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HEALTH ASPECTS OF NIGHTSOIL AND SLUDGE USE IN AGRICULTURE AND AQUACULTURE

Part III
An Epidemiological Perspective

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Part III
An Epidemiological Perspective

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FOREWORD

Animal and human wastes have been used in all parts of the world and for many centuries to fertilise fields and ponds where fish and aquatic vegetables are grown. No country could afford to waste this important nutrient source. However, only in the last few decades, after having developed a high energy consuming technology to produce mineral fertilisers, many industrialized countries ceased to recycle the nutrients contained in faecal wastes. This tendency was probably reinforced mainly by the increasing awareness of the health risks related to the use of faecal matter in agriculture, and by the low energy prices. In the United States for instance, where energy prices were very low until recently, it is still common practice to incinerate the sludge produced in communal sewage treatment plants, whereas in many European countries, where energy prices have always been considerably higher, all the animal manure and most of the sludge generated from human waste is applied to fields after appropriate treatment. As a result of increasing energy prices, the growing awareness of natural resource limitations, and for ecological reasons in general, the concept of recycling nutrients has recently regained popularity in the industrialized countries. Unfortunately, these countries are faced today with a new problem: the contamination of sludge with heavy metals and other industrial pollutants is limiting sludge use in agriculture.

Unlike the situation in industrialized countries, in most developing countries animal and human excreta have always been regarded as the most important and often only affordable nutrient source in agriculture and aquaculture. Due to economic reasons, the concept of recycling nutrients was never abandoned in these countries. In many countries in Asia, even raw or only marginally treated human excreta (nightsoil) are traditionally and widely used to fertilise fields and fish ponds. Such practices create potential health risks to those who consume vegetables or fish grown there. Over the past decades, research has been focused on the potential health risks associated with the outside-host environment, i.e. in water, wastewater, sludge, soil and on crops. However, relatively little is known about how and to what extent disease transmission is really associated with the practice of recycling nutrients of human wastes. Nor does one know much about the relative importance of excreta fertilisation in comparison with other possible routes of pathogen transmission. Consequently, exisiting basic concepts and standards relating to the use of human wastes have been based on potential risks and are therefore very conservative. However, unduly restrictive standards on human waste reuse which are not justified on health grounds, can lead - especially in countries with great economical difficulties - to situations where unregulated reuse projects become tacitly accepted even if they actually pose real health risks.

In 1982, the International Reference Centre for Wastes Disposal (IRCWD), in collaboration with WHO, started a project on the actual (as opposed to the theoretical or potential) health risks related to the use of human excreta. A further objective of the project is to highlight sociocultural, technical and institutional aspects of such excreta-use practices. In the first phase of the project three state-of-knowledge reviews were prepared based on three types of perspectives. Part I, prepared by Piers Cross, a sociologist presently working in Harare, Zimbabwe, highlights cultural differences in excreta management practices, discusses beliefs and habits, and suggests ways to strengthen the role of sociocultural perspectives in programmes dealing with excreta disposal and hygiene-related problems. Part II presents compiled information reviewed by Martin Strauss, a sanitary engineer working at IRCWD, on survival of excreted pathogens in excreta and faecal sludges prior to utilisation (i.e. during storage and treatment), and reports about the fate of these pathogens in the soil, on crops and in nightsoil-enriched fish ponds. Part III has been prepared by Deborah Blum and Richard Feachem of the London School of Hygiene and Tropical Medicine, with the objective of providing an overview of the existing documented epidemiological evidence regarding disease transmission through nightsoil and sludge use as a fertiliser. It highlights gaps in epidemiological knowledge and outlines possible epidemiological approaches to field investigations of health risks of excreta use.

The reviews presented in this publication series focus on the use of excreta, nightsoil and sludge, and not on the use of wastewater for agricultural purposes. This separation is artificial and was done for practical reasons only. It is even reasonable to assume that the range of pathogens is the same for both nightsoil and wastewater, and that health risks associated with their use as fertilisers are of a similiar nature. The World Bank as executing agency for the United Nations Development Programme (UNDP) on the Integrated Resource Recovery Project, has commissioned a team of consultants headed by Professor Hillel Shuval to do a parallel review on the health effects of wastewater irrigation. This report will be published by the World Bank in the technical paper series.

The project on the "Health Aspects of Nightsoil and Sludge Use in Agriculture and Aquaculture" will continue. After field visits to several countries where use of human wastes is practised, we hope that further epidemiological studies will be initiated and conducted in the near future. Based on these field visits, a further report describing actual case studies will be prepared and published as Part IV of this publication series. The final goal of the project is the preparation of a set of guidelines on the type of treatment required by human wastes to keep health risks to workers and consumers to a minimum.

I would like to express my gratitude to all the people involved in this interdisciplinary project for their enthusiasm and good collaboration, particularly to Deborah Blum, Ursula Blumenthal, Piers Cross, Richard Feachem, Gunnar Schultzberg, Martin Strauss and Somnuek Unakul.

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Roland Schertenleib
Director IRCWD

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CHAPTER 1: INTRODUCTION

1.1 General introduction

The use of human excreta in agriculture and aquaculture is attracting considerable attention in developed and developing countries. In developed countries, excreta are generally available as raw, partially- or fully-treated sewage and sludge. The ever-increasing volume of sewage for disposal, coupled with environmental concerns about contamination of water bodies, has focused attention on landspreading disposal options, including agricultural use. In developing countries excreta are largely available in the form of nightsoil. There is a long tradition of nightsoil use in agriculture and aquaculture in some countries, most notably China and nearby Asian countries where human nightsoil is an economically valued commodity. Nightsoil use is common in many other parts of the world: in some countries it takes place in a somewhat surreptitious manner, out of sight of the public health authorities. In a relatively small number of countries, especially those in eastern and southern Africa, the use of excreta is considered culturally unacceptable and is seldom, if ever, practised. A combination of factors, including the cost of chemical fertilisers in the face of an economic recession, the need to increase domestic agricultural production to feed rapidly growing populations and the use of double-pit latrine technologies may soon lead to more widespread and more organised use of excreta in the developing world.

The use of raw excreta or conventionally treated wastewater or sludge is a mixed blessing. On the one hand, excreta are a plentiful natural resource with varied potential applications in agriculture, aquaculture and the production of biogas. Application of nightsoil, sewage, wastewater effluent or sludge to soil or fish ponds provides a rich and inexpensive source of nutrients to promote plant or fish growth and condition soil. Wastewater provides a ready source of water for irrigation in water-scarce areas. Excreta can be used to provide methane as an energy source. A major additional benefit, particularly in developed countries, of more widespread application of excreta to land or fishponds is the protection of surface water bodies polluted by current disposal practices. On the other hand, excreta harbour a wide variety of bacterial, viral, protozoal and helminthic pathogens, the range of these pathogens reflecting the pattern of infection in the community. Wastewater and sludge, particularly in industrialised countries, may be contaminated with heavy metals and organic chemicals. Finally, excreta may be associated with unpleasant odours and insect-breeding.

Past and current practices of excreta use reflect the importance attached to these economic, aesthetic and health considerations in different cultures. Despite differing viewpoints and practices, there appears to be widespread acceptance that the use of excreta, particularly untreated or partially treated excreta, in agriculture or aquaculture represents a real health risk to certain occupational groups and to the general public. Accordingly, in some countries, strict regulations have been formulated on the minimum degree of excreta treatment prior to use, microbiological standards and the type of crops to which excreta may be applied (W.H.O. 1981). These regulations largely stem from intuitive impressions of health risk, based on data on the survival of pathogens in the environment and their removal by conventional treatment processes.

The subject of infectious disease risks of excreta use has been reviewed mainly from an environmental perspective, drawing heavily on pathogen survival and removal studies to define potential health risks (Elliott and Ellis 1977, Hays 1977, Burge and Marsh 1978, Engelbrecht 1978, Pahren et al. 1979 and Golueke 1983). However, an epidemiological perspective is required to distinguish between real and potential health risks and to quantify those risks, formulate appropriate safety regulations and to determine the cost-effectiveness of alternative use or disposal options. This review examines the epidemiological literature to determine the strength of the evidence documenting infectious disease transmission from the use of nightsoil or sludge in agriculture and from excreta use in aquaculture. Health risks from wastewater use in agriculture are not discussed at any length since this subject has been recently reviewed in detail elsewhere (Gunnerson et al. 1985 and Shuval et al. forthcoming). It is recognised, however, that this division of focus is an artificial one. In view of the similarity in the range of pathogens likely to be present in nightsoil, wastewater, and sludge, documented health risks from nightsoil or sludge use are relevant to discussions of health outcomes of wastewater use, and vice versa.

1.2 Potential risks to human health from nightsoil or sludge use

The list of pathogens which are excreted in faeces or urine and may therefore be present in human nightsoil or sludge is long. However, the list of those pathogens which are of major public health importance - because of the burden of infection or severity of disease they cause - is shorter and it is these pathogens which are of concern in assessing the health risks of nightsoil or sludge use. Table 1.1 lists the major pathogens potentially spread by land application of nightsoil or sludge and Table 1.2 lists pathogens potentially spread by the use of excreta in aquaculture. Table 1.2 includes some of the pathogens listed in Table 1.1, but in addition contains a number of pathogens - belonging to the cestode and trematode classes of helminths - which are particularly likely to be spread by excreta use in aquaculture because their life cycles involve intermediate aquatic hosts which may be found in ponds used for aquaculture. We believe that the use of excreta to fertilise marine or brackish water aquaculture is uncommon, and such practices are not included in this document. Such practices would, however, be associated with a risk of infection by *Vibrio cholerae* and *Vibrio parahaemolyticus* (Miller et al. 1985) in addition to some of the other pathogens listed in Table 1.2.

While the presence of a given pathogen in nightsoil or sludge is a necessary pre-condition for a potential health risk to exist, a number of

Table 1.1 Important infectious disease agents with a potential for spread by land application of human nightsoil or sludge

Agent	Illness
VIRUSES	
Enteroviruses	diarrhoea, respiratory disease, polio
Hepatitis A	infectious hepatitis
Rotavirus	diarrhoea
BACTERIA	
Campylobacter jejuni	diarrhoea
Pathogenic _Escherichia coli_	diarrhoea or dysentery
Salmonella spp. (non-typhoid)	diarrhoea
Salmonella typhi	typhoid fever
Shigella spp.	diarrhoea or dysentery
Vibrio cholerae	diarrhoea (cholera)
PROTOZOA	
Entamoeba histolytica	diarrhoea or dysentery
Giardia lamblia	diarrhoea
HELMINTHS	
Nematodes	
Ascaris lumbricoides	roundworm infection
Hookworm (_Ancylostoma duodenale_ and _Necator americanus_)	hookworm infection
Trichuris trichiura	whipworm infection
Cestodes	
Taenia spp.	tapeworm infection
Trematodes	
Schistosoma spp.	schistosomiasis

Table 1.2 Important infectious disease agents with a potential for spread by the use of excreta in aquaculture

Agent	Illness	Intermediate host(s)
VIRUSES		
Enteroviruses	diarrhoea, respiratory disease, polio	none
Hepatitis A	infectious hepatitis	none
Rotavirus	diarrhoea	
BACTERIA		
Campylobacter jejuni	diarrhoea	none
Pathogenic *Escherichia coli*	diarrhoea or dysentery	none
Salmonella spp. (non-typhoid)	diarrhoea	none
Salmonella typhi	typhoid fever	none
Shigella spp.	diarrhoea or dysentery	none
Vibrio spp. (?)[1]	cholera or diarrhoea	none
PROTOZOA		
Entamoeba histolytica	diarrhoea or dysentery	none
Giardia lamblia	diarrhoea	none
HELMINTHS		
Cestodes		
Diphyllobothrium latum	fish tapeworm infection	freshwater copepod and freshwater fish
Trematodes		
Clonorchis sinensis	bile duct infection	freshwater snail and freshwater fish
Fasciola hepatica	liver fluke infection	amphibious snail and aquatic vegetation
Fasciolopsis buski	intestinal fluke infection	freshwater snail and aquatic vegetation
Opisthorchis spp.	bile duct infection	freshwater snail and freshwater fish
Schistosoma spp.	schistosomiasis	snail

1 Considerable uncertainty surrounds the ecology of these organisms.

factors intervene in a complex manner to define the likelihood that a potential risk will result in measurable human disease or infection. This sequence of events and the pathogen-host properties influencing each step in the sequence are summarised diagramatically in Figure 1.1. For a potential risk from nightsoil use to exist, an infective dose of virulent pathogens must reach the land or ponds being fertilised. The likelihood that this dose will be reached for a given pathogen and for a given route of infection is dependent on several properties of the pathogen (Feachem et al. 1983) - the concentration of pathogens excreted (excreted load), the time between excretion and infectivity (latency), the survival of the pathogen in the environment (persistence), the survival of the pathogen following any excreta treatment to which it is subjected, and the ability of the pathogen to multiply in the environment. These properties vary from pathogen to pathogen. In the case of some important excreted agents (Campylobacter jejuni, rotavirus and hepatitis A virus), much is still to be learned about their survival properties. There is extensive evidence that many of the pathogens listed in Tables 1.1 and 1.2 may be present in raw excreta in high concentrations, that they may survive for periods of several days to several months in wastewater, nightsoil or sludge, and that they may pass through many types of conventional excreta-treatment process (Feachem et al. 1983, Cross and Strauss forthcoming and Shuval et al. forthcoming). There is every likelihood that raw and treated nightsoil or sludge applied to land or added to ponds will contain sufficient numbers of some of these pathogens for human infection to be theoretically possible.

However, this likelihood is of little consequence unless this infective dose reaches a human host by a pathway which allows transmission of that agent. For all of the pathogens listed in Tables 1.1 and 1.2 with the exception of hookworm and species of Schistosoma, the pathogen must reach the human mouth since spread is by faecal-oral pathways. For Schistosoma species, the agents must penetrate the skin for transmission to occur. For the 2 major species of hookworm the situation is more complex. While infection with Necator americanus occurs almost exclusively by the percutaneous route, infection with

Figure 1.1 Pathogen-host properties influencing the sequence of events between the presence of a pathogen in excreta and measurable human infection attributable to excreta use

EXCRETED LOAD

↓

- latency
- multiplication
- persistence

INFECTIVE DOSE APPLIED TO LAND/WATER

↓

- persistence
- intermediate host
- type of practice
- type of exposure

INFECTIVE DOSE REACHES HUMAN

↓

- pattern of human immunity
- human behaviour

RISK OF ILLNESS OR INFECTION

↓

- alternative routes of transmission

PUBLIC HEALTH IMPORTANCE OF EXCRETA USE

Ancylostoma duodenale may be acquired by either the oral or percutaneous route; the relative importance of each of these routes in different parts of the world is unknown. The factors influencing the probability that an infective dose of pathogens will come into "proper" contact with a human host are the following:

(a) persistence of the pathogen in soil, on crops or in water;
(b) the presence of the required intermediate host(s) in the case of the cestodes and trematodes;
(c) the type of crop to which the nightsoil or sludge is applied;
(d) how and when excreta are applied; and finally
(e) the nature of the exposure of the human host to the contaminated crop, soil or water.

All of the factors thus far described determine the potential or theoretical health risks of nightsoil or sludge use. Taking into consideration pathogen properties and usual routes of transmission, theoretical infectious disease risks of nightsoil or sludge use for different exposure groups can be formulated; these are presented for agricultural use in Table 1.3 and for aquacultural use in Table 1.4. For each type of crop and group at risk listed in these tables, the potential risks from sewage or wastewater use are identical to those from nightsoil or sludge use (Feachem and Blum 1985). In most of the situations represented in Tables 1.3 and 1.4, several biological classes of pathogens pose potential health risks. However, the long persistence and low infective dose of the nematodes make these agents particularly likely to be spread by excreta use in agriculture. Sludge use may represent a greater potential risk for dissemination of helminthic agents than the use of other forms of excreta since helminth eggs are concentrated in sludge during sewage-treatment processes.

Two important additional factors - host immunity and behaviour - intervene to determine whether a potential health risk becomes observed disease or measurable infection (Figure 1). The important role of immunity is most evident in the case of certain viral infections where

Table 1.3 Agricultural use: theoretical risks of human infection with the major groups of pathogens according to the type of use of nightsoil or sludge and type of exposure

Exposure group[a]	Potential infectious disease risks from nightsoil or sludge fertilisation of:		
	crops for humans	crops for animals	non-consumable crops
persons consuming crops	V,B,P,N	-	-
persons consuming meat or milk	-	B,C	-
agricultural or sanitation workers at site of use	V,B,P,N,T	V,B,P,N	V,B,P,N

V = excreted viruses

B = excreted bacteria

P = excreted protozoa

N = excreted nematodes

C = excreted cestodes

C = excreted trematodes

- = not applicable

[a] In wastewater use, people living near the site of use present an additional potential group at risk from aerosols generated by spray irrigation. The density of nightsoil or sludge and methods of application make it unlikely that aerosols would travel a sufficient distance to present a potential risk to nearby inhabitants.

SOURCE: after Feachem and Blum (1985)

Table 1.4 Aquacultural use: theoretical risks of human infection with the major groups of pathogens according to the type of excreta use and type of exposure

Exposure group	Potential infectious disease risks from excreta fertilisation of:		
	crops for humans	crops for animals	non-consumable crops
persons consuming crops	V,B,P,C,T	-	-
persons consuming meat or milk	-	B	-
aquacultural or sanitation workers at site of use	V,B,P,T	V,B,P,T	V,B,P,T

V = excreted viruses

B = excreted bacteria

P = excreted protozoa

C = excreted cestodes

T = excreted trematodes

\- = not applicable

SOURCE: after Feachem and Blum (1985)

widespread early infection is common and as a result the adult population is largely immune to subsequent disease (and often, infection). In these cases, the fact that a nightsoil-use practice causes an infective dose of virulent pathogens to come into contact with a human host may be unassociated with any detectable excess morbidity. Likewise, host behaviour, especially with regard to personal hygiene, food hygiene, and, in the case of occupational exposures, the wearing of protective clothing, can protect against disease or infection even in the face of otherwise potentially dangerous exposures. It is notable that little attention has been focused on immunological and behavioural influences on risk since they partially determine the need for strict regulations concerning the kind of treatment to which excreta must be subjected and the kind of crops to which excreta can be applied.

Finally, the public health importance of excreta use in the spread of a particular infection depends on an assessment of attributable risk, the extent to which disease or infection can be attributed to the excreta-use practice in question. Attributable risk corresponds to an estimate of how much disease reduction may be expected with the termination or alteration of a particular practice. This risk measure is dependent on the relative importance of alternative routes of transmission for a given agent. Where multiple routes of transmission contribute to spread of a particular pathogen, nightsoil or sludge use may contribute only a small additional risk and control measures aimed at improving excreta-use practices may show little measurable effect. In contrast, where the entire incidence of disease or infection is due to excreta use, major disease reductions can be expected with changes in such practices.

This discussion highlights the complexity of the issues which determine the infection risks of excreta use and the distinction which must be made between potential risks from the mere presence of pathogens and observed disease or infection. This distinction has been considered in relatively few discussions of the risk of infectious disease from excreta use but among those are the reviews by Elliott and Ellis (1977), Benarde (1973), Alderslade (1981), Barua (1981), Gunnerson et al. (1985) and Shuval et al. (forthcoming).

1.3 Epidemiological studies - methodological issues

There are relatively few epidemiological studies which have measured the frequency of disease or infection associated with excreta use in agriculture. The majority of these studies have considered wastewater use and very few have specifically examined nightsoil or sludge use, although as discussed earlier, similarities in health risks may be expected. Risks associated with the use of excreta in aquaculture have only rarely been the subject of epidemiological investigation. In the consideration of health risk of nightsoil or sludge use, a dependency on environmental studies of pathogen survival and removal, rather than on epidemiological studies of disease frequency and determinants may cause inappropriately conservative or liberal regulatory actions to be taken (Block 1983). While routine monitoring of the microbiologic quality of excreta intended for use is desirable to define potential risks (and relatively easy to conduct routinely), epidemiological studies are required to test the validity of assumptions about potential risks in a given situation. In this way an information base is created on which to base rational regulatory actions and to plan and improve projects.

Well conducted epidemiological studies on health risks of excreta use may be expected to answer the following broad questions.

(a) Have excreta use practices been associated with morbidity? If so, which diseases or infections have been associated with various types of practice and exposure and with various degrees of excreta treatment? What is the relative likelihood of disease or infection associated with each of these practices and how does this risk differ according to the level of hygiene in the community?

(b) What is the likely impact on observed disease or infection of stopping, changing or introducing a particular practice?

(c) What are the most cost-effective options for using excreta while at the same time not increasing disease transmission? Should measures be aimed at excreta treatment, the method of application, the type of crop fertilised and/or hygiene behaviour?

To date, epidemiological studies on excreta use bear almost exclusively on some aspects of question (a). There are limited data on question (b) and no data on question (c).

A number of general cautionary notes are in order before summarising the results of these studies. First, the restricted geographical distribution represented in these studies, with Africa and Latin America conspicuously absent, limit the applicability of the results to other cultural settings. Second, the studies examine only a few types of infection so that most of the available data pertain to the nematodes in the case of agricultural use and trematodes in aquacultural use. This focus is perhaps warranted on theoretical grounds but it is well to keep in mind that risks are unlikely to be identified unless sought. Third, most studies examine health risks from the use of untreated nightsoil or sludge and thus provide no information on the risks associated with the use of treated forms of nightsoil or sludge, as currently advocated in some countries. Lastly, most of the studies are plagued by a number of serious methodological problems which are common to the environmental health impact literature as a whole (Blum and Feachem 1983). The 3 most recurrent and serious problems are the lack of measurement of important potential confounding variables, the lack of behavioural data, and the failure to define the nature of the risk under investigation; these are discussed below.

(a) Confounding variables. Confounding variables are factors which are associated with both a risk factor and an outcome. Failure to measure such variables and control for them in the selection of comparison groups or in the analysis of data may produce spurious associations. In studies on health risks of excreta use, the confounding variables which should be measured include: age, season, socio-economic status, literacy, level of hygiene and the type of excreta-disposal facilities and water supply used. Few studies appear to have examined these either in the choice of comparison groups or in the analysis of data. Thus differences in morbidity ascribed to different practices may in fact be due to the influence of 1 or more of the confounders listed above.

(b) Behavioural data. Just as the studies on health impacts of water supplies and sanitation fail in most cases to record the usage of facilities and therefore provide little information on how the observed outcome occurred, most excreta-use studies fail to document how, or even if, exposure to excreta occurred. Thus, in many studies, potential rather than actual exposure to risk is examined.

(c) Nature of risk. In many studies information is lacking, at least in the published report, on the type of crop to which the excreta were applied, the type of exposure under investigation (foodborne, occupational or both); and the quality of the excreta at the time of use, in terms of the degree of treatment (if any) provided and the microbiological quality of the excreta at the time of application.

Other methodological problems which occur in some studies include: inadequate sampling and sample sizes, lack of a control sample, and an inadequate follow-up period in situations where interventions have been introduced.

Despite these limitations, a review and summary of the epidemiological studies to date serve several useful purposes. First, where the findings among several studies, especially among the more methodologically sound studies, are concordant and supported by theoretical considerations, certain conclusions about health risks in defined settings are possible. Second, a review of previous work is necessary to understand the current gaps in knowledge and pitfalls in methodology which must be considered in the next generation of epidemiological studies.

In this review an attempt has been made to group studies according to the cells delineated in Tables 1.3 and 1.4; use in agriculture and aquaculture are considered separately. Where the type of exposure and type of practice could not be precisely determined from the published report a "best guess" was made. The non-English literature was reviewed from either the English summaries provided by authors with the original articles or from English abstracts prepared especially for this review. Accordingly, the information from the non-English studies may be less complete and it is likely that some studies published in languages other than English have been inadvertently omitted. The results of each study are summarised in Appendices 1-5. Only reports containing information of an epidemiological nature are included in the appendices.

CHAPTER 2: HEALTH RISKS OF NIGHTSOIL OR SLUDGE USE IN AGRICULTURE - A LITERATURE REVIEW

2.1 Risk to persons consuming crops fertilised with nightsoil or sludge (Appendix 1)

Workers in China in the 1920s and 1930s had clear views on the importance of nightsoil-fertilised crops in the dissemination of parasitic infection. For example, Faust (1926) states:

> "The most usual methods by which parasitic infections are dispersed is by pollution of water and of food with night soil... Where the disease is not incurred by direct contamination, food products consumed raw serve as a via major for transmitting the infection to man".

Robertson (1936), writing 10 years later, concurs:

> "The role which imperfectly cooked and fresh raw vegetables play in the transmission of certain helminthic infestations is very considerable. We know for certain that many vegetables act as simple mechanical vectors of parasitic ova, larvae and cysts due to their contamination during cultivation by fertiliser containing human or animal excrement."

There continues to be a strong belief that the use of excreta as fertiliser is a health risk to the human consumer. In some countries this belief has led to regulations banning the use of excreta, regardless of treatment, on crops for human consumption. There is extensive evidence that crops grown in excreta-fertilised soil can harbour a wide variety of human pathogens for variable periods of time (Feachem et al. 1983). There is less evidence that disease transmission has occurred from consumption of such crops and only limited information on the extent to which such disease transmission occurs.

The main evidence in support of disease transmission from the use of nightsoil or sludge on crops for human consumption derives from studies on helminth, primarily *Ascaris*, prevalence in relation to the use of nightsoil or sludge on gardens in Germany or on fields in Japan. These studies are summarised in Appendix 1. In Germany, Anders (1952) and Harmsen (1953, cited by Kreuz 1955) in separate studies investigated the prevalence rate of *Ascaris* in populations differing in their potential exposure to garden crops fertilised with human nightsoil or sludge. In both studies, rates were markedly higher in persons from families using such excreta in their gardens. These results suggested that transmission might be occurring by this route, but more definite statements are unwarranted owing to the likely influence of confounding differences in the comparison groups and the lack of information on the nature of the crops grown in such gardens, their handling and preparation in the kitchen and any definite history of consumption of such crops by those infected.

If transmission of *Ascaris* infection does occur through consumption of crops fertilised with raw nightsoil or sludge as the studies from Germany might indicate, then it is reasonable to speculate that abolishing such use, or alternatively, improving the practice, might be accompanied by a decrease in *Ascaris* prevalence rates. No studies were located which examined the first alternative, that is, the outcome of abolishing the use of nightsoil, but the work of Rosenberg (1960) indirectly bears on this issue. He found that the high prevalence rates of *Ascaris* on nightsoil-fertilised soil and fruit samples were markedly decreased after the introduction of hygienic measures and cessation of the use of raw nightsoil as fertiliser; the percentage of eggs in soil and on fruit which were viable decreased from 41% and 19% to 0% respectively. Although his study was uncontrolled, the data suggest that such hygiene and sanitary measures may decrease the likelihood of human infection. There is evidence from the wastewater literature that abolishing wastewater-irrigation of vegetables can markedly reduce the prevalence rates of *Ascaris* and *Trichuris* (Shuval *et al*. 1984).

Concerning the second alternative, workers in Japan in the 1950s and 1960s examined the impact of improvements in parasitological quality of nightsoil on the prevalence or positive conversion rates of Ascaris (Katayama 1955, Kawagoe et al. 1958, Kozai 1962 and Kutsumi 1969) and Trichuris (Kutsumi 1969). All studies reported a marked impact of introducing nightsoil treatment on parasite-prevalence rates. The explanation for this observed outcome may be that foodborne transmission of infection by crops fertilised with nightsoil was interrupted or lessened by treatment of nightsoil with heat or an ovicide prior to its use on food crops. However, since neither the type of crops fertilised with nightsoil nor the type of exposure that the study population had to nightsoil (or to the crops it fertilised) is specified, the role of nightsoil in foodborne spread of Ascaris and Trichuris and the extent to which such spread was lessened by excreta treatment in these studies is speculative. In 2 of the studies (Katayama 1955 and Kawagoe 1958), it cannot be known whether the observed reductions in prevalence rate (due to whatever exposure) were in fact related to the interventions, because there was no control sample.

The work of Kozai (1962) and Kutsumi (1969) allow a degree of quantification of the risk reduction following measures to improve nightsoil quality before its use as fertiliser. Kozai studied positive conversion rates after mass chemotherapy in a population divided into 2 nightsoil treatment groups and 1 group continuing to use raw nightsoil as fertiliser. Comparisons between these 3 groups are probably not influenced by the major confounding factors since the baseline prevalence rates prior to the interventions were similar. Kozai found that the risk of acquiring infection with Ascaris at 8 months after chemotherapy was approximately 1.5 times greater in the untreated-nightsoil group than in the 2 nightsoil treatment groups ($p<0.001$). In the group exposed to raw nightsoil the excess prevalence rate (at 8 months) attributable to that exposure was approximately 14% (attributable risk).

Kutsumi (1969) examined the effect of nightsoil treatment on Ascaris and Trichuris prevalence rates (in separate studies). In each study, intervention-control comparisons are problematical because there were pre-existing baseline differences in prevalence rates, suggesting the intervention and comparison groups were not comparable for important confounding variables. Focusing therefore on before-after differences in the study group receiving only nightsoil treatment, there was a reduction in the prevalence rate of Trichuris from 65% to 47% over 2 years ($p<0.001$) and a reduction in Ascaris prevalence rate from 33% to 21% ($p<0.05$) over a similar period. The excess prevalence rates attributable to exposure to raw nightsoil were 18% in the Trichuris study and 12% in the Ascaris study. These findings are difficult to interpret vis-a-vis statements on risks associated with nightsoil use on crops because it is unclear from his report how widespread the practice of nightsoil use as fertiliser was in these areas and it seems that in some instances nightsoil was buried rather than used as fertiliser.

Both Kozai and Kutsumi defined their intervention-control groups by the differences in the hygienic quality of nightsoil to which groups were exposed; therefore the attributable risks derived from their data pertain to the difference in prevalence between 2 groups with exposure to nightsoil in some form, whether raw or treated. No studies were located which allowed computation of the risk attributable to the use of treated nightsoil, that is, where prevalence in groups not practising nightsoil use were compared with groups using treated nightsoil. The risk associated with this situation is of important practical concern where consideration is being given to introducing excreta use. The attributable risk of using treated nightsoil will be less than the total prevalence observed in those who use it, because a considerable, but unknown, proportion of Ascaris and Trichuris transmission is probably occurring through yard contamination by the faeces of young children. The importance of yard contamination has been demonstrated in such diverse cultural settings as China (Winfield 1937 and Scott 1952) and the U.S.A. (Otto et al. 1931). This peri-domestic transmission will limit the degree to which improved nightsoil use can reduce prevalence rates and may at least partly explain the high "unattributable" risk in the studies of Kozai and Kutsumi.

In addition to contributing to the load of endemic helminthic infection, the use of raw nightsoil or sludge on vegetables consumed raw has been held responsible for foodborne disease outbreaks (Sepp 1963 and Bryan 1977). Outbreaks of amoebiasis in Palestine (Aldridge 1947), paratyphoid fever in Austria (Harmsen 1954), and typhoid fever in France (Kreuz 1955), Germany (Harmsen 1954) and the U.S.A. (Pixley 1913) have been attributed to the consumption of nightsoil-fertilised vegetables. Likewise the high prevalence rates of ascariasis in the Darmstadt area of Germany following World War II compared to other areas of Germany has been attributed to the use of sewage and sludge on vegetable crops (Baumhögger 1949 and Krey 1949). However, the reports citing these outbreaks present insufficient epidemiological detail to judge the role of nightsoil-contaminated crops in their propagation. For example, in none of these outbreak reports were attack rates for those consuming and not consuming these crops presented or mentioned. The wastewater literature, however, does suggest that excreta-fertilised vegetables can propagate foodborne disease outbreaks. A well documented case in point is the cholera outbreak in Jerusulem in 1970 (Cohen et al. 1971 and Shuval et al. 1984). The proportion of foodborne disease outbreaks that may be associated with foods fertilised with raw excreta is unknown.

2.2 Risk to persons consuming meat or milk from animals that have consumed crops fertilised with nightsoil or sludge

In order for human infection to occur by this route, animals must first be infected by consuming grass or other green fodder which has been fertilised with nightsoil or sludge. Then the infection must be passed from infected animal to man. The 2 pathogens of major veterinary and human importance which may be found in significant numbers in nightsoil or sludge and which may have significant risk attributable to excreta use are Taenia saginata and Salmonella species. There is epidemiological evidence, all from developed countries, that animal infection with these agents can and does occur from the use of untreated excreta on fields although the magnitude of this risk is uncertain. There is little information on the risk from the use of treated excreta. Documented evidence of disease or infection in humans subsequently consuming meat or milk from these infected animals is rare, although in most animal studies evidence of associated human morbidity was not sought. The epidemiological studies which examine the veterinary risks from consumption of crops fertilised with nightsoil, sludge or farm slurry (a liquid mixture of farm waste and animal faeces and urine) or the human risks from consuming meat or milk from such animals are summarised in Appendices 2 and 3.

2.2.1 Taenia saginata infection (Appendix 2)

A major veterinary risk from the use of excreta on food crops for animals is bovine infection with Cysticercus bovis (C. bovis), the larval stage of the beef tapeworm, Taenia saginata (T. saginata). The potential importance of the use of excreta in agriculture in propagating taeniasis is more straightforward than in the case of salmonellosis where there are multiple routes of transmission and human-animal infection cycles can operate equally well in series or in parallel. In order for animals to become infected with C. bovis, human faeces containing T. saginata eggs must come into contact with cattle and in order for uninfected humans to become infected, humans must eat undercooked meat infected with C. bovis. There are only a limited number of ways in which human faeces can come into contact with cattle. The 3 possibilities most often mentioned (Silverman and Griffiths 1955, Greenberg and Dean 1958, Crewe 1967 and Crewe and Owen 1978) are:

(a) indiscriminate defecation by humans on pasture;
(b) droppings of seagulls that have fed on sewage at sewage treatment plants and;
(c) use of sewage or sludge on pasture.

Little is known of the relative importance of these modes of transmission. Epidemiological studies has been hampered by the need to examine carcasses at slaughter to determine _C. bovis_ prevalence and by the difficulty in distinguishing _T. saginata_ eggs from the eggs of other taeniid worms, for example those infecting domestic animals. The recent development of serological techniques should make epidemiological studies more feasible in the future.

Given the knowledge that _Taenia_ eggs tend to concentrate in sewage sludge where a high percentage may survive for over 6 months (Feachem _et al_. 1983), it is reasonable to speculate that spreading of raw nightsoil or sludge on pasture is likely to be associated with a risk of _C. bovis_ infection. Two epidemiological studies were located which documented _C. bovis_ infection in cattle exposed to sludge- or slurrry-fertilised pasture (Hammerberg _et al_. 1978 and Macpherson _et al_. 1978); evidence of associated human disease was not investigated in these studies. There are also passing references to such transmission in the literature (Sewell and Harrison 1978, Williams 1979 and Alderslade 1981). In addition Appendix 2 summarises a large outbreak of bovine cysticercosis in which there was suggestive, if inconclusive, evidence of transmission from faecally contaminated feed. Further, a human case of _T. saginata_ was epidemiologically associated with that outbreak (MMWR 1968). There is experimental data from Denmark (Jepsen and Roth 1952) to suggest that _Taenia_ eggs do survive for varying lengths of time on grass contaminated with human faeces and that calves fed such grass become infected.

There is also evidence from the wastewater literature that the use of human excreta may be an important risk factor for transmission of _C. bovis_ in certain areas. In Australia, Rickard and Adolph (1977) examined cattle at slaughter that had grazed on sewage-irrigated pastures. By microscopy, they found _C. bovis_ prevalence rates of 33-51%, depending on the age of the cattle, with 8% of the cysts viable; the observed prevalence was about 30% lower when only gross examination was performed. Even if the lower figures are used, these rates are markedly higher than the 0.05-0.39% found in previous prevalence surveys at other abattoirs in New South Wales and Victoria several years previously. In

Germany, Krueger (1935) noted a higher prevalence of C. bovis in cattle fed sewage-fertilised grass than in cattle fed other green fodder. However, the total number of animals examined in each group is not clear, so that the data are difficult to interpret.

The relative importance of the purposeful use of sewage, sludge or nightsoil on pasture as opposed to indiscriminate defecation by humans on pasture is unclear and will depend on the social and cultural circumstances in which transmission is occurring. The likelihood that such practices will result in human infection depend on prevailing food habits in areas where taeniasis is endemic. No epidemiological studies were located which specifically examined the magnitude of the human taeniasis risk attributable to excreta use.

2.2.2 Salmonella infection (Appendix 3)

Appendix 3 presents epidemiological evidence that outbreaks of salmonellosis in animals have occurred from the use of sludge or slurry on pasture in developed countries (Jack and Hepper 1969, Strauch and Perrácová 1969, Hess and Breer 1976 and Pike 1981). There is less information linking human outbreaks of salmonellosis to consumption of meat or milk from such animals, but Burnett et al. (1980) traced an outbreak of human salmonellosis to consumption of milk from animals infected after grazing on sludge-fertilised pasture. In the wastewater literature there are 2 documented outbreaks of salmonellosis in cattle which followed accidental contamination of pasture from raw sewage overflow in 1 case (Bicknell 1972) and wastewater effluent in the other (Bederke et al. 1956); in the latter case, there were subsequent human cases. In all the outbreaks, the temporal relationship between excreta use and disease and the isolation of the identical serotype from pasture and animals (especially where the serotype was unusual) were highly suggestive of disease transmission to cattle through excreta use. It should be recognised, however, that the finding of the same serotype in cattle and on pasture could represent secondary contamination of pasture from animals infected via another route, for example commercial animal feeds or contact with newly purchased infected animals. Definitive conclusions from outbreak investigations are frequently hampered by the time lapse between exposure to risk and investigation of outcome which makes it difficult to establish the temporal sequence of events.

Nonetheless it seems reasonable to conclude from the outbreak investigations in Appendix 3 that use of excreta on land may result in outbreaks of bovine salmonellosis in Europe. These investigations provide no information on the frequency with which such outbreaks occur and the proportion of all outbreaks of salmonellosis in cattle which occur by this route. The lack of information on these issues reflects the fact that only a small, but unknown, percentage of outbreaks are recognised and even fewer investigated or reported; this situation is true for both developed and developing countries. There is limited evidence to suggest that an unknown (but likely small) percentage of outbreaks of human salmonellosis may be attributable to consumption of meat or milk from animals infected by grazing on sludge- or slurry-fertilised pasture.

The role of nightsoil or sludge use on pasture in propagating endemic bovine salmonellosis is uncertain. The seasonality of bovine salmonellosis in many European countries is well recognised (Hess and Breer 1975, Williams 1975 and Wray and Sojka 1977) and the observed peak during the grazing season (summer and autumn) has been taken as evidence that sludge-fertilised pasture is an important factor in propagating salmonellosis in cattle (Hess and Breer 1975 and Williams 1975). However, the higher infection rate in the summer grazing season could equally well be ascribed to factors such as the consumption of water from contaminated surface sources during the grazing period. As Feachem et al. (1983) point out, salmonellosis in man also peaks during the warmer months and humans neither graze on pasture nor do the majority of human infections derive from consumption of beef or milk. Hess's finding (1981) that the seasonality of infection rates in cattle grazed outdoors was absent in the cattle reared in confinement is difficult to interpret since the two groups of cattle were no doubt reared under conditions which differed in more ways than just exposure to sludge. Further, while the work of Hess and Breer (1976) suggests that cattle exposed to sludge-fertilised pasture did have a higher infection rate (5%) than cattle not exposed (0%), the fact remains that exposure to sludge only rarely resulted in infection.

The experimental studies listed in Appendix 3 suggest that Salmonella infection of animals resulting from the use of excreta on fodder crops may be an unlikely event, requiring ingestion of doses of organisms in excess of 10^4-10^5 (Hall and Jones 1978) or field application of excreta containing concentrations of salmonellae in excess of that likely to be found in "typical" U.K. sludge or slurry[1] (Taylor and Burrows 1971 and Taylor 1973). If it is true that the risk of animal infection from the use of excreta on fodder crops is small, then one would expect that outbreaks of clinical disease in cattle due to this cause may be even rarer as the dose required to produce symptoms is usually larger than that needed to produce asymptomatic infection.

There is little information on the risk of Salmonella infection in animals exposed to treated sludge, but it may be that the risk is small, given the apparent low risk suggested by the experimental work described above. In the U.S.A., Ayanwale et al. (1980) failed to find salmonellae in faecal speciments from 36 goats fed silage grown on fields fertilised with sewage sludge that had been stored for 6 months prior to application.

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1 The median concentration of salmonellae per 100 ml of sludge in the U.K. is about 70 (Feachem et al. 1983).

2.3 Risk to farmers engaged in agricultural work on land receiving nightsoil or sludge or to sanitation workers applying nightsoil or sludge to agricultural land (Appendix 4)

People working in close contact with nightsoil or sludge are potentially at high risk of contracting any disease spread by faecal-oral pathways or by skin penetration. Studies which examine the occupational risks of the use of nightsoil or sludge in agricultural settings are summarised in Appendix 4.

Two studies, both from developed countries, investigated risks of viral faecal-oral diseases in persons in close contact with sewage sludge in agricultural settings. Neither study mentioned the extent of sludge treatment, if any, prior to field application. The outbreak investigation from the U.K. (Timothy and Mepham 1984) suggests that sludge spreaders may be at risk of contracting hepatitis A. In contrast, preliminary results from a prospective study in the U.S.A. (Ottolenghi et al. 1980 and Hamparian et al. 1982) suggest that farm workers (and their families) on sludge-receiving farms are not at higher risk of infectious hepatitis than workers (and their families) on farms that do not use sludge. This apparent discrepancy could be explained by differences in sludge quality, method of application or degree of exposure, none of which are specified in the brief reports. The U.S.A. study also examined, by serology, the risk of infection with enteroviruses. No clear risk was identified. Persons on sludge-receiving farms did not have higher rates of infection with enteroviruses although an antibody rise to more than 1 type of enterovirus was more common in persons on sludge-receiving farms. The clinical implications of these antibody rises were not presented, but it is likely that these serological changes were accompanied by few if any symptoms, at least in adults and older children where a degree of pre-existing immunity would be expected. More detailed data are required fully to interpret these results.

No studies were located which provided information on the risks of bacterial or protozoal infection associated with occupational exposure to nightsoil or sludge in agricultural settings. The final results of the study from the U.S.A. (Ottolenghi et al. 1980 and Hamparian et al. 1982) will, however, provide data on the prevalence of infection with salmonellae and shigellae among farm workers and their families on sludge-receiving farms and control farms.

The occupational risk of hookworm infection has been examined in several studies from the Far East. Two different perspectives on the problem have been taken. Studies from Japan examined the magnitude of risk and measured the degree to which this risk may be lessened by improving nightsoil quality. In contrast, a study from China takes a non-quantitative approach and uses detailed observation to define the determinants of hookworm infection and to explain observed patterns. Both approaches are useful in defining the role of nightsoil use in agriculture in the epidemiology of hookworm infection in these areas.

In Japan, studies similar to those which examined the impact of nightsoil treatment on Ascaris and Trichuris infection were undertaken on hookworm infection (Katayama 1955, Kawagoe et al. 1958, Kozai 1962 and Kutsumi 1969) A marked impact on hookworm prevalence or positive conversion rates was reported in all studies. The studies of Katayama (1955) and Kawagoe et al. (1958) did not include a control group and it is therefore difficult to attribute changes in prevalence to the nightsoil treatment.

Kozai (1962) and Kutsumi (1969) used positive conversion rates following mass chemotherapy to examine the impact of nightsoil treatment with ovicide on hookworm prevalence. Kozai found that the risk of acquiring hookworm infection 7 months after mass anthelmintic therapy was 1.8 times higher in the group continuing to use raw nightsoil as fertiliser compared to the groups in which nightsoil treatment was introduced ($p<0.005$). The excess prevalence in the untreated nightsoil group was 14.5% Unfortunately, Kozai did not examine age-specific rates. It is, however, the infection rate among those working in the fields, mainly adults, which is of concern in quantifying occupational risk.

Kutsumi (1969) did a similar hookworm re-infection study in treated and untreated nightsoil groups in a farming community. His baseline data showed that hookworm was primarily an infection of adults and that adults working in vegetable fields were at higher risk than other adults. Accordingly, he analysed the data on positive conversion rates for adults and children separately. Positive conversion rates at 6 months after chemotherapy were similar in the treated nightsoil group and untreated nightsoil group among children, but higher in the untreated nightsoil group among adults. Since not all families whose nightsoil was either treated or untreated actually used nightsoil as fertiliser, Kutsumi analysed data for this user group separately. The risk of hookworm infection among adults in families that used nightsoil as fertiliser in their fields was 1.8 times greater in the untreated nightsoil group than in the treated nightsoil group. The excess hookworm prevalence in the former group was 5%. Although a trend towards higher risk was found in the untreated nightsoil group, the sample sizes were not large enough for the differences detected to be statistically significant. Among adults from families not using nightsoil as fertiliser, the risk of hookworm infection was only 1.3 times greater in the untreated nightsoil group than in the treated nightsoil group and the excess prevalence in the former group was 1.3%. These data suggest that occupational exposure to raw nightsoil may confer a risk of hookworm infection; the additional risk attributable to use of treated nightsoil cannot be predicted from these data, nor the magnitude of the risk associated with raw nightsoil after the effect of mass chemotherapy is no longer operating.

By means of a more qualitative epidemiological approach, Cort et al. (1926) also identified hookworm infection as an occupational risk of farmers in China. Further, they identified a number of important factors that influenced which occupational groups were at highest risk. A questionnaire survey of hospitals and other health centres revealed an uneven distribution of hookworm infection in China: hookworm appeared to be an important public health problem in Central and South China, but of less importance in North China. In all areas, hookworm was found to be a rural problem. Detailed parasitological studies of stool, nightsoil and soil samples were used in combination with behavioural observations to define the determinants of this observed distribution. The studies suggested that the use of nightsoil per se as fertiliser did not explain observed patterns. Their limited studies in North China suggested that climatic factors - the predominantly cool and dry weather - restricted hookworm transmission in that part of China, despite the widespread use of nightsoil as fertiliser and pollution around the edges of latrines. The practice in North China of composting nightsoil did not appear to be as important as the adverse climatic conditions in explaining the low intensity of hookworm infection since the parasitological study of compost piles recorded a moderate concentration of infective hookworm larvae in most samples. More detailed studies in Central and South China where climatic conditions were favourable for hookworm transmission showed that the prevalence and intensity of hookworm infection were closely related to the type of crop and method of cultivation, despite the universal use of raw nightsoil diluted with water (stored for variable periods) as fertiliser. The cultivation of rice under water was associated with poor survival of hookworm larvae and consequent low infection rates among rice farmers. In contrast, the method of cultivation of mulberry trees was associated with high levels of soil infestation and high hookworm prevalence rates, intensities of infection and evidence of clinical disease among mulberry farmers. Several factors promoted hookworm transmission among this occupational group. First, the large amounts of nightsoil needed just after the first picking of leaves exceeded the supply of stored nightsoil so that all fresh nightsoil available was also used. Second, the nightsoil was applied in such a way as to promote the development of hookworm larvae, that is the nightsoil was poured onto turned-up soil or buried in shallow holes. Third, the barefoot pickers entered the fields at the peak of intensity of soil infestation and they had to stand for long periods at the base of the trees where the nightsoil had been concentrated. These studies highlight the importance of defining the type and extent of occupational nightsoil contact in a given environmental setting in order to understand the magnitude of the risk associated with different types of occupational exposure.

There is also evidence from China (Faust and Meleney 1924) that occupational exposure to nightsoil, in this case rice farming, represents a risk of infection with Schistosoma japonicum (S. japonicum). The evidence is based on the distribution of schistosomiasis in China and an investigation of the methods of rice cultivation. Schistosomiasis was found to coincide in distribution with the rice-growing areas of China. A number of aspects in the cultivation of rice were favourable for transmission of schistosomiasis to rice workers. First, both fresh and stored nightsoil were used to fertilise the fields prior to planting. Although this nightsoil was not examined parasitologically before use, the high prevalence of schistosomiasis in this area makes it likely that the nightsoil contained high concentrations of S. japonicum eggs. Second, after the seeds were planted the fields were flooded with water, providing a suitable habitat for the intermediate snail hosts which were washed down from the canal, pond or lake supplying water for irrigation. These snails were found in the irrigation ditches and in great numbers in the nursery beds nearest the canals. Finally, rice farmers had to enter the flooded rice fields to transplant the crop, providing an opportunity for cercariae to penetrate the skin of the farmers' unprotected arms and legs. While this study presents strong evidence of occupationally related schistosomiasis transmission, the magnitude of the risk of transmission by this route, and the risk attributable to the use of nightsoil as fertiliser, compared with transmission by other water-contact activities in this part of China are not clear.

CHAPTER 3: HEALTH RISKS OF EXCRETA USE IN AQUACULTURE - A LITERATURE REVIEW

The 3 most common types of aquaculture are fish farming, algae culture and macrophyte culture. In many parts of the world, including parts of the Far East, India, the Middle East, Europe and North America, excreta are added to freshwater bodies used for aquaculture to promote fish and plant growth and as a method of excreta treatment. Where excreta are used in conjunction with aquaculture, 3 groups of people may be at risk for a number of viral, bacterial, protozoal and helminthic infections: people who consume fish or aquatic plants; people who consume the meat or milk of animals that have been fed fish or aquatic plants; or people with occupational exposure to aquacultural ponds fertilised with excreta, principally sanitation workers, fishermen, fish farmers or aquatic-plant farmers. The review of the aquaculture literature was largely, although not exclusively, limited to studies published in English, and while these studies are mainly from the Far East, it is likely that there is a relevant non-English literature from the Far East which was not examined. The few epidemiological studies that specifically examined infectious-disease transmission associated with excreta use in aquaculture are summarised in Appendix 5 and discussed below, by exposure category.

3.1 Risk to persons consuming fish or aquatic plants grown in ponds fertilised with excreta (Appendix 5)

Edible fish or plants grown in excreta-fertilised ponds may present a health risk to the human consumer by serving to transfer passively pathogens on their surfaces (or in fish viscera) or by acting as an intermediate host. In the first instance, transmission of bacterial, viral and protozoal agents may occur; helminth eggs which do not hatch in water will tend to settle and are unlikely to represent a hazard. In the second instance, a variety of trematode infections may be transmitted to man.

With the exception of 1 study from Israel (Fattal et al. 1981 and Fattal 1983), no epidemiological studies were located which examined the risk of bacterial, viral or protozoal infections in people consuming fish or plants from excreta-enriched ponds. However, it is possible that such transmission does occur since a number of foodborne disease outbreaks have been described which implicate fish or plants grown in incidentially polluted freshwater as the vehicle of transmission (Bryan 1977). There is inconclusive epidemiological evidence that outbreaks of typhoid fever and infectious hepatitis may have resulted from consumption of raw watercress grown in faecally contaminated water (Anon 1903 and MMWR 1971) and that the whitefish implicated in an outbreak of salmonellosis may have been contaminated when washed with water from a faecally polluted river (Gangarosa et al. 1968).

In a study of health risks associated with wastewater irrigation in Israel (Fattal et al. 1981 and Fattal 1983), the risk of enteric diseases among people living on 10 kibbutzim (cooperative agricultural settlements) practising wastewater effluent use in fish ponds was examined; some of these kibbutzim used the fish-pond effluent for agricultural irrigation. Foodborne or occupational exposure was not measured but was assumed. A retrospective review of clinic records over a 4-year period revealed a higher rate of clinical enteric diseases and laboratory-confirmed salmonellosis, but not of viral hepatitis or shigellosis, in kibbutzim practising aquacultural use compared to kibbutzim not practising effluent use for any purpose. There was also a higher rate of throat infections, suggesting that these 2 groups of kibbutzim differed in more ways than just effluent use. These data are difficult to interpret owing to reporting and recording biases inherent in this type of retrospective study. The relevance of these data to foodborne disease risks of using excreta for fish production is likewise problematical since the nature and degree of exposure were not recorded.

The potential importance of excreta-enriched aquacultural waters in foodborne disease transmission is clearer for certain cestodes and trematodes, the transmission of which can only occur through the disposal of human or animal excreta in water containing appropriate intermediate hosts and the subsequent consumption of an intermediate host by a human or animal. The diseases that are spread in this way are clonorchiasis, diphyllobothriasis, fascioliasis, fasciolopsiasis, opisthorchiasis and paragonimiasis. In the specific setting of excreta-enriched ponds, however, the list is more limited since Paragonimus infects freshwater crustaceans which live in flowing rivers or streams and is therefore not associated with excreta-enriched ponds and Diphyllobothrium infects larger freshwater fish which inhabit lakes and therefore is unlikely to be a risk where smaller ponds are used in aquaculture. Although there is a substantial literature on each of these pathogens and their epidemiology (Feachem et al. 1983), few studies have focused, either descriptively or analytically, on the role of excreta use in aquaculture in the transmission of these trematodes.

There are a few descriptive epidemiological studies from the Far East which suggested that excreta-enriched ponds were important in transmission of Clonorchis sinensis. In Taiwan, Cross (1969) attributed the focal distribution of human Clonorchis infection to a combination of excreta use in aquaculture and the custom of some ethnic groups of eating raw fish. In one area of high prevalence, fish consumed raw were cultivated in ponds to which human nightsoil and pig faeces were applied to promote fish growth. The intermediate hosts were found in these ponds and fish from these waters were shown to be infected (Komiya 1966).

In China, Faust and Khaw (1927) studied the conditions responsible for human Clonorchis infection in a province of known high prevalence. Detailed descriptive studies in one area suggested that nightsoil fertilisation of fish ponds was an important factor. In this area a large percentage of land was devoted to fish farming. The ponds were directly fertilised with nightsoil from latrines placed over the ponds, allowing fresh faeces to drop into the water. The high prevalence of human

Clonorchis infection in the area ensured that the faeces contained *Clonorchis* eggs. Appropriate intermediate snail and fish hosts were found in these ponds and both were found infected. The pathway of transmission was completed when these fish were consumed raw. It is likely that nightsoil use in these fish ponds presented a risk of *Clonorchis* infection. However, their observations in another area of the same province suggests that the risk attributable to excreta use, even under such ideal conditions for transmission, may have been small. In another fish-farming area, high human prevalence rates were found in the absence of purposeful nightsoil use in the fish-ponds. In this area it was found that ponds became polluted with human faeces in other ways. If this incidental faecal contamination of fish ponds (or other waters containing the appropriate intermediate hosts) was significant in the area where nightsoil was used in fish culture, much transmission would be unassociated with such use.

There is some evidence from China implicating nightsoil use in macrophyte culture in transmission of *Fasciolopsis buski* (Barlow 1925). In an area of high human *Fasciolopsis* prevalence, Barlow observed that certain aquatic vegetables peeled with the teeth and eaten raw were grown in ponds fertilised with raw nightsoil. The snail intermediate host was found in large numbers on these plants and large numbers of cysts were found on the plants, particularly the water caltrop.

It appears that in some areas where nightsoil is used in aquaculture, ideal conditions exist for transmission of both *Clonorchis sinensis* and *Fasciolopsis buski* and high prevalence rates may be associated with this practice. However, there is evidence that infection is similarly facilitated by incidental pollution of water bodies in areas where purposeful nightsoil use is not practised, as was demonstrated by Barlow (1925) in China for *Clonorchis* and Sadun and Maiphoom (1953) in Thailand for *Fasciolopsis*. No studies were located which quantified the risk attributable to aquacultural use of excreta; this risk will vary from area to area, according to the prevailing social and cultural circumstances, including local defecation habits, and the importance of animal reservoirs. The likelihood that either excreta use or incidental pollution will result in human infection is ultimately dependent on the cooking and eating habits of people living in endemic areas.

No studies were located which examined excreta use in aquaculture as a risk factor in the transmission of diphyllobothriasis and fascioliasis. Diphyllobothriasis is not endemic in those areas in which excreta use in aquaculture is practised most widely. Transmission is associated with the discharge of sewage into rivers or lakes. Fascioliasis is predominantly an infection of sheep and cattle and therefore the use of human excreta in the cultivation of watercress and other aquatic vegetation is unlikely to be important in transmission. A number of outbreaks of fascioliasis in the U.K. have been attributed to pollution of watercress beds by faeces of infected animals (Facey and Marsden 1960 and Hardman _et al_. 1970).

3.2 Risk to persons consuming meat or milk from animals that have consumed crops grown in ponds fertilised with excreta

The disease risks to the human consumer of meat or milk from animals fed fish or vegetation from excreta-enriched ponds include infection with _Salmonella_ species and _Campylobacter jejuni_. It has been suggested that _Taenia_ eggs might be transferred on algae fed to cattle (or pigs) and thereby spread taeniasis (Barua 1981). However, the heavy _Taenia_ eggs will pass to the bottom of the pond and it seems unlikely that they would settle on surface vegetation. No epidemiological studies were located which examined the risk of human disease from consuming meat or milk from animals fed foodstuffs from excreta-enriched ponds. Similarly, no studies were found which examined the veterinary risk of salmonellosis or campylobacteriosis associated with consumption of foods grown in such ponds. _Salmonella_-contaminated fishmeal has been incriminated in bovine salmonellosis (Wray and Sojka 1977) but the relationship between enriched ponds and fish used in fishmeal has not been investigated.

3.3 Risk to persons with occupational exposure to aquacultural ponds fertilised with excreta

Those persons who work in close contact with excreta-fertilised ponds, including sanitation workers, fisherman, fish farmers and aquatic-plant farmers may accidentally ingest pathogens and therefore are potentially at high risk of faecal-oral infections. No epidemiological studies were located which specifically examined this risk, although the exposures of people studied on kibbutzim in Israel (Fattal *et al*. 1981 and Fattal 1983) may have been partially occupational.

Workers who wade into excreta-enriched ponds are potentially at risk of percutaneous infections. Hookworm infection is unlikely in this setting because hookworm eggs do not hatch under water (Cort *et al*. 1926). There is a potential risk of infection with species of *Schistosoma*, depending on the degree of pollution and suitability of given pond habitats for survival of the snail intermediate hosts. No epidemiological studies were located which examined the risk of infection with species of *Schistosoma* in aquacultural workers.

CHAPTER 4: UNANSWERED QUESTIONS

The current state of knowledge on the infectious-disease risks of nightsoil or sludge use in agriculture and aquaculture, based on epidemiological rather than environmental studies, are presented in Tables 4.1 and 4.2. All data pertain to the use of raw excreta. There is reasonably good epidemiological evidence for the transmission of certain helminthic infections - specifically *Ascaris*, *Trichuris*, hookworm and *Schistosoma japonicum* - by nightsoil use in agriculture. While studies in China have clearly defined how and under what circumstances nightsoil use in agriculture promotes occupationally acquired hookworm and *S. japonicum* infection, the way in which such use promotes the spread of *Ascaris* and *Trichuris* is speculative since studies did not specify adequately the types of nightsoil use and exposure studied. Very little is known about the risk of human infection with viral, bacterial or protozoal infections associated with nightsoil or sludge use in agriculture. For some globally important excreted pathogens, such as *Campylobacter jejuni*, enterotoxigenic *Escherichia coli* and rotavirus, no studies have been located that document the risks of infection or disease associated with the use of nightsoil, sludge, or indeed wastewater.

There are insufficient data to allow comparisons of risk among different classes of pathogens in a given nightsoil- or sludge-use situation or to determine how the risk from different pathogens might vary according to the level of hygiene in the community. In the absence of epidemiological data, it can be argued that the risk attributable to excreta use is likely to be greater in more hygienic than in less hygienic communities, or that the opposite relationship is true, depending on the extent to which improved hygiene reduces other exposures and herd immunity on the one hand, and reduces the concentration of pathogens in excreta (and hence on crops) and improves hygiene behaviour on the other hand (Feachem and Blum 1984). There is some epidemiological evidence in this paper and in the wastewater literature (Gunnerson *et al*. 1985)

Table 4.1 Agricultural use: current state of epidemiological knowledge on risks of human infection with the major groups of pathogens according to the type of use of nightsoil or sludge and type of exposure

Exposure group	Infectious disease risks from nightsoil or sludge fertilisation of:		
	crops for humans	crops for animals	non-consumable crops
persons consuming crops	V $\boxed{B}$ P N	-	-
persons consuming meat or milk	-	B C	-
agricultural or sanitation workers at site of use	$\underline{V}$ B P N T	$\underline{V}$ B P N	$\underline{V}$ B P N

V = excreted viruses	V = potential risk: no epidemiological data
B = excreted bacteria	V = risk supported by epidemiological data
P = excreted protozoa	$\boxed{V}$ = risk from nightsoil or sludge use likely on the basis of wastewater epidemiological data
N = excreted nematodes	
C = excreted cestodes	V = risk reported but insufficient epidemiological data for confirmation
T = excreted trematodes	
- = not applicable	$\underline{V}$ = risk inconsistently supported by epidemiological data

SOURCE: after Feachem and Blum (1985)

Table 4.2 Aquacultural use: current state of epidemiological knowledge on risks of human infection with the major groups of pathogens according to the type of excreta use and type of exposure

Exposure group	Infectious disease risks from excreta fertilisation of:		
	crops for humans	crops for animals	non-consumable crops
persons consuming crops	V B P C T	-	-
persons consuming meat or milk	-	B	-
aquacultural or sanitation workers at site of use	V B P T	V B P T	V B P T

V = excreted viruses

B = excreted bacteria

P = excreted protozoa

C = excreted cestodes

T = excreted trematodes

\- = not applicable

V = potential risk: no epidemiological data

V = risk supported by epidemiological data

SOURCE: after Feachem and Blum (1985)

that in relatively hygienic communities, such as in Israel, excreta use presents a risk of nematode infection but little risk of viral infection. There are no epidemiological data on the risk of viral infections associated with excreta use in less hygienic communities and while there is evidence of a risk of nematode infection, there are no data which allow the magnitude of that risk in more and less hygienic communities to be compared. More epidemiological data are required to examine the health implications of excreta use in less hygienic areas.

Epidemiological studies are almost totally lacking on the health risks of the use of excreta in aquaculture. A few descriptive studies do, however, provide evidence of transmission of some trematode infections, specifically Clonorchis sinensis and Fasciolopsis buski by ingestion of fish or water plants grown in raw excreta-enriched ponds.

There are many excreta-use projects currently underway and there is every indication that the pressure to use excreta will increase, both in developed and developing countries. For the present, the decisions taken by the planners of such projects to minimise health risks should be guided by the limited number of good epidemiological studies currently available and by reasonable deductions from considerations of potential risk (IRCWD 1985). At the same time, priority should be given to filling the important present gaps in knowledge on the health risks of excreta use.

Very little is known about the health risks that may accompany the use of treated excreta, how these risks may vary according to the level of hygiene in the community and how these risks may be minimised at least cost, using technologies appropriate to a given situation. The epidemiological studies to date, with their focus on the use of untreated or minimally treated excreta and examination of a limited number of potentially important pathogens in a few economic and cultural settings, do not provide a sound basis for predicting health outcomes of new projects. The usefulness of many of these studies is further limited by their methodological inadequacies.

There will be an ongoing need for additional information to guide future technical policy and to allow the planners of excreta-use projects to make the most appropriate and cost-effective decisions. There are no easy answers or short-cuts: such decisions should be based on information from well conceived and carefully conducted epidemiological investigations which must take into consideration the multiple determinants of the health outcomes of excreta use.

CHAPTER 5: THE NEXT GENERATION OF EPIDEMIOLOGICAL STUDIES

In the formulation of an epidemiological approach to the problem of assessing health risks of excreta use, a series of choices must be made to identify:

(a) the health risks to evaluate;
(b) the methodologies most appropriate for the study of health risks in a given setting;
(c) the type of projects to evaluate;
(d) the localities for project evaluation; and
(e) the type of personnel required for the planning and implementation of epidemiological studies of excreta use.

5.1 Selection of appropriate health risks for study

Those factors which define the most appropriate and important health risks to study in a given situation are discussed below.

5.1.1 The pattern of excreta-related diseases in the area from which the excreta originated

In order for a potential risk of infection with a given pathogen to exist from excreta use, that pathogen must be present in human excreta. In other words, the infection must be endemic or epidemic in the area and the infection must be of the excreted type. For instance, the use of excreta from an area where guinea worm is endemic does not present a risk of guinea worm to others because guinea worm is not an excreted infection. Equally, if there is no taeniasis in a community, there will be no *Taenia* eggs in the faeces from that community and no risk that its excreta when used will transmit taeniasis. Some diseases, such as infectious hepatitis and ascariasis, have an almost global distribution while others, such as schistosomiasis and clonorchiasis, are focal, even within individual countries. The records from local health facilities or interviews with local health personnel can give a good indication of which excreted infections are occurring in an area, although these sources of information cannot be used to derive disease incidence or prevalence rates.

5.1.2 The transmission potential of given pathogens in the area using excreta

Where the excreta derive from the same area in which the excreta will be used the pattern of excreta-related disease in the area will highlight appropriate health risks for study. Where excreta are imported into an area as fertiliser, the selection of health risks for study will depend both on the pathogen content of the excreta and on the presence of specific conditions required for transmission of given agents. These conditions include biological requirements such as the presence of appropriate intermediate hosts, and behavioural requirements such as the observance of certain dietary customs.

5.1.3 The type and extent of excreta treatment prior to use

Raw sewage and nightsoil and the products of conventional sewage-treatment processes or septic tanks will contain all classes of pathogens and the choice of health indicators for study will depend on other factors. Where more extensive treatment is provided, the selection of appropriate health indicators may be narrowed. For example, where double-vault batch-composting toilets are in use, the only pathogens which are likely to survive to represent potential risk are the eggs of helminths. In contrast, viruses and bacteria will be more appropriate health indicators where effluent from waste-stabilisation ponds with a minimum of 3 cells and minimum retention time of 20 days is used (Feachem *et al*. 1983).

5.1.4 The type of use and exposure

The 2 major types of use are agricultural and aquacultural and within this broad subdivision are 3 main types of crop to which excreta may be applied - crops for human consumption, crops for animal consumption and non-consumable crops. A risk of human infection is possible only when certain groups of people come into very specific types of contact with these crops. These exposure groups are persons consuming a crop (or fish raised in a pond) fertilised by excreta, persons consuming meat or milk from an animal that has consumed a crop (or fish raised in a pond) fertilised by excreta, and persons in occupational contact with excreta at the site of use.

The different exposure groups and practices form a grid (see Tables 1.3 and 1.4) which defines broad categories of potential health risks. Information on disease occurence and extent of excreta treatment can then be used to define more precisely the most appropriate health risks to study in a specific excreta-use scheme. Where it is decided to study helminthic infections, it may be illuminating to examine the intensity of infection, in addition to prevalence, as a more sensitive indicator of transmission. In addition, since helminthic infections are usually of relatively long duration, it may be useful to examine re-infection rates following a course of mass anthelmintic therapy rather than the slower spontaneous decreases in prevalence rates.

5.2 Selection of methodologies for epidemiological investigation of excreta use

Although it is important that the functioning and utilisation of all excreta-use projects be regularly monitored, it is neither desirable nor feasible to suggest that every project be evaluated for health risks. Rather, it is desirable that epidemiological studies be done on a sufficient number of different kinds of projects in a variety of economic and cultural settings to allow predictions of likely health outcomes of proposed schemes. The type of methodology which is most suitable for evaluations of health risks of excreta-use projects is debatable. The optimal methodology is one that will provide sound data in limited time and at reasonable cost. The following discussion highlights the more appropriate options.

The types of epidemiological studies that might be undertaken to assess the health risks of excreta reuse fall into 2 broad categories: experimental studies or observational studies.

5.2.1 Experimental studies

Experimental studies are those in which specific changes are introduced and allocated among comparable groups, preferably chosen on a random basis, for the purpose of then evaluating the outcome. Observational studies examine cause-effect relationships in existing situations or where a project is introduced without regard for the comparability of comparison groups. In an experimental study one is often evaluating a project designed to serve the purposes of the study whereas in an observational study one is generally making opportunistic use of projects that are in place or are being planned and statistical techniques are used to minimise the effects of confounding variables. Creating tailor-made situations has 2 major drawbacks - cost, and the danger of evaluating a project that is not representative of the kinds of schemes which are and will be implemented by governments. Experimental studies have other major drawbacks, including ethical dilemmas and the frequent violation of the basic assumption of comparability of comparison groups. It is therefore suggested that the health risks of excreta use be evaluated by observational studies.

5.2.2 Observational studies

There are several types of observational studies which might be considered in these settings: retrospective cohort, prospective cohort, cross-sectional, or case-control.

5.2.2.1 Retrospective cohort. In this type of study, groups differing in exposures at some time in the past are studied with regard to subsequent health outcome and disease rates are compared; the study is retrospective because it is initiated after the exposure and outcome have occurred. Thus information must be obtained historically from existing records. This type of study can only be done if it is possible retrospectively to define the cohorts of interest and determine the outcome from existing records. There are 2 main reasons why this type of study is rarely feasible for assessing the health risks of excreta use. First, retrospective cohort identification will not be possible from examination of records alone where cohort members are defined by specific behaviour or characteristics which are known only to the individuals in question, as is the case in determining the type and extent of exposure to the excreta. Second, many of the health indicators of possible interest in studies of excreta use, like *Ascaris* prevalence and intensity of infection, will not be found in existing records (even if records are available and accurate which is doubtful in many developing countries) since only a small (and unknown) proportion of people in the cohort (if the cohort could be defined) seek medical attention for these problems.

It should be noted, however, that in those rare instances where the required exposure and infection information can be obtained retrospectively, a retrospective cohort study can be a powerful and low-cost tool for the assessment of health risk. A case in point is the work of Shuval *et al*. (1984) on the role of wastewater-irrigated vegetables in the transmission of *Ascaris* and *Trichuris* in Jerusalem.

5.2.2.2 Prospective cohort. A prospective cohort study follows a cohort forward in time from exposure to development of disease or infection. In a prospective cohort study, the health outcome of interest has not yet occurred at the time the investigation is initiated. A prospective cohort study may be initiated prior to the implemention of a project or carried out on existing projects. For example, if it is known that a government will soon initiate an excreta-use project, a prospective cohort study can be organised to examine a sample of people in the project catchment area. A sample of people from areas without excreta-use projects may be selected for comparison purposes or the comparison group may be defined by the exposure status of people drawn solely from within the project area. It is recommended that a baseline survey be carried out since this ensures that changes in health status after the scheme is initiated can be reasonably attributed to excreta-use exposures. Special attention should be paid to the measurement of potential confounding variables and health status. After the scheme is underway, the cohort is continuously or periodically resurveyed to determine the type and extent of exposure to excreta and to measure disease rates. While controlling for the effect of confounding variables, exposed-unexposed and before-after comparisons in disease rates are computed. Relative and attributable risks of disease may be directly computed from incidence rates. It is important to measure exposure carefully and not to assume that people living in areas where the scheme is operating are necessarily exposed. The timing of the surveys is also extremely important, since both excreta-use practices, exposures and, in many cases, disease incidence are seasonally influenced.

A prospective cohort methodology may also be used to measure disease incidence associated with schemes already underway. As above, comparison groups can be drawn from within or from outside the area involved in the scheme. The exposure groups are followed and differences in disease or infection rates are measured over a defined period. Since the scheme is already operating, there are no baseline data from which the prior comparability of exposure groups with respect to disease rates may be ascertained. Provided that sample sizes are adequate and confounding variables have been carefully identified, measured and taken into account in the statistical analysis, observed differences in disease rates, especially if large, may be reasonably attributed to excreta-use exposures.

There are several major drawbacks to using a prospective cohort approach in assessing the health risks of excreta-use projects. Some of these problems relate to the methodology itself and others derive from the excreta-use context in which it would be used. First, cohort studies may require large numbers of subjects (the sample size being dependent on the frequency of the disease being measured and the disease reduction to be detected) with attendant logistical, manpower, time and cost requirements. For a given health risk and level of detection of disease reduction, the sample size generally will be larger in a prospective cohort study than that required in a case-control study where the sample size is dependent on the frequency of exposure A less obvious consequence of surveying large numbers of persons is the limited time available to interview subjects carefully about exposures and examine specimens to determine health status. Errors in exposure or disease classification can seriously bias the results. Second, where people outside the scheme catchment area are surveyed and the scheme is viewed as desirable, cooperation among those not served by the project may wane, so the results may be biased. Third, ethical problems arise when disease or infection is identified but treatment is withheld because it would interfere with the measurement of the health indicator being followed. Fourth, while cohort studies do not by definition require community-based surveys, the type of exposure and health information required in the context of excreta-use projects would require that people be followed in the community. The logistics of community-based surveys can be formidable in some developing countries. Fifth, the time-span of prospective cohort studies with their focus on incidence or changes in prevalence is at least 1 year (to take into account seasonality of disease incidence) and often longer where before-after surveys are undertaken. Lastly, several of the above factors combine to make this approach expensive. It is therefore recommended that other more cost-effective methodologies be considered in assessing the health risks of excreta-use projects.

5.2.2.3 <u>Cross-sectional</u>. This type of study is a once-only investigation where exposure and health status are ascertained simultaneously, and prevalence rates (or incidence over a limited recent time) in groups varying in exposure are compared. Since groups are not followed in time, this approach is not appropriate for measurement of long-term incidence rates in relation to exposure. The non-exposed or less-exposed comparison group may be drawn from within the project area or from without, but as discussed earlier it is important to determine actual exposure among those potentially exposed. Since a comparative cross-sectional study is performed only after a project is in operation, there are no baseline data to use in assessing the comparability of groups with respect to disease rates. Careful measurement and statistical contol of confounding variables is therefore of critical importance to try to disaggregate the effect of these factors on observed prevalence. A cross-sectional approach has been taken in several assessments of health risks of excreta use (see Appendix 1), but the usefulness of such studies to date has been limited by the failure to control for confounding variables and to document the type and extent of exposure in potentially exposed persons.

A cross-sectional methodology in the context of excreta-use projects has some of the same drawbacks as a prospective cohort methodology, including often large sample sizes and bias due to exposure and disease misclassification. A cross-sectional approach has the additional disadvantage of being more limited in the information it can provide than a prospective cohort study: a cross-sectional study can provide information on whether or not an exposure and disease are associated, but is not suitable where information on incidence is required, or where it is important to establish the time course of events or the natural history of a disease in a particular setting. When both exposure and disease may be seasonal, as in some excreta-use situations, the use season will dictate the timing of a cross-sectional study. However, the health effects of excreta use may not occur until some time later, and therefore risks may be underestimated in a one-off survey and the season-specific effects of use on specific diseases cannot be determined. An option is to do 2 or more cross-sectional surveys, at different seasons, on the sample population.

Balanced against these constraints in a cross-sectional approach are a number of important advantages which derive from the timing of the study and the fact that people are studied only once. First, since the study is performed only after a project is operational, it is possible to ensure that the project is functioning properly and being used before initiating data collection. Second, where people are approached for information only once there may be less likelihood of bias resulting from poor cooperation. Third, the ethical problem of withholding treatment does not arise since treatment can be given without affecting the results. Finally, with the careful measurement of confounding variables and documentation of exposure, a cross-sectional study can provide meaningful prevalence data in a limited time and at relatively low cost. Since the health risks of interest in many excreta-use situations are helminthic infections where prevalence rather than incidence is the more relevant measure of frequency, it is suggested that further consideration be given to the use of cross-sectional studies in excreta-use risk assessment.

5.2.2.4 Case-control. Unlike the other approaches discussed above which either follow groups forward from exposure to development of disease or measure both at the same point in time, a case-control study looks backward from disease to exposure. People with a disease (cases) and people without the disease (controls) are identified and their exposure status determined and compared. These data may be used to estimate the relative risk of disease of the exposed and unexposed. Likewise, estimates of attributable risk may be derived from estimates of relative risk, the disease incidence rate in the target population and the proportion of people exposed to the risk factor. Controls may consist of all or a sample of non-diseased (or non-infected) individuals or may be matched for certain confounding variables (such as age) to individual cases. Cases (and controls) may be identified from the community, health centre, or existing records as appropriate. The proper choice of controls is critical to the validity of this methodology and can be an important source of bias.

A case-control approach has most often been used in chronicdisease epidemiology, but has also been applied to outbreak investigations and more recently to examine vaccine efficacy (Smith 1982 and Smith *et al*. 1984). The potential of this approach in project evaluation is receiving increased attention and a case-control method is being developed to examine the impact of water-supply and sanitation projects on diarrhoeal diseaes (Briscoe *et al*. 1985). This latter situation is analogous in many respects to studying the risks associated with excreta use. The attractiveness of case-control studies in evaluation of impact or assessment of risk is that they generally require smaller sample sizes, fewer resources, less time and less money to organise and implement than cohort studies. An additional advantage of case-control studies over those cohort studies which collect baseline data is that data collection can be delayed until an excreta-use project has been shown to be working and used properly. The difficulties and uncertainties in using this methodology are in the proper study design to minimise bias, select appropriate controls and control for confounding variables.

For excreta-use schemes, a case-control approach will have a great logistical advantage over other methodologies if the design can be clinic-based, as opposed to community-based. Where the health indicator of interest is an illness that tends to bring people to the health centre, for example typhoid fever, hepatitis A or severe diarrhoea or dysentery, cases can be recruited on the spot, according to a specific clinical case definition. Controls might then be selected as the next person of similar age presenting with a non-excreta-related complaint which tends to be reported to a similar extent. Information is gathered from both cases and controls to allow measurement of important potential confounding variables and the type and extent of excreta-use exposures. Several major problems of design remain to be resolved before applying the case-control method in this context.

5.2.3 Routine surveillance and outbreak investigation

An important adjunct to specific studies to examine the health risks of excreta use is improved routine surveillance of diseases likely to present to health facilities and to be transmitted by excreta use. The importance of surveillance in the context of excreta use is highlighted by Alderslade (1981). Such surveillance has been used to identify unusual numbers of cases of illness (outbreaks) associated with excreta-use and may be especially useful in those areas where specific health-risk studies are not undertaken. Many health centres in developing countries keep records of some type on their patients. Although such records do not provide information on disease incidence or prevalence rates in the catchment area, they can be helpful in alerting health personnel to the existence of an outbreak. Where such records are not kept or are unreliable, it may be advisable to designate specific health facilities to assist in recording such information (sentinel clinics). Investigations of outbreaks of diseases that tend to bring people to health centres and which may be associated with excreta use, for example infectious hepatitis, typhoid fever or cholera, may increase our understanding of the risks of disease associated with excreta-use schemes.

5.2.4 Recommendations on methodology

The assessment of health risks of excreta-use projects, whatever methodology is selected, will require careful thought with particular attention to sampling, minimising bias, controlling for important confounding variables and reliably measuring exposure, and on the logistical side to minimising cost, manpower, and time requirements. It is not possible to recommend a single methodology for studying all excreta-use situations since the most appropriate and cost-effective methodology in a given situation will depend on a combination of local factors.

The studies which are likely to be most cost-effective and warrant further attention are the cross-sectional and case-control types. These 2 methods will be particularly appropriate in situations where exposure to excreta is an individual (rather than community) characteristic. A cross-sectional study will be the more suitable method when the health indicator is a disease which is common and not generally a cause of reporting to a health facility; examples include the excreted helminthic infections. On the other hand, a case-control study may be more appropriate when the health indicator is a relatively rare disease which tends to bring people to a health facility; candidate diseases for a case-control study include severe diarrhoea, typhoid fever and hepatitis A. It is suggested that a standard protocol be developed, subject to local adaptation, for using these 2 methods to assess the health risks of excreta use in agriculture and aquaculture. Improved surveillance and outbreak investigation should be advocated in all areas using excreta, whether or not specific health studies are undertaken.

5.3 Selection of projects for evaluation

A selective approach will be required in the choice of projects for which a formal assessment of health risks is undertaken. In part this decision will depend on local interest and a variety of logistical and resource factors, including manpower and the accessibility of laboratory facilities. It is important to include several different types of schemes, for example those involving secondary wastewater effluent, waste-stabilisation pond effluent and composted nightsoil and to choose sites from a variety of economic and cultural settings. These considerations will still leave a considerable number of schemes which could be evaluated. Cost and the need for epidemiological expertise may require that priority be given to certain factors and that efforts be concentrated initially on the assessment of risk in only a few projects. It is suggested that priority be given to those projects which can best allow the most important missing pieces of information in Tables 4.1 and 4.2 to be determined. Those situations for which little is known but significant morbidity is expected include, for agricultural use, the risk to persons consuming crops fertilised with excreta and the occupational risk associated with different types of projects; and for aquacultural use, the risk to persons consuming fish or plants grown in excreta-fertilised ponds. The definition of groups consuming excreta-fertilised foods may prove particularly troublesome as there are undoubtedly many situations where there is no market segregation of such foods. Studies of health risks to the human consumer may need to be restricted to schemes operating in areas where accurate identification of the consumer exposure group is possible.

Although only a few projects may be selected for detailed health-risk evaluations, all projects should have a monitoring component. As in water-supply and sanitation projects, it is important to monitor the functioning and use of excreta-use schemes so that they can be improved. In those schemes selected for detailed evaluation of health risks, information on functioning and use will be important in interpreting the results. Monitoring might also include microbiological studies of nightsoil, sludge or effluent quality.

5.4. Selection of localities for project evaluation

Many of the determinants of the health outcomes of excreta-use projects are site-specific. The value placed on excreta, the form of excreta available for use, the extent of excreta treatment, the aesthetic acceptibility of different types of practice, and the extent of exposure to crops fertilised with excreta are dependent in part on the economic and cultural circumstances. These factors determine the type of excreta-use scheme which is likely to be introduced and how well it functions. The pattern of endemic disease also is influenced by the local economic, cultural, and physical environment. Therefore the schemes and attendant potential health risks will vary from community to community. It is therefore important to asses schemes in a variety of settings and take a site-specific perspective in interpreting the results.

In addition to studying excreta-use schemes from different sites, it is important to examine the effect of a scheme on populations having different levels of hygiene and socio-economic status among which the relative importance of different transmission pathways for a given agent and the level of host immunity may vary. It may be that the risks attributable to excreta use will differ not only among countries but among populations in the same country with differing levels of development and hygiene.

5.5 Selection of types of personnel required for the planning and implementation of epidemiological studies of excreta use

There is a need for a multidisciplinary approach in both the planning and monitoring of excreta-use projects and in the assessment of possible adverse health outcomes. Such schemes, the technical aspects of which are planned by engineers, in collaboration with agronomists and economists, are introduced into a background of specific beliefs about excreta, their handling and use which are best understood by social scientists, and into an existing pattern of endemic disease which is best understood and studied by epidemiologists.

The design of studies to assess the health risks of excreta use will be methodologically difficult, reflecting the complex determinants of risk, and will require much thought on the part of epidemiologists to design sound studies which can be implemented in a limited time and at low cost. The design must be adapted to specific projects, and to particular economic, social and cultural settings, requiring close collaboration among engineers, social scientists and epidemiologists. The development of methods for eliciting sensitive behavioural information on excreta exposure and hygiene requires particularly close attention by social scientists (Cross and Strauss forthcoming).

CHAPTER 6: SUMMARY AND CONCLUSIONS

The use of excreta in agriculture and aquaculture is becoming increasingly important. The economic benefits of such use must be balanced against the associated public health risks. There has been a tendency to examine the infectious-disease risks of excreta use from a strictly environmental perspective and to assume that the potential risks presented by the presence of pathogens in excreta (both treated and untreated) will result in disease or infection. This reasoning has led, in some countries, to stringent regulations on the use of excreta. However, many factors related to pathogen biology, human biology and human behaviour intervene in a complex manner to determine whether or not excreta use results in a measurable health risk in a given situation. An epidemiological perspective is required to document the nature and magnitude of the disease risks associated with the use of excreta, and to understand how and why disease transmission associated with such use has occurred.

In this paper, epidemiological studies which examined the infectious disease risks of nightsoil or sludge use in agriculture and excreta use in aquaculture have been reviewed. These studies are few in number, generally weak in methodology, examine only a few of the potentially important health risks (mainly the nematodes in the agricultural setting and the trematodes in the aquacultural setting) and focus almost exclusively on the use of raw or minimally treated excreta. The results suggest that the use of raw nightsoil or sludge in agriculture has been associated with transmission of hookworm, *Ascaris*, *Trichuris* and *Schistosoma japonicum* infection, while the use of raw nightsoil in aquaculture has been associated with transmission of *Clonorchis* and *Fasciolopsis* infection.

The relevance of these data for assessing health risks in currently advocated nightsoil or sludge-use projects is limited. Studies which examine the risks of using treated nightsoil or sludge in agriculture or treated excreta in aquaculture are lacking, although there is some evidence that introducing the use of treated nightsoil in agriculture lowers the risk of helminthic infections among people previously using raw nightsoil. Without information on the risks attributable to using treated forms of nightsoil, it is difficult to predict accurately the likely health outcomes of introducing such schemes and to arrive at the most cost-effective options in a given setting.

These serious gaps in knowledge and the continual need for sound epidemiological data to guide future technical policy require that a new generation of epidemiological studies be developed. The following factors should be considered in selecting the most appropriate and important health risks to study in a given situation: (a) the pattern of excreta-related diseases in the area from which the excreta originated, (b) the transmission potential of given excreted pathogens in the area using excreta; (c) the type and extent of excreta treatment prior to use, and (d) the type of use and exposure. It is suggested that consideration be given to the use of cross-sectional and case-control studies as the most cost-effective methodologies for evaluating the health risks of excreta use. Epidemiological studies should examine those risks for which little is known and much morbidity may be expected; these risks include, for agricultural use, the risks to people consuming crops fertilised with treated nightsoil or sludge and the risks to persons with occupational exposure, and for aquacultural use, the risks to people consuming fish or aquatic plants grown in excreta-enriched ponds. It will be necessary for studies to be carried out on a variety of different types of project in a variety of economic, social and cultural settings. The design and implementation of excreta-use schemes, their monitoring and the assessment of health risks must be a multidisciplinary approach involving engineers, epidemiologists and social scientists. Improved routine disease surveillance to aid in outbreak identification and investigation should be encouraged in all areas where excreta use is practised, whether or not specific epidemiological studies are undertaken.

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A P P E N D I C E S

Appendix 1. Agricultural use: epidemiological studies which examine the risk to persons consuming crops fertilised with nightsoil or sludge

Country	Type of study[a]	Type of excreta	Health indicator(s)	Crops	Results	Reference
Germany	cross-sectional	septic tank contents	*Ascaris* prevalence	garden	*Ascaris* prevalence rates were 14.3% among schoolchildren living in a non-sewered high income suburb where vegetable gardens were fertilised with the contents of septic tanks filled to overflowing, 6.7% among schoolchildren in a non-sewered rural area where human faeces were either composted with animal manure or applied at an "appropriate" point in time, and 2.9% among schoolchildren living in a sewered urban area.	Anders (1952)
Germany	cross-sectional	nightsoil	*Ascaris* prevalence	garden	There were no cases of *Ascaris* infection among 22 families using animal manure as garden fertiliser while 52% of 120 families using human faeces as garden fertiliser were affected.	Kreuz (1955) citing Harmsen (1953)
Japan	experimental	nightsoil	*Ascaris* and *Trichuris* prevalence	unspecified	Heat treatment of nightsoil prior to its use as fertiliser led to a "striking decline" in prevalence rates of *Ascaris* as well as a decrease in levels of soil infestation with embryonated *Ascaris* ova.	Katayama (1953)
Japan	experimental	nightsoil	*Ascaris* and *Trichuris* prevalence	unspecified	Heat treatment of nightsoil prior to its use as fertiliser was associated with a small decrease in prevalence rates of *Ascaris* over 8 months. Heat treatment in association with mass chemotherapy maintained low infection rates during a 5-month follow-up.	Kawagoe *et al.* (1958)
Japan	experimental	nightsoil	*Ascaris* prevalence and re-infection and *Trichuris* prevalence	unspecified	Nightsoil treatment with ovicide (area A) reduced *Ascaris* prevalence by 35% and nightsoil treatment plus chemotherapy (area B) by 45% over 2 years; chemotherapy alone had little effect (area C). Positive conversion rates were similar in the 3 areas, but the percentage of conversions in which fertilised eggs were found (probably signifying new infection) was higher in area C than in the other areas. In another study, nightsoil treatment with ovicide reduced *Trichuris* prevalence by 28% over 2 years compared with little change in an untreated area.	Kutsumi (1969)

Appendix 1. Agricultural use: epidemiological studies which examine the risk to persons consuming crops fertilised with nightsoil or sludge (cont.)

Country	Type of study[a]	Type of excreta	Health indicator(s)	Crops	Results	Reference
Japan	experimental	nightsoil	Ascaris re-infection	unspecified	At 8 months after mass chemotherapy, the Ascaris-positive conversion rate in the areas using ovicide-treated nightsoil was 27.4% and 25.9% and in the untreated nightsoil area, 41.5%.	Kozai (1962)
U.S.S.R.	experimental	nightsoil	Ascaris prevalence on crops	fruit and vegetables	Prior to a hygiene campaign and cessation of nightsoil use as fertiliser, 100% of soil and 71% of fruit samples were contaminated with Ascaris. Following these measures, prevalence rates decreased by 65%. The percentage of eggs which were viable decreased to 0% from 41% and 19% respectively. Associated human infection was not investigated.	Rosenberg (1960)

[a]Type of study:

cross-sectional: exposure to nightsoil or sludge and prevalence rates of infection were measured at the same point in time and prevalence rates in different exposure groups were compared.

experimental: among comparable groups, exposure to nightsoil or sludge was modified specifically to investigate changes in health status associated with the intervention; it should be noted, however, that allocation to exposure groups was not on a random basis in the listed studies.

prospective cohort: a group of individuals with different exposures to nightsoil or sludge were selected and followed up for development of disease or infection; disease rates were compared according to exposure.

descriptive: the distribution of disease or infection within a population, by person, place and time, was studied.

outbreak investigation: an investigation was performed to examine exposures associated with an unusual frequency of disease or infection.

retrospective cohort: health records were reviewed to determine the past health experience in groups which differed in exposure to excreta use and disease rates were compared in different groups.

Appendix 2. Agricultural use: epidemiological studies which examine the Cysticercus bovis risk to cattle consuming crops fertilised with nightsoil, sludge or slurry and the risk of associated human Taenia saginata infection resulting from consumption of meat from such cattle

Country	Type of study[a]	Type of excreta	Health indicator(s)	Crops	Results	Associated human disease/ infection	Reference
Denmark	experimental	liquid manure, nightsoil	bovine cysticercosis	grass	Calves fed grass sprayed 14 days earlier with liquid manure, or contaminated 15-159 days earlier with human faeces containing Taenia gravid segments were found to have cysticerci at slaughter.	not investigated	Jepsen and Roth (1952)
U.S.A.	outbreak investigation	sewage sludge	bovine cysticercosis	pasture	Over a 6-month period 18 of 40 cattle (45%) slaughtered were infected with C. bovis. These cattle had grazed on pasture fertilised with nonheat-treated sludge. No T. saginata infections were found among the people involved in cattle rearing and incidents of promiscuous defecation were not recalled. Taenia eggs were not detected in sewage sludge but the routine application of such sludge was thought likely to be responsible for the outbreak.	not investigated	Hammerberg et al. (1978)
U.S.A.	outbreak investigation	human slurry	bovine cysticercosis	pasture	At a slaughterhouse, a high C. bovis prevalence was found among cattle from a single farm. These cattle had grazed on pasture fertilised with human slurry 30 days prior to slaughter. The cysts were estimated as being 4-5 weeks old. In an experiment, slurry from the sewage works was fed to a calf and cysts were found at post-mortem 4 weeks later.	not investigated	Macpherson et al. (1978)

Appendix 2. (cont.) Agricultural use: epidemiological studies which examine the Cysticercus bovis risk to cattle consuming crops fertilised with nightsoil, sludge or slurry and the risk of associated human Taenia saginata infection resulting from consumption of meat from such cattle

Country	Type of study[a]	Type of excreta	Health indicator(s)	Crops	Results	Associated human disease/ infection	Reference
U.S.A.	outbreak investigation	nightsoil	bovine cysticercosis	silage	Investigation of a large epizootic among cattle sent to slaughter in Texas suggested that animals became infected in feedlots A and B. No other common exposures were identified including grazing on sewage-irrigated pasture. The investigation of feedlot A implicated faecal contamination by a human carrier of T. saginata of a trench silo supplying silage to several cattle pens. The investigation at feedlot B was inconclusive but it was speculated that infection resulted from defecation on the grounds of the feedlot by a human carrier.	Yes. A woman with a history of eating rare beef developed taeniasis. She purchased her beef at a single store. Investigation revealed that 2 sources of beef for this store were slaugtherhouses that had processed cattle infected with C. bovis during the epizootic.	MMWR (1968)

[a]see bottom of appendix 1

Appendix 3. Agricultural use: epidemiological studies which examine the risk of *Salmonella* infection to food animals consuming crops fertilised with nightsoil, sludge or slurry and the risk of associated human *Salmonella* infection resulting from consumption of milk or meat from such animals

Country	Type of study[a]	Type of excreta	Health indicator(s)	Crops	Results	Associated human disease/ infection	Reference
Germany	outbreak investigation	sewage sludge	*Salmonella paratyphi B* infection in cattle	pasture	*S. paratyphi B* infection, which usually occurs only in man, affected cattle within 3 weeks of grazing on pasture fertilised with municipal sewage sludge which had been stored on a drying bed for 3 weeks.	not investigated	Strauch and Perrácová (1969)
Switzer-land	uncertain from brief report	sewage sludge	*Salmonella* prevalence in cattle	pasture	The *Salmonella* isolation rate from cattle at 5 slaughterhouses showed an increase during the grazing season; such seasonal variations were not seen among cattle reared in confinement.	not investigated	Hess (1981)
Switzer-land	oubreak investigation	sewage sludge	*Salmonella* outbreak in cattle	grass	An outbreak of salmonellosis caused by a rare serotype occurred a few days after cattle were fed grass grown on pasture fertilised with sludge 4 weeks previous-ly. 7 weeks after sludge fertilisation, the identical serotype was isolated from grass samples from the fertilised pasture.	not investigated	Hess and Breer (1976)
Switzer-land	uncertain from brief report	sewage sludge	*Salmonella* prevalence in cattle	pasture	5.3% of 600 cattle slaughtered during the grazing season over 2 years were infected with salmonellae; most of these cattle had come from areas where sludge was partly used as fertiliser. There were no *Salmonella* infections among 83 cattle from a region where sludge fertilisation was not practised.	not investigated	Hess and Breer (1976)

Appendix 3. (cont.) Agricultural use: epidemiological studies which examine the risk of Salmonella infection to food animals consuming crops fertilised with nightsoil, sludge or slurry and the risk of associated human Salmonella infection resulting from consumption of milk or meat from such animals

Country	Type of study[a]	Type of excreta	Health indicator(s)	Crops	Results	Associated human disease/ infection	Reference
U.K.	outbreak investigation	sewage sludge	Salmonella outbreak humans	pasture	Epidemiological investigation of an outbreak of *S. typhimurium* in humans suggested that the vehicle of infection was raw milk from cattle infected after grazing on sludge-fertilised pasture. The same serotype was isolated from affected humans, milk cattle and a sludge well from which sludge had been applied to pasture 2 months prior to the outbreak. The sludge included effluent from a poultry factory and *S. typhimurium* was isolated from the sludge well there.	Yes (see results)	Burnett *et al.* (1980)
U.K.	experimental	sewage sludge	Salmonella infection in cattle	silage	No infections occurred in cattle fed for 28 days with 1 litre daily or weekly of raw sewage sludge (added to silage) containing up to 10^5 naturally occurring salmonellae per litre. Salmonellae were isolated from faeces of 1 animal and carcasses of 2 cows fed 1 litre daily of sterilised sewage sludge containing 10^5 *S. dublin* per litre.	not investigated	Hall and Jones (1978)
U.K.	outbreak investigation	slurry	Salmonella outbreak in cattle	pasture	Cattle grazing on pasture irrigated with slurry 3 weeks previously developed dysentery and died; *S. typhimurium* type 15A was isolated from affected cattle and the slurry system.	not investigated	Jack and Hepper (1969)

Appendix 3. (cont.) Agricultural use: epidemiological studies which examine the risk of *Salmonella* infection to food animals consuming crops fertilised with nightsoil, sludge or slurry and the risk of associated human *Salmonella* infection resulting from consumption of milk or meat from such animals

Country	Type of study[a]	Type of excreta	Health indicator(s)	Crops	Results	Associated human disease/ infection	Reference
U.K.	experimental	slurry	*Salmonella dublin* infection in cattle	silage	Only 1 of 12 cows grazing for 4 weeks on land contaminated 1 week previously with 10^5 *S. dublin* per millilitre became infected.	not investigated	Taylor (1973)
U.K.	experimental	slurry	*Salmonella dublin* infection in cattle	pasture	67% of 12 cows grazing for either 1 or 5 days on land to which 10^6 avirulent *S. dublin* per millilitre of slurry had been applied became infected. No cow became infected when grazed for 1 day on pasture contaminated with 10^3 avirulent *S. dublin* per millilitre of slurry.	not investigated	Taylor and Burrows (1971)
U.K.	experimental	sewage sludge	*Salmonella* infection in goats	silage	No infections occurred in 36 goats fed corn silage grown on fields fertilised with sewage sludge that had been stored for 6 months prior to application, nor in 7 goats fed corn silage from non-sludge fertilised fields. Both raw and stored sludge contained *S. newport* C2. The concentrations of salmonellae in the raw and treated sludge were not reported.	not investigated	Ayanwale *et al.* (1980)

[a]see bottom of appendix 1

Appendix 4. Agricultural use: epidemiological studies which examine the occupational risk to farmers engaged in agricultural work on land receiving nightsoil or sludge or to sanitation workers applying nightsoil or sludge to agricultural land

Country	Type of study[a]	Type of excreta	Health indicator(s)	Occupational group(s)	Results	Reference
China	descriptive	nightsoil	*Schistosoma japonicum* distribution	rice farmers	The distribution of schistosomiasis coincided with the rice-growing areas of China. This distribution was explained by the method of rice cultivation which included fertilisation of rice fields with nightsoil (both fresh and ripened) before planting, flooding of the fields after planting and finally the need for the rice farmers to wade in the flooded fields. The intermediate host was found in irrigation ditches in rice fields and in great numbers in the nursery beds where nightsoil was most often applied.	Faust and Meleney (1924)
China	descriptive	nightsoil	hookworm distribution	farmers	Hookworm was found to be mainly an occupational disease of farmers in rural areas of Central and South China where both climatic conditions and the "wet method" of nightsoil fertilisation favoured spread. The cultivation of mulberry trees with nightsoil was associated with particularly high prevalence rates.	Cort *et al.* (1926)
Japan	experimental	nightsoil	hookworm prevalence	farming population	Heat treatment of nightsoil prior to its use as fertiliser led to a "striking decline" in prevalence rates of hookworm.	Katayama (1955)
Japan	experimental	nightsoil	hookworm prevalence	farming population	Heat treatment of nightsoil prior to its use as fertiliser was associated with a small decrease in prevalence rates over 8 months. Heat treatment plus mass chemotherapy led to decreased prevalence rates which persisted at low levels during a 5-month follow-up.	Kawagoe *et al.* (1958)
Japan	experimental	nightsoil	hookworm re-infection	farming population	At 7 months following mass chemotherapy, the positive conversion rate in the areas using nightsoil treatment with ovicide was 17.7% and 17.4% and in the comparison area, 32.2%.	Kozai (1962)

Appendix 4. (cont.) Agricultural use: epidemiological studies which examine the occupational risk to farmers engaged in agricultural work on land receiving nightsoil or sludge or to sanitation workers applying nightsoil or sludge to agricultural land

Country	*Type of study*[a]	*Type of excreta*	*Health indicator(s)*	*Occupational group(s)*	Results	*Reference*
Japan	experimental	nightsoil	hookworm re-infection	farming population	Following mass chemotherapy, the positive conversion rate among persons whose families used nightsoil as a fertiliser was 7.1% in the area with ovicide-treated nightsoil and 12.5% in the area with untreated nightsoil.	Kutsumi (1969)
U.K.	outbreak investigation	sludge	hepatitis A	sludge spreaders	67% of 6 sludge spreaders developed hepatitis A over a 10-month period. 1 additional person with sludge contact also became ill with hepatitis. No common exposures were identified other than to sludge. No sludge tank drivers without sludge contact became ill.	Timothy and Mepham (1984)
U.S.A.	prospective cohort	sewage sludge	Incidence of infection with enteroviruses and hepatitis A	farm workers and families	Data from 1 of 3 study areas was presented after a 3-year study. Among an average of 20 people studied each year on sludge-receiving farms and 17 people on control farms, "significant" antibody increases to enteroviruses occurred in the sera of 18 people - 8 people on sludge farms and 10 on control farms. People on sludge farms were more likely to have more than 1 significant antibody rise. No hepatitis A infections were detected. Faeces were also examined for salmonellae and shigellae but results were not presented.	Ottolenghi et al. (1980) Hamparian et al. (1982)

[a]see bottom of appendix 1

Appendix 5. Aquacultural use: epidemiological studies which examine the risk to persons consuming crops grown in ponds fertilised with excreta

Country	Type of study[a]	Type of excreta	Health indicator(s)	Crops	Results	Reference
China	descriptive	nightsoil	*Fasciolopsis buski* distribution	aquatic plants	In an area of high prevalence of human *Fasciolopsis buski* infection, the parasite, intermediate host and nightsoil practices were studied. Aquatic plants were grown in raw nightsoil-fertilised ponds. The snail intermediate host was found in large numbers on these plants and large numbers of cysts were found on plants, particularly the water caltrop. The outer covering of the water caltrop is removed with the teeth before the nuts are eaten.	Barlow (1925)
China	descriptive	nightsoil	*Clonorchis sinensis* distribution	fish	In an area of known high prevalence of human *Clonorchis sinensis* infection, aquaculture practices were examined. Fish were raised in ponds directly fertilised with nightsoil from overhanging latrines. Infected snail and fish intermediate hosts were found in the ponds. These fish were at times consumed raw.	Faust and Khaw (1927)
Taiwan	descriptive	nightsoil	*Clonorchis sinensis* distribution	fish	In an area of reported high prevalence of human *Clonorchis* infection, nightsoil (and hog faeces) were used in the cultivation of fish in ponds containing snail intermediate hosts. Fish were subsequently consumed raw.	Cross (1969)
Israel	retrospective cohort	wastewater effluent	enteric diseases	fish	A retrospective review of clinic records over a 4-year period revealed a higher rate of clinical enteric diseases, laboratory-confirmed salmonellosis, and throat infections in kibbutzim practising wastewater effluent fertilisation of fish ponds than in non-effluent-utilising kibbutzim.	Fattal (1983) Fattal *et al.* (1981)

[a]see bottom of appendix 1