemic, or both.

PASSIVE TRANSFERENCE OF EXCRETED PATHOGENS. Fish may passively carry excreted human pathogens in their intestines or on their body surfaces, and these pathogens may subsequently infect people who handle, prepare, or eat these fish. There is little risk to fish eaters except in areas where fish are eaten raw or partially cooked. Thorough cooking will destroy all excreted pathogens. The risk to those who handle or prepare the fish, however, is unaffected by the local eating habits.

Most studies on pathogen carriage by fish are related to fish caught in sewage-polluted seawater or rivers, but the principles of pathogen carriage will apply to fish farming as well. There is abundant evidence that the intestinal bacteria of humans and animals are not the normal resident flora of fish. Fish raised in contact with these bacteria may, however, acquire substantial numbers of them on their bodies and in their intestines. Fecal coliforms, fecal streptococci, and salmonellae are easily isolated from fish grown in polluted waters. A concentration effect is discernible, and concentrations of enteric bacteria in fish intestines tend to be higher than in the water in which the fish live. There is even evidence of their ability to multiply in the intestines of some fish (see chapters 13 and 15).

It is quite possible for pathogenic bacteria carried by fish in this way to infect people. It is equally possible for the contaminated fish to infect (especially with *Salmonella*) the animals fed on fishmeal and the people who eat these animals. In practice, however, it is equally likely that the fish will become infected after harvesting and during handling, transport, and processing (Brown and Dorn 1977). The major outbreaks of salmonelloses in animals and man known to be associated with fish have been associated with contamination after harvesting. It remains quite possible for fish to carry bacterial pathogens passively from enriched ponds to humans and thereby to cause infection. The survival of excreted bacteria in fish entrails or in fish transferred to clean water is generally reported as less than 14 days (see chapter 13), although some data suggest that salmonellae may survive for 2 months in fish guts (see chapter 15).

There is little information about the carriage of nonbacterial pathogens by fish. One must assume that viruses, protozoal cysts, and helminth eggs can all be carried, and even concentrated, in or on fish and thereby infect the eaters or handlers of fish. Helminth eggs will tend to settle to the pond bottom and therefore may only be ingested by bottom-feeding fish (such as the common carp, *Cyprinus carpio*).

HELMINTHS HAVING FISH AS INTERMEDIATE HOSTS. The second, and quite distinct, health problem associated with fish farming is the transmission of worms parasitic to man that have fish as intermediate hosts. The major helminths of this kind are: *Clonorchis sinensis* (Chinese liver fluke), *Diphyllobothrium latum* (fish tapeworm), *Heterophyes heterophyes*, and *Metagonimus yokogawai*. Of these, *Heterophyes* and *Metagonimus* are of no major public health importance (they are primarily parasites of dogs and cats, and *Heterophyes* only infects fish in brackish water—see chapter 30). *Diphyllobothrium* infects pike, perch, turbot, and other fish found in lakes or rivers and is not associated with enriched ponds (see chapter 25). *Clonorchis sinensis* and the related species of cat liver flukes, *Opisthorchis viverrini* and *O. felineus*, however, are associated with excreta-fed fishponds and are intensively transmitted where fish are eaten raw or partially cooked. Infection occurs principally in China, Korea, Taiwan, Thailand, and Vietnam, and the local prevalence can reach 60 percent. Cooking of fish must be thorough to kill the encysted larvae, and most preservative and pickling techniques for fish have little effect (see chapter 24).

Where fish are grown in pretreated or presettled sewage, *Clonorchis* eggs will have settled. Transmission is therefore associated with the direct enrichment of ponds with night soil or raw sewage. *Clonorchis* eggs are fragile and die if stored for a few days in night soil. Seven-day storage of night soil prior to pond enrichment is therefore a sound strategy for the control of this infection, but it must be noted that this helminth has other vertebrate hosts (such as dogs and cats) besides man and that the control of human excreta may only partially reduce transmission.

HELMINTHS WITH OTHER AQUATIC INTERMEDIATE HOSTS. Third, it is possible that schistosomiasis transmission—through the presence of the appropriate species of snails as intermediate hosts—may occur in the ponds and infect fishermen. This requires that fresh eggs or miracidia are reaching the ponds, an event that can be prevented by using only sewage treated in stabilization ponds or stored night soil (see chapter 32).

PATHOGEN CONTROL. In summary, fish farming that uses excreta or sewage carries with it the hazards of passive carriage of a range of pathogens and of transmission of *Clonorchis* and schistosomes in some parts of the world. Pathogen control may be accomplished by:

- Enriching ponds only with treated sewage, stored night soil, or sludge
- Allowing fish to reside in clean water for several weeks prior to harvesting
- Clearing vegetation from pond banks to discourage the molluscan intermediate hosts of *Clonorchis* and the schistosomes
- Promoting good hygiene in all stages of fish handling and processing
- Discouraging the consumption of undercooked fish.

Algal culture

Instead of growing fish in waste-enriched ponds with large algal populations, it is possible to harvest the algae directly. This is as yet only an experimental technique, but it may well find large-scale application in the coming decades. The advantage is that harvesting at a lower trophic level ensures far higher yields of biomass and protein. For instance, the yields to be hoped for from sewage-enriched fishponds are in the order of 10,000 kilograms per hectare yearly

(Muthuswamy and others 1978), whereas algae production in high-rate ponds may be up to 150,000 kilograms per hectare yearly. The algae are approximately 50 percent protein, and thus protein yields of 75,000 kilograms per hectare yearly are achieved. This compares favorably with protein yields from rice (56 kilograms per hectare yearly), corn (270 kilograms per hectare yearly), and soybeans (650 kilograms per hectare yearly) (McGarry 1971).

Algae may be harvested by flocculation with lime or aluminum sulfate followed by flotation (McGarry 1971), or by partial removal by microstraining. Oswald and others (1978) reported that algae are harvested from shallow ponds in the Philippines by simple sedimentation, with a production of 47,000 kilograms per hectare yearly. These various methods produce an algal paste or sludge containing 8–10 percent solids, which is then sun dried. An overview of the engineering and economic aspects of algae production in high-rate ponds is given by Lee and others (1980).

HEALTH ISSUES. High-rate ponds have a short retention time of around 1 day. Pathogen removal is therefore minimal, and the harvested algae will be rich in excreted viruses, bacteria, protozoa, and helminth eggs.

PATHOGEN CONTROL. The most effective removal process is sun drying. If the algae are dried to less than 5 percent water, pathogen removal will be complete. If not, pathogens will survive to a degree dependent upon drying time, final moisture content achieved, and sunlight intensity. There are no data on pathogen survival on drying algae, but it may be assumed that protozoa will be rapidly removed (in a few weeks) and that bacteria may be killed by algal toxins and other factors. Viruses and helminth eggs will be long-term survivors, with the latter enduring for a year or more if moisture content in the algal sludge stays above 10 percent.

The health hazards involved in the reuse of this algal product will vary. If the algae are fed to cattle, the major requirement will be the elimination of *Taenia saginata* eggs, *Salmonella* spp., and *Mycobacterium tuberculosis* (see above). If they are fed to chickens, the major requirement may be removal of *Salmonella* and *Campylobacter*. If they are fed to people (as in Japan), they will require thorough disinfection prior to packaging and marketing.

Macrophyte culture

Around the world, but especially in Southeast Asia, many water plants are used for human or animal food. Some are harvested wild, and some are cultivated; they include water spinach (*Ipomoea aquatica*), water chestnut (*Eleocharis dulcis* or *E. tuberosa*), water hyacinth (*Eichhornia crassipes*), water bamboo (*Zigania* spp.), water calthrop (*Trapa* spp.), and lotus (*Nelumbo nucifera*). Some of these plants (for instance, water spinach) are intensively fertilized with human and animal wastes, whereas others are grown in water that may be incidentally contaminated (National Academy of Sciences 1976).

Attention has recently focussed upon the use of water hyacinth in waste treatment and recycling systems (Dinger 1978*a*, 1978*b*; Wolverton and MacDonald 1979). Water hyacinth removes nutrients, metals, and phenols from wastewaters (Cornwall and others 1977). The hyacinth can be harvested and used as animal feed, processed to produce fertilizer, or used to generate methane (see the section on biogas below). If water hyacinth is introduced, however, the ecological consequences of its escape into irrigation systems (it grows rapidly and can clog waterways) must also be considered. Such systems for intense recycling of wastes are usually fed by sewage but could be fed by night soil or sludge.

HEALTH ISSUES. The health hazards associated with these aquacultural practices are of three types.

First, there is the occupational risk to those who work in the water, especially where intensive use of night soil occurs. These workers may accidentally swallow pathogens or carry pathogens back to their homes on their clothing or bodies, and they may become infected percutaneously with schistosomiasis in areas where the disease is endemic and the intermediate host snails reside in the ponds or flooded fields.

Second, the harvested plants may be heavily contaminated with pathogens and may infect those who harvest, handle, prepare, or eat them. Some of these plants, such as water chestnut in China, are eaten raw.

Third, the parasitic fluke *Fasciolopsis buski* is locally important in some parts of Asia and may infect 10 million people. This worm has a life cycle that moves from man (or pig or dog) to snail to water plant to man. Animals or people become infected by eating the encysted metacercariae on water plants, especially *Eleocharis*, *Eichhornia*, *Trapa*, and *Zigania* (see chapter 28).

PATHOGEN CONTROL. Control of these health problems depends chiefly upon the treatment of night soil and other wastes prior to their discharge or prior to their use as fertilizer for aquatic plants. The health requirements for a particular plant production system must derive from a consideration of exactly what kinds of process are being used to grow which crops, and the degree of mechanization incorporated. In addition to adequate treatment of the fecal wastes used, attention to crop harvesting and marketing techniques and education for both producers and consumers are important preventive health strategies.

Reuse for Biogas Production

When organic wastes are digested anaerobically, a mixture of methane, carbon dioxide, and other gases is given off. This gas has become known as "biogas" and can be produced in various quantities by different technologies. In conventional sewage treatment works, anaerobic sludge digestion produces biogas that is sometimes used to heat the digesters or for some of the other energy needs of the works. Biogas production usually refers to the production of methane on a small scale by individual farmers, communes, or rural institutions in hot climates.

Technical description

Biogas digesters have been installed in large numbers in China, and it is probably there that the technology has become most developed (McGarry and Stainforth 1978) (see figure 7-1).[8] Significant numbers also operate in India, Korea, and Taiwan. The biogas plants are fed with diluted animal feces, with or without human excreta and with or without vegetable refuse. The effluent slurry is reused in agriculture[9] and can also be used to enrich fishponds; the biogas is used primarily for domestic cooking and lighting. The dung from one medium-size cow or similar animal may produce around 500 liters of gas daily, and the calorific value of this gas may be around 4–5 kilocalories per liter (McGarry 1977). In contrast, human excreta only produce 30 liters of biogas per person daily. The process is very sensitive to temperature. In the mesophilic range, optimum gas production occurs at around 35°C, but in rural applications digesters are not heated (although they may be lagged or buried), and so they operate at around ambient temperatures. Gas production falls off considerably at lower temperatures and may be negligible below 15°C.

Pathogen control in reuse of biogas plant slurry

The health problems associated with biogas plants come entirely from the reuse of the slurry because the gas production itself has no health implications (that is, unless the digesters explode or the gas starts a fire). Average retention times in biogas plants are commonly short (5–30 days), and the operation is usually continuous, rather than batch. Pathogen removal will therefore be considerably less effective than in conventional sludge digestion processes.[10] Protozoal cysts should not survive, but pathogenic viruses, bacteria, and helminth eggs may be expected to be present in the effluent slurry in considerable concentrations.

There is little information from the field on the quality of effluent from biogas plants. Data from China (McGarry and Stainforth 1978) indicate an average of 15,000 helminth eggs, 4 hookworm eggs and 8×10^7 *E. coli* per liter of biogas-plant effluent. In the same report the authors found that survival times for *Salmonella*, *Shigella*, spirochetes, schistosome eggs, and hookworm eggs in the anaerobic environment of the biogas tank are up to 44 days, 30 hours, 30 hours, 40 days, and 75 days, respectively. Therefore, for a plant with a retention time of 10–30 days, it can be expected that salmonellae, schistosomes, and hookworms will be in the effluent, but that shigellae or spirochetes will not. *Ascaris* eggs will survive considerably longer than hookworm eggs and therefore will also be present. (It is likely that the major proportion of the 15,000 helminth eggs per liter reported in the study mentioned above were *Ascaris*.) In another investigation in China (Research Institute of Military Medical Sciences 1977), inflow to a biogas plant contained 5.4×10^6 *E. coli* per liter, whereas the outflow contained 1.4×10^4 (a 99.7 percent reduction). *Shigella flexneri*, kept in conditions simulating those of a biogas tank, survived for up to 13 days, thus contradicting the study reported above.

It is clear from the data above that the effluent slurry from a biogas plant is unlikely to be significantly less pathogenic than raw sludge. Its direct reuse on crops is therefore not advised (see "Reuse in Agriculture," above). It may, however, be reused in agriculture following prolonged drying (>1 year) or after

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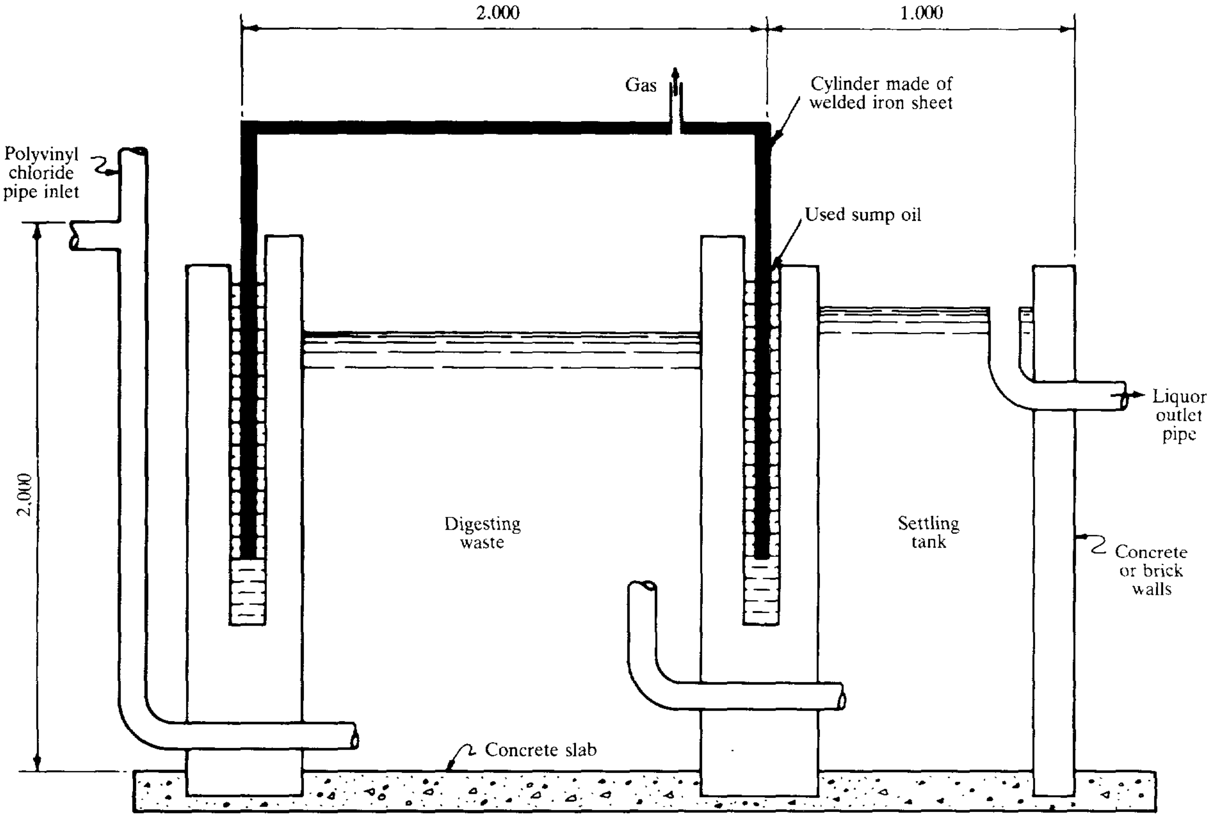
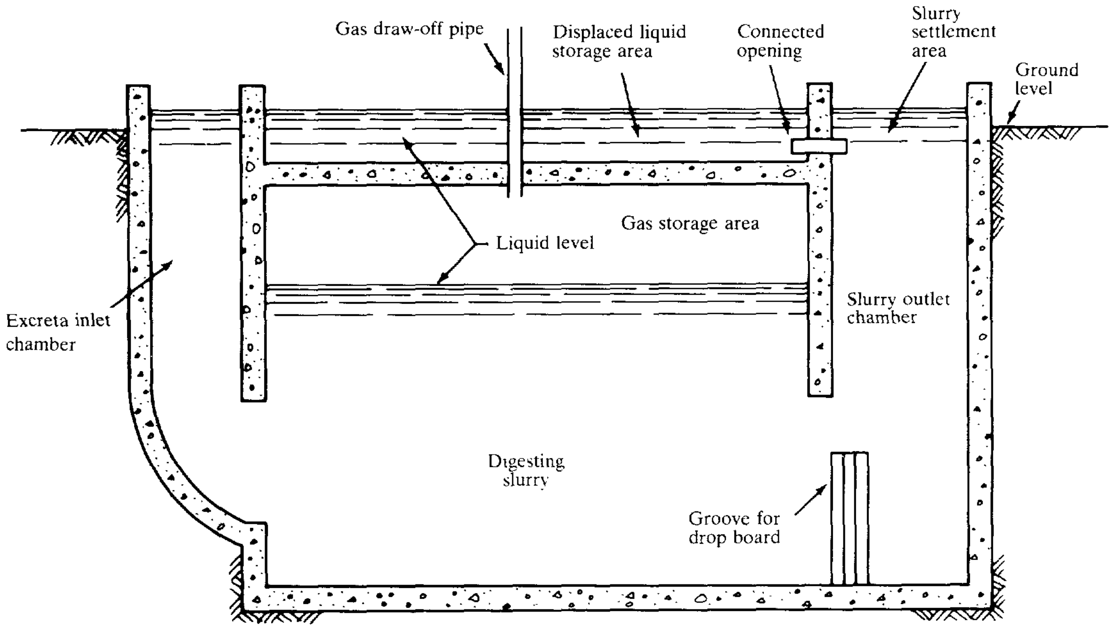
[8] In addition to the two designs of biogas units shown in figure 7-1, the reader will find further details of the technology in Barnett, Pyle and Subramanian (1978); Freeman and Pyle (1977); McGarry (1977); McGarry and Stainforth (1978); Rybczynski, Polprasert and McGarry (1978); Subramanian (1977); and Van Buren (1979).

[9] It is reported from China that biogas slurry increases the yields of corn and wheat by 19 percent and of vegetables by 50–60 percent (Research Institute of Military Medical Sciences 1977).

[10] See the previous chapter, the section "Conventional Sewage Treatment" and figures 6-5 and 6-6.



South Pacific design



Chinese design

Figure 7-1. *Typical biogas digesters* (dimensions in millimeters). From Kalbermatten and others (1982); top, from a design by G. L. Chan composting (see chapter 5; the area of land required for prolonged drying will be so great that composting will generally be the preferred treatment method). Biogas plant effluent may also be used to enrich fishponds. *Clonorchis sinensis* eggs will be eliminated in the plant, and the health hazard involved is the passive transmission of other pathogens by harvested fish (see "Reuse in Aquaculture," above).

Discharge of Effluents

This chapter began with an expression of the view that sewage effluent, sludge, and night soil are important natural resources to be reused if possible. There will be occasions, however, when the most economically or environmentally appropriate solution to disposal is not reuse but the discharge of wastes to rivers, lakes, the sea, or groundwater. The health implications of each of these alternatives are discussed in this section.

Into rivers and lakes

The survival of pathogens in freshwater has been examined in chapter 4. Survival times are considerable for all groups of organisms, and they increase in the following order: protozoa, bacteria, viruses, and helminths. Moreover, pathogens may travel substantial distances after being discharged into freshwater. Pathogens discharged into rivers and lakes may contaminate fish in the same way described for marine discharge (below). Where discharge is to a river, pathogens may be carried to its mouth, where they may infect shellfish.

HEALTH ISSUES. There are two overriding health problems associated with discharge of effluents into rivers or lakes: pathogens may be ingested by waterside human populations who use the river or lakewater for domestic purposes; and discharge to freshwater may promote the transmission of those parasitic worms that have aquatic intermediate hosts.

WATERBORNE PATHOGENS. People who use a polluted river or lake for their drinking water may become infected by pathogens that have previously been discharged into their water supplies. Viral, bacterial, and protozoal pathogens may all be transmitted in this way—although, where these infections are endemic in the community, the magnitude of this waterborne transmission may be minor compared with other, more direct routes (see chapters 2 and 3). Poor and seasonally arid countries are especially at risk from river or lake pollution of this kind for two reasons. First, the waterside dwellers may have no alternative, potable water supply and therefore may be compelled to use the polluted water. Second, at some period of the year river flow may be low or nonexistent, so that the discharged effluent will receive little or no dilution. These factors make it essential to guard against substantial pathogen pollution of lakes and rivers.

HELMINTHS WITH AQUATIC INTERMEDIATE HOSTS. The excreted helminths that require one or more intermediate aquatic hosts are: *Clonorchis sinensis*, *Diphyllobothrium latum*, *Fasciola hepatica*, *Fasciolopsis buski*, *Gastrodiscoides hominis*, *Heterophyes heterophyes*, *Metagonimus yokogawai*, *Paragonimus westermani*, and *Schistosoma* spp.[11]

Fasciola is primarily a parasite of cattle and sheep and is present in wet pastures and small streams. *Fasciolopsis* and *Gastrodiscoides* are associated with the cultivation and ingestion of water plants (see "Reuse in Aquaculture," above). *Heterophyes* and *Metagonimus* are of limited public health importance and have a very restricted geographical distribution. It is thus *Clonorchis*, *Diphyllobothrium*, *Paragonimus*, and *Schistosoma* infections that are associated primarily with discharge of effluents to rivers and lakes.

Clonorchis sinensis—and the related helminth species *Opisthorchis felineus* and *O. viverrini*—are transmitted from human (or dog or cat or other fish-eating mammal) to snail to fish to human, and they are particularly associated with fish farming in ponds enriched with excreta. *Diphyllobothrium latum* is transmitted from human (or dog or bear or other fish-eating mammal) to copepod (minute crustacean) to fish to human. It is especially prevalent in lakeside areas of temperate countries. *Paragonimus westermani* is transmitted from human (or many other animals) to snail to crab or crayfish to human. These three parasites all may be controlled by preventing untreated human excreta from reaching bodies of water where the intermediate hosts are found and by persuading affected communities not to eat undercooked fish, crabs, or crayfish. In the case of *Clonorchis* and *Paragonimus*, asexual multiplication takes place in the snail, so that one viable miracidium infecting a snail can ultimately infect many fish or crabs and, thus,

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[11] A full account of the life cycles and distribution of these parasitic worms, and guidance on the treatment processes required to remove eggs from sewage, sludge, or night soil, will be found in Part Two.

many people. The discharge of the parasite eggs in the effluent must accordingly be cut to extremely low levels if transmission is to be reduced significantly. In all cases, animals other than man act as definitive hosts, and the management of human excreta alone can never guarantee the cessation of transmission. But keeping all untreated human wastes out of rivers and lakes should have a dramatic effect on transmission in most endemic areas.

Schistosome worms are transmitted from human to snail and directly to humans through the skin. The discharge of inadeqately treated wastes to rivers and lakes is a major factor in the transmission of these important parasites. Adequate treatment of all wastes before discharge should be helpful in the control of the fecal species (*S. mansoni* and *S. japonicum*). Waste treatment will have less effect on *S. haematobium*, whose eggs are passed in the urine, because people may freely urinate near water. Once again, multiplication takes place in the snail, so that a great reduction in the number of viable eggs reaching the water is necessary before a marked reduction in transmission can be expected.

Into the sea

Night soil and raw sludge are often taken out to the open sea by boat and dumped; less commonly, these wastes are dumped from the shore. Dumping of night soil or sludge in the open sea should pose no significant health problems, but dumping from the shore is so offensive that it should never be a feature of any well-designed disposal system. Only the more usual practice of discharging effluents from sewage treatment facilities into the sea near the shore is discussed below.

HEALTH ISSUES. The discharge of sewage effluent into coastal waters can create two kinds of health problem: the risk of contaminating fish or shellfish, which may subsequently be eaten, and the risk of contaminating bathing areas and beaches.

PATHOGEN SURVIVAL. Enteric viruses and bacteria discharged into seawater survive for considerably shorter periods than they do in freshwater. Coliforms in seawater undergo a 90 percent reduction in 0.6–8 hours compared with 20–100 hours in freshwater. Fecal streptococci may survive a little longer than coliforms in seawater, and salmonellae longer still. Enteroviruses survive for longer periods in seawater than excreted bacteria—90 percent reductions in 15–70 hours—but this is still considerably shorter than their survival in freshwater.[12] Excreted viruses and bacteria are eliminated very much faster in warm seawater than in cool seawater. Protozoal cysts and helminth eggs do not experience any particular lethal effects in seawater, and their survival is similar to that in freshwater (table 4-3). They do tend to settle, however, and so present little health hazard.

SEAFOOD CONTAMINATION. Fish and shellfish in polluted seawater may be contaminated by human excreted viruses and bacteria. The spread of pathogenic pollution for more than a few kilometers from sewage outfalls is not normally reported, and fish caught in the open sea are therefore found to harbor no human pathogens. Fish caught in the littoral zone, however, may well have excreted viruses and bacteria on their body surfaces and in their intestines, a hazard examined in the subsection "Fish farming," above. Excreted viruses and bacteria may survive in fish guts for a few weeks and can infect humans who handle or eat them, and may also infect animals fed on fishmeal, which may in turn infect humans. However, a more common hazard is the contamination of fish after they are caught, and most fish-associated outbreaks of salmonellosis or typhoid have been linked to this form of contamination.

A more serious problem than fish contamination is the contamination of edible shellfish (Hughes, Merson and Gangarosa 1977). Mussels and oysters are grown along coasts and in estuaries where the salt concentration is 0.8–3 percent (compared with 3.5 percent in the sea). Shellfish therefore live in the marine environment most exposed to pollution from sewage outfalls and from contaminated riverwater. Because they filter water to feed, shellfish concentrate excreted bacteria and viruses in their tissues. *Salmonella* spp. (including *S. typhi*) and enteroviruses have frequently been isolated from shellfish at concentrations well above those of surrounding seawater (see chapters 15 and 9). Outbreaks of poliomyelitis, hepatitis A, and diarrheal diseases all have been associated with the ingestion of of shellfish originating in polluted water.

Shellfish can be decontaminated by placing them in clean water. Chlorinated water that has been dechlorinated is often used (chlorinated water is ineffective because it discourages the shellfish from

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[12] The survival of indicator bacteria, salmonellae, and enteroviruses in seawater are reviewed in chapters 13, 15, and 9, respectively. Rapid bacterial death rates may be due to the injury of bacterial cells by seawater, such that they cannot grow on standard laboratory isolation media, rather than to actual death (Dawe and Penrose 1978). These injured bacteria can be resuscitated by special techniques, but it is not known whether they are still infective.

pumping and feeding and so will not flush out viruses or bacteria lodged in their tissues). Studies reviewed in chapters 9, 13, and 15 indicate that 2 days in disinfected water may be sufficient to cleanse shellfish of *E. coli*, but that several days are required for elimination of enteroviruses and several weeks for elimination of salmonellae. Even small numbers of pathogenic bacteria remaining in the shellfish tissues may subsequently multiply in warm conditions and infect someone eating inadequately cooked shellfish.

A related problem is that of acute gastroenteritis caused by *Vibrio parahaemolyticus*. *V. parahaemolyticus* has been reported as a cause of acute diarrhea in several countries, and it may be the single most common cause of food poisoning in Japan (Miwatani and Takeda 1976). The bacterium occurs widely in nature and is not restricted to the animal intestine. It is a halophile and has frequently been isolated from seawater, estuarine water, brackish lagoon water, marine sediments, fish, shellfish, crabs, and prawns (Baross, Liston and Morita 1978; De and others 1977; Felsenfeld and Cabirac 1977; Franca and others 1980; Sirca and others 1979; van den Broek, Mossel and Eggenkamp 1979; and Vanderzant and Nickelson 1973). Outbreaks of *V. parahaemolyticus* diarrhea in humans have usually been associated with the ingestion of inadequately cooked seafood, and the organism may also be a pathogen of marine fish and shellfish. It remains unclear to what degree disease outbreaks are associated with *V. parahaemolyticus* deriving from sewage discharges into estuaries and coastal waters, rather than to naturally occurring aquatic reservoirs of *V. parahaemolyticus*. In this connection it is noteworthy that pathogenicity in humans is particularly associated with those strains of *V. parahaemolyticus* which produce a thermostable hemolysin (the Kanagawa phenomenon). Yet, in studies in the Andaman Islands (Lall and others 1979), Britain (Ayres and Barrow 1978), India (Chatterjee and others 1978; De and others 1977; Natarajan, Abraham, and Nair 1980), and Togo (Bockemühl and Triemer 1974), from 89 to 100 percent of environmental isolates were Kanagawa negative.

RECREATIONAL HAZARDS. An active debate continues about the magnitude of the health risk associated with swimming in fecally polluted seawater and the correct approach to water quality standards and legislation (Cabelli 1979; Evison and Tosti 1980; Moore, Perin and Maiden 1979). Recent evidence from Egypt and the USA (Cabelli 1979; Cabelli and others 1979) revealed a small but measurable difference in the incidence of gastrointestinal illness between swimmers and nonswimmers at polluted beaches. The recorded risks of swimming in seawater containing 10^2–10^3 fecal coliforms per 100 milliliters were an additional attack rate of one to two cases of gastrointestinal illness per 100 people in the 8–10 days following the visit to the beach. It must be kept in mind, however, that especially in developing countries the infections that may be transmitted to swimmers at polluted beaches will usually be highly endemic in the community at large (the community producing the wastes that are polluting the sea), and swimming may constitute a negligible additional risk. Set against this is the possibility that swimmers from high socioeconomic strata (who experience a low risk at home owing to adequate water supply, sanitation, and hygiene) may be exposed to a substantially increased risk of infection when they bathe in seawater polluted by the wastes of all socioeconomic strata. The same level of additional risk may apply to tourists—who are usually either local residents from upper socioeconomic groups or foreign visitors. A perceived risk to tourists, whether it is real or imaginary, may have serious economic consequences.

To groundwater

Effluents and liquid wastes are frequently discharged to groundwater. This usually occurs unintentionally—when soakaway effluent or pit latrine seepage percolates down to reach the water table, for instance. It can also occur through seepage losses from the base of waste stabilization ponds or, in arid areas, when effluents are discharged into low- or no-flow streams that are losing flow to the ground. In some countries in which groundwater resources are being deliberately conserved or augmented, treated effluents may be recharged to groundwater as a means of indirect recycling. [See note on page 116.]

HEALTH ISSUES. There are two central questions in considering the health implications of waste discharge to groundwater: how far do the pathogens move vertically and horizontally from the point of discharge, and for how long are they able to survive? The movement of protozoan cysts and helminth eggs can be expected to be limited because their size will cause them to be retained in soil. It is therefore viral and bacterial movement and survival that are of interest, and inadequately treated groundwater is a major cause of outbreaks of diarrhea (both viral and bacterial) and hepatitis A in some countries (Craun 1979).

PATHOGEN TRAVEL. Studies on bacterial movement through soil and rock indicate normal maximum travel distances of up to 30 meters in sand and fine soils and up to several hundred meters in gravel or fractured rock (see chapter 13). Despite their tendency to become adsorbed onto soil particles, viruses may travel through soil for longer distances than bacteria (see chapter 9). Retention does not necessarily imply inactivation. It must be noted that, when moving through soils, the great majority of bacteria and viruses are retained in the first meter and that only a small fraction is able to travel more than 10 meters.

PATHOGEN SURVIVAL. Excreted bacteria and viruses are likely to survive for longer in groundwater than in surface water (table 4-3) because groundwater is cooler, not exposed to sunlight, and has less microbial and biological activity. Bacterial survival in groundwater may be up to 5 months, with most reduction taking place in the first few days. Fecal coliforms survive longer than salmonellae and can multiply in the presence of nutrients (for example, when effluent is reaching the groundwater; see chapters 13 and 15). Virus survival may be similar or somewhat longer (see chapter 9).

PATHOGEN CONTROL. In areas where there are many pit latrines, soakaways, unlined stabilization ponds, or a recharge system, there will always be a risk of pathogenic viruses and bacteria reaching groundwater. In pit latrines, soakaways, and ponds the waste-soil interface quickly becomes clogged with solids and thus more effectively retains these microorganisms. The risks to health occur when the contaminated groundwater is used as a source of drinking water. The pathogen content of polluted groundwater will, in general, be much lower than that of surface waters in the same area. Where untreated water is being used for domestic purposes, there will therefore be a lower risk from wells than from nearby streams or ponds. Where water is chlorinated, the bacterial pathogens will be effectively destroyed.

Special vigilance is required wherever dense populations use untreated wellwater as their only domestic source and wherever there is widespread use of soakaways or pit latrines. If routine water quality monitoring demonstrates a significant pollution problem from groundwater, it is necessary to supply piped water of better quality or to change the excreta disposal method in use. The former solution will in general be less costly and more practicable than the latter.

Nitrates from effluents

This study concerns health problems related to biological agents contained in excreta. It would be inappropriate, however, not to mention one chemical pollution problem, the problem of nitrate accumulation, which can occur as a result of waste discharge to rivers, lakes, or groundwater. Nitrates are an end product of the oxidation of many nitrogenous compounds. Nitrate levels may be high in lakes and groundwater receiving continuing discharge of raw or treated sewage or wastewaters leaching from pit latrines, soakaways, or garbage dumps (Berwick 1979; Brooks and Cech 1979; Nicholson 1979; Schalscha and others 1979). Domestic and industrial effluents may cause high nitrate levels in receiving rivers during periods of low rainfall when the rivers are providing inadequate dilution. High nitrate levels in surface and groundwater may also derive from surface runoff water that has picked up organic material and nitrates from soil or agricultural fertilizers.

The reduction of nitrite and nitrate levels in wastewaters prior to discharge is normally achieved by the action of denitrifying bacteria under anaerobic conditions. Such a process may be included as a tertiary treatment stage in a sewage treatment plant (Anderson and Ibrahim 1978), but its expense and sophistication makes it inappropriate in most circumstances in developing countries. In hot climates, denitrification sometimes occurs in secondary sedimentation tanks that have become almost anaerobic. The consequent release of gas (N_2 and N_2O) seriously interferes with the settlement process within the tanks.

HEALTH ISSUES. Nitrate levels of over 100 milligrams per liter of NO_3 have been associated with clinical methemoglobinemia in bottle-fed infants (Winton, Tardiff and McCabe 1971). The nitrates are reduced to nitrites in the intestine and thence enter the bloodstream, where they oxidize hemoglobin to methemoglobin. This molecule is unable to transport oxygen; thus if too great a proportion of methemoglobin is created, serious and sometimes fatal anoxia and cyanosis may ensue. This condition is rare and apparently restricted to infants (chiefly those under 3 months of age). Exposure to excessive nitrite may also cause methemoglobinemia in animals and fish (Raju and Rao 1979).

Methemoglobinemia is particularly associated with bottle-fed infants ingesting powdered milk formula made up with high-nitrate water. However, Shuval and Gruener (1977) studied the liquid intake of 104 infants (1–5 months old) in Israel and showed that "while during the cool months 90 percent of the total liquid intake is made up of milk, as much as 50 percent can be *in the form of tap water supplements during the hottest* month." Thus, in hot climates, even young breast-fed infants may be exposed to a considerable intake of high-nitrate water. The same study detected raised levels of methemoglobin in bottle-fed infants whose water supply contained 45–55 milligrams per liter of NO_3 (the usual accepted standard for NO_3 in drinking water is <45 milligrams per liter of nitrate or 10 milligrams per liter of nitrate-nitrogen).

Several factors operating in hot climates and developing countries may have the effect of increasing the probability of an infant's developing methemoglobinemia. These factors include high fluid intakes due to heat; the practice of boiling water of uncertain microbiological quality, which increases the nitrate concentration; and the high incidence of infant diarrheal disease, malaria, and anemia, which may all act to compound any methemoglobinemia caused by high-nitrate water. In addition, some antimalarial drugs may induce an increased level of methemoglobin in the blood. Despite these theoretical dangers, and despite the fact that some communities in some developing countries (for instance, Botswana, Senegal, and Tanzania) habitually drink wellwater with several hundred milligrams per liter of nitrate, it remains undemonstrated that any significant amount of morbidity or mortality results.

High nitrate intake (from drinking water or food) has also been implicated in adult stomach cancers in Chile, Colombia, England, Japan and elsewhere (Cuello and others 1976; Drasar and Hill 1974; Haenszel and others 1976; Hill, Hawksworth and Tattersall 1973). It is hypothesized that nitrite (produced by the bacterial reduction of ingested nitrate), secondary amines, and bacteria may come together in the stomach of individuals with gastric achlorhydria (reduced stomach acidity), or in the bladder of individuals (especially females) with bladder infection, to produce dimethylnitrosamine—a potent carcinogen of the stomach. The health hazards associated with high nitrate ingestion have been reviewed more fully elsewhere (Fraser and Chilvers 1981; National Academy of Sciences 1978).

NITRATE CONTROL. These problems may be countered by surveillance of drinking water sources to identify the communities at risk. In any one country, communities affected by highly nitrate-contaminated water will probably be small in number and restricted in geographical distribution. If the nitrate problem derives from discharges or seepages of sewage or night soil, it may be possible to prevent these occurrences. Nitrates may, however, come from many other sources, particularly agricultural runoff, and it may be more practical to provide an affected community with piped water of low nitrate content. There is currently no simple and economic method of removing nitrate from drinking water (Adam 1980; Nicolson 1979), and so nitrate reduction is normally achieved by blending high-nitrate water with waters having lower nitrate concentrations.

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Note added in proof

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