Health guidelines for the use of wastewater in agriculture and aquaculture

Report of a WHO Scientific Group

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Geneva, 18–23 November 1987

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HEALTH GUIDELINES FOR THE USE OF WASTEWATER IN AGRICULTURE AND AQUACULTURE

Report of a WHO Scientific Group

1. INTRODUCTION

A WHO Scientific Group on Health Aspects of Use of Treated Wastewater for Agriculture and Aquaculture met in Geneva from 18 to 23 November 1987. Dr W. Kreisel, Director, Division of Environmental Health, opened the meeting and welcomed participants on behalf of the Director-General. He emphasized the need to ensure, on the one hand, that appropriate controls are incorporated in schemes for wastewater use to protect both the environment and public health and, on the other hand, that proposed protective measures are feasible. Feasibility is important, since appropriate management of the limited water resources available is perhaps the greatest challenge of the next century.

Dr Kreisel also pointed out that recent reviews of available epidemiological data and research findings had led to the conclusion that the risks from irrigation with treated wastewater were much smaller than had previously been assumed and that current bacteriological standards were unjustifiably restrictive. However, it had been recognized that, in many developing countries, the main risks were associated with helminthic diseases and that safe use of wastewater in agriculture and aquaculture would therefore require a high degree of helminth removal.

The Scientific Group was the second meeting of experts to be convened by WHO to consider the health implications of the reuse of treated wastewater and to review and evaluate the health safeguards necessary in reusing effluents for irrigation and aquaculture. The report of the first WHO meeting of experts on the reuse of effluents, held in 1971, was published in 1973 (1) and the recommendations contained in it have served as guidelines since that time.

In July 1985, a review meeting of environmental specialists and epidemiologists was held in Engelberg, Switzerland, to consider the
health aspects of wastewater and excreta use in agriculture and aquaculture. It was concluded that the existing guidelines were unsatisfactory in that: (1) some of them were unjustifiably restrictive; and (2) they did not take account of the variety of pathogens which could be transmitted through wastewater use, so that public health was not adequately safeguarded, especially in respect of helminthic infections. Tentative wastewater quality guidelines, including helminth limits, were therefore suggested (2).

In June 1987, a WHO/United Nations Environment Programme project meeting of experts took place in Adelboden, Switzerland, to review the safe use of human wastes in agriculture and aquaculture. The publication produced as a result of the meeting (3) is aimed at encouraging governments to use such wastes for agriculture and aquaculture, but in a controlled way in order to minimize health risks. Participants in the Adelboden meeting unanimously agreed on the validity of the Engelberg recommendations and decided that they should form the basis of the approach to public health protection in schemes for wastewater use.

The objectives of the present Scientific Group were: to review the use of wastewater in agriculture and aquaculture from the point of view of its health effects; to recommend guidelines and alternative measures for the control of infectious disease transmission; and to identify the needs for further research and development.

2. BACKGROUND

2.1 The 1971 Meeting of Experts

Since the Meeting of Experts in 1971 (1), WHO has recognized the increasing importance of wastewater reuse, especially in agriculture, and the need for health safeguards in any such reuse. At the 1971 Meeting, it was noted that wastewater had been used in irrigation without treatment for many years in a large number of countries, either directly or indirectly, by way of irrigation with surface water containing substantial amounts of wastewater. Neither form of use was considered acceptable from the health point of view. However, little authoritative information on the health effects of wastewater reuse was then available to guide the experts, who therefore adopted a cautious approach in making recommendations.
Following a review of the literature available at the time, the Meeting concluded that a potential health hazard existed if crops recently irrigated with fresh or partially treated sewage were consumed uncooked, since sufficient numbers of pathogens would survive in the soil and/or on the crops to create such a hazard. However, it was recognized that the strict standards adopted by the California State Department of Public Health (4) were not achievable in many countries. In the absence of clear epidemiological evidence regarding health risks, it was considered that an effluent having a bacteriological quality of 100 coliform organisms¹ per 100 ml would give rise to only a limited health risk if it was used for the unrestricted irrigation of agricultural crops.

Such a high standard, it was suggested, could often be achieved only by primary treatment of sewage (usually done by sedimentation) and conventional secondary biological treatment followed by heavy and carefully controlled effluent chlorination. Even treatment in stabilization ponds (open ponds where algae, bacteria and sunlight provide natural purification) was not believed to produce a satisfactory effluent for use in unrestricted irrigation without chlorination. The final recommendations on the treatment of sewage for irrigation of crops eaten cooked and for aquaculture were that primary and secondary treatment were essential and that both “polishing” of the effluent by sand filtration or another method (to remove suspended solids) and disinfection were required in certain circumstances. In the case of crops eaten raw, disinfection was considered essential in addition to primary and secondary treatment, while in some cases sand filtration or an equivalent polishing treatment was also necessary. Crops not intended directly for human consumption, it was agreed, could be irrigated with effluent from primary sewage treatment.

Considerable importance was attached to the quality control of wastewater for reuse and examination or testing for the following was suggested: protozoan cysts and eggs of helminthic parasites (it was recommended that, if these were found, their viability should be determined); faecal coliforms and, where anaerobic conditions might exist, Clostridium species; viruses; and chemicals, including trace

¹ Coliform bacteria are a group of bacteria of the enteric tract of mammals, belonging to the family Enterobacteriaceae. Some of them, namely the faecal coliforms, are normally found in human and animal faeces and are used as an indicator of faecal pollution.
organics. In addition to the need for well equipped laboratories to conduct such monitoring and testing of treated effluents, the Meeting drew attention to the fact that effective quality control depends on the accuracy and reliability of measurements.

2.2 Trends in wastewater reuse

The use of wastewater in agriculture in what was called “sewage farming” was started in Australia, France, Germany, India, the United Kingdom and the USA in the latter part of the 19th century and in Mexico in 1904. However, in certain temperate regions, with the ever-increasing volumes of sewage being collected and the diminishing availability of land close to cities, the area required for sewage farming became so large as to be prohibitive. Of the countries mentioned, only Australia (Melbourne), India, what is now the Federal Republic of Germany and Mexico continue to use wastewater in this way; other forms of wastewater reuse are practised elsewhere. Indirect reuse, i.e., the abstraction of water from rivers receiving wastewaters, occurs throughout the world.

Over the past 20 years, there has been a considerable revival of interest in the use of wastewater for crop irrigation in arid and semi-arid regions as a result of the scarcity of alternative water supplies and the need to increase local food production. Water resources planners have come to recognize the value of this practice, in terms of both water conservation and nutrient recycling and as a method of preventing the pollution of surface and ground water, and the public has not objected so long as the necessary health safeguards have been included. Reuse of treated effluent for the irrigation of crops and urban “greenspaces” (such as parks and golf courses) has expanded significantly in Australia, Latin America, North Africa, Spain, other Mediterranean countries and the USA. In some countries, such as Israel, Jordan, Peru and Saudi Arabia, it is government policy to reuse all effluents from sewage-treatment plants, mainly for crop irrigation.

In the past 50 years, very strict microbiological standards for treated wastewater have been adopted in many countries, based exclusively on bacterial indicator criteria. Some countries adopted the tertiary treatment approach, when they could afford to, and installed facilities for rapid sand filtration and chlorination after secondary biological sewage treatment. In several regions, it is intended in the future to ozonate effluents, even after such tertiary
treatment, in an attempt to eliminate any health risk to a public which now enjoys a very high level of health.

Although such costly approaches, involving tertiary treatment, are not now considered necessary in any country, a lack of knowledge of the real health risks and the wide adoption of unenforceable standards have tended to encourage the belief in poorer countries that reuse of effluent for irrigation is a costly process requiring sophisticated treatment technology. This has resulted both in a failure to plan for wastewater reuse where sewerage schemes have been installed and in the uncontrolled use by farmers of raw sewage or treated effluent after discharge to surface water channels. In arid and semi-arid regions especially, but also in other areas, it is imperative that reuse be taken into account as a feasible option for the disposal of collected wastewaters rather than as something that is possible only under exceptional conditions. To achieve this and yet ensure the incorporation of measures for the protection of health, more realistic guidelines are now needed, taking account of the knowledge gained in recent years on the epidemiological implications of reuse.

The need to assess the performance of different sewage-treatment processes for removing different types of contaminants was identified by the 1971 Meeting of Experts (1). For wastewater reuse, pathogen removal becomes the most important measure of treatment process performance, rather than removal of suspended solids and reduction of biochemical oxygen demand (a measure of the organic "strength" of sewage), as usually required for pollution control. Although conventional primary, secondary and tertiary sewage-treatment processes have not been evaluated to the same extent in tropical or subtropical developing countries as in temperate industrialized countries, it is generally accepted that the usual primary and secondary treatments are not very efficient at removing pathogenic organisms. Whether a satisfactory effluent can be reliably produced after tertiary treatment in countries with little experience of operating even conventional secondary sewage-treatment plants is yet to be determined. On the other hand, studies of waste stabilization ponds used for secondary sewage treatment have confirmed their effectiveness in removing pathogens, if properly designed. Moreover, they have the advantage of providing a form of treatment technology that is both cheap and simple. Ponds are now accepted as the most appropriate sewage-treatment technology for producing effluent suitable for use in irrigation and aquaculture,
except where land is not available or is very costly, or where peculiar local conditions militate against them.

The production of fish in ponds fertilized with human wastes is an ancient practice in many parts of Asia, where aquatic plants (macrophytes) are also cultivated in this way, and was also known in medieval Europe. The use of wastewater to fertilize ponds was developed in Germany at the end of the 19th century and independently in Calcutta in 1930, which now has the largest wastewater-fed aquaculture system in the world (5) (see p. 24). In India as a whole, there are now more than 130 wastewater-fed fisheries, with some 12,000 ha\(^1\) of ponds (5), and wastewater is used for aquaculture in a number of other countries including the Federal Republic of Germany and Hungary. As the use of stabilization ponds for wastewater treatment has become more widespread, there has been increasing interest in the use of the final ponds in the series for fish production. Most of the existing aquaculture reuse systems use raw or partially treated wastewater, although it generally undergoes considerable dilution in the ponds so as not to cause undue oxygen depletion. It is unclear at present to what extent the use of raw wastewater promotes the transmission of enteric pathogens, and this question is the subject of current research.

2.3 Health risks—the epidemiological perspective

Previous quality guidelines and standards for wastewater reuse have been based essentially on microbiological criteria, in the absence of adequate epidemiological data at the time that they were drawn up. The aim was to eliminate the potential risk to health posed by the presence of faecal microorganisms and therefore to remove all pathogenic faecal organisms. The standards set were the minimum bacterial concentrations which could be detected in the wastes by routine monitoring, or which could be achieved in practice by currently available treatment processes. In some cases, these were equivalent to the prevailing quality standards for drinking-water. However, the detection of faecal indicator organisms (i.e., bacteria that normally, and preferably exclusively, live in the intestinal tract of humans and other warm-blooded animals without causing disease) or even pathogens in wastewater does not necessarily mean that additional cases of disease occur, because this requires the

\(^1\) One hectare is equivalent to \(10^4\) m\(^2\).
intervention of a series of other factors, each of which depends on local conditions. The epidemiological approach to health protection requires risks to be evaluated in terms of the disease which can be attributed to the wastewater use, and not of the mere presence of pathogenic organisms (see section 6.3).

The epidemiological evidence, including many recent studies, has been reviewed over the last few years (2, 6), making it possible to develop new guidelines based on epidemiological rather than microbiological criteria. Epidemiological studies have indicated that significant disease can be associated with wastewater reuse, and particularly with reuse of raw wastewater. This disease is, however, caused by pathogens, particularly helminths, that are neither detected by the techniques used in conventional microbiological monitoring of wastewater quality nor necessarily removed by conventional treatment processes. New guidelines should therefore include a more realistic bacterial indicator value consistent with the epidemiological approach and with the fact that risks from bacterial infections are lower than was previously suspected. They should also include a helminth egg guideline in response to the epidemiological evidence which suggests that the greatest risks from wastewater use are from helminth infections (see section 6.5).

The epidemiological approach also focuses attention on the specific groups of people who are exposed to the risk of disease from wastewater reuse, namely field and pond workers, crop handlers and consumers, and those living near to or visiting fields or ponds where wastewater is applied. It also identifies opportunities for the application of a range of other measures for health protection besides treatment of the wastewater (3).

A more integrated approach to minimizing health risks is now thought to be appropriate, and wastewater treatment, while potentially providing the greatest degree of health protection, should be only one of the measures considered in planning future reuse projects, together with crop restriction, control of wastewater application, exposure control and promotion of hygiene. There is a need to update existing guidelines to include the new information on wastewater use and thereby encourage countries to take advantage of this valuable resource, while at the same time protecting public health. In addition, benefits in terms of environmental control, such as a reduction in the pollution of surface and ground water, will undoubtedly result from the controlled use of wastewater in agriculture and aquaculture. The opportunity to reduce the
dependence on technical equipment and take advantage of organizational and managerial approaches to health protection, such as crop restriction, should not be missed.

3. SCOPE OF THE REPORT

The report of the 1971 Meeting of Experts (1) covered a broad range of wastewater reuse possibilities, including municipal non-potable and potable uses, recreational uses, and uses in aquaculture, agriculture and industry. The present report concentrates on the use of wastewater in agriculture and aquaculture and for municipal non-potable applications, such as watering urban greenspaces, as shown in Fig. 1, which is the same as Fig. 2 of the previous report with these areas of concern shaded.

In the context of the present report, agricultural reuse, the major area of interest, includes the irrigation of orchards and vineyards, fodder, fibre and seed crops, crops consumed after processing and crops consumed raw. Aquaculture, the cultivation of fish or aquatic plants for human consumption, animal feed or, indeed, for fish feed, is an increasing area of wastewater reuse in developing countries, and guidelines for the protection of public health are urgently needed. Watering of greenspaces for urban landscaping is an important and significant application of wastewater reuse in arid areas. In countries affected by water shortages, traditional sources tend to be used essentially for potable water supply and crop irrigation, leaving little for municipal non-potable uses, and the desire for greenery in urban areas has been a strong motivating force in the promotion of effluent reuse. Although industrial and recreational uses of wastewater are increasing in some countries, the three uses identified for discussion in this report are now more important globally and cover the major sectors for which developing countries should be considering wastewater reuse.

Raw wastewater is used for crop and fish production in many countries, often illegally and without the approval of the health authorities. Providing assistance in improving existing practices, not only to minimize health risks but also to increase productivity, is preferable to outright prohibition. Generally, the upgrading of existing schemes should take precedence over the development of new wastewater reuse projects in any country, but the planning and implementation of such projects are also considered here.
Fig. 1. Intentional use of wastewater

- Municipal wastewater
  - Municipal non-potable
  - Drinking
  - Recreation
  - Fish culture
- Agriculture
- Industry
- Industrial wastewater
  - Intra-plant
  - General
- Stock watering
- Orchards and vineyards
- Fodder, fibre crops and seed crops
- Crops consumed after processing
- Crops consumed raw
Although the Scientific Group did not deal in detail with the use of excreta in agriculture and aquaculture, the importance of the health risks associated with this practice is fully recognized by WHO. Some consideration has already been given to the subject (3, 7, 8, 9) and the possibility of convening another Scientific Group meeting on the topic is being explored.

Although it was appreciated that health risks might arise from the chemical content of wastewaters and from sludges\(^1\) produced in wastewater treatment, these matters did not come within the scope of the Meeting and were not dealt with in any great depth. Other publications are available as a source of guidance on these matters (10, 11), including the Environmental Health Criteria series published by WHO. In certain locations, chemical toxicity and disease transmission through wastewater sludge may be as important as the health risks more thoroughly dealt with here.

### 4. MAJOR ASPECTS OF WASTEWATER REUSE

#### 4.1 Wastewater as a valuable resource

As a substitute for fresh water in irrigation or aquaculture, wastewater has an important role to play in water resources management. By releasing fresh water sources for potable water supply and other priority uses, wastewater reuse contributes to water conservation and has certain economic advantages. Wastewater is available close to urban areas, where the demand for food and fuelwood crops is concentrated. Reuse of wastewater for irrigation of these crops can thereby help both to improve the nutritional status of urban populations and to provide energy for cooking and heating; in some countries, such reuse is essential. The primary objective must therefore be to ensure that wastewater is reused rationally while at the same time health is protected.

Some pollutants which, if discharged directly to the environment, could create serious pollution problems (especially organic matter and nitrogen, phosphorus and potassium compounds) serve as nutrients when present in irrigation water or in fish-ponds. Studies in many countries have shown that, with proper management, crop

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\(^1\) Sludge is the solid matter (often having a high water content) that is formed both when sewage is allowed to stand so that the denser solids settle out, and as a product of various treatment processes.
yields may be increased by irrigating with raw wastewater or with effluents that have undergone primary and secondary treatment. For an irrigation rate of 20 000 m³/ha per year (equivalent to a depth of 2 m of water over the year), which is commonly required in semi-arid areas, typical concentrations of 15 mg/l of total nitrogen and 3 mg/l of total phosphorus in well treated sewage (say, after treatment in a properly designed series of stabilization ponds) correspond to annual nitrogen and phosphorus application rates of 300 and 60 kg/ha, respectively. Such nutrient inputs can reduce or eliminate completely the need for commercial fertilizers. In addition, the organic matter added through wastewater irrigation acts as a soil conditioner, increasing the capacity of the soil to store water.

4.2 Environmental control

The discharge of untreated or partially treated wastewater into the environment can give rise to pollution problems in both surface and ground waters and on land. The planned use of wastewater in irrigation or aquaculture prevents such problems and reduces the resulting damage, thus partly offsetting the cost of the scheme. In addition, the use of wastewater for irrigation instead of ground water in those areas where over-utilization of the latter is causing problems, such as salt-water intrusion in coastal areas, might result in further environmental benefits. Wastewater reuse is often the preferred disposal method from the point of view of environmental protection.

The use of wastewater in forestry can also bring considerable environmental benefits to the surroundings of large cities. In many developing countries, these areas are suffering from deforestation and the resulting environmental degradation caused by the demand for fuelwood. In arid zones, tree belts help to stabilize the desert around cities and control dust storms, while at the same time improving the environment and providing a valuable crop.

One possible environmental problem which might result from the use of wastewater in irrigation, and from applying sewage sludge to land, is ground-water contamination; nitrate accumulation in ground water is a serious problem in many countries. The risk of contaminating ground water through wastewater irrigation will depend on local conditions as well as on the rate of application. Where a deep homogeneous unsaturated zone overlies the saturated layer of the aquifer, most pollutants are removed in the unsaturated
layer and there is a very low risk of ground-water contamination. Only if there is a shallow or highly porous unsaturated zone above the aquifer, and especially if this zone is fissured, will a high risk of nitrate accumulation arise. On the other hand, crops will take up nitrogen from the irrigation wastewater and thereby reduce ground-water contamination.

Care should always be taken in schemes for wastewater reuse to prevent the creation of a habitat for disease vectors, such as mosquitos or snails. A problem which has sometimes been associated with sewage farms in the past is the breeding of mosquitos of the *Culex pipiens* group in slowly moving polluted water and standing pools. In addition to constituting a nuisance, they can transmit bancroftian filariasis in most of the areas where it is endemic. Standard vector control techniques should be applied wherever appropriate to avoid the transmission of such vectorborne diseases.

### 4.3 Chemical pollutants

Municipal wastewater is likely to contain chemical pollutants wherever industrial discharges are allowed to enter the sewerage system. Of particular concern are those that are toxic to man, plants and aquatic biota; heavy metals and non-degradable organics fall into this category. Boron, a constituent of synthetic detergents, is toxic to plants, especially citrus crops, and should be monitored when wastewater is used for irrigation. Preventing chemical pollutants from entering sewers is the best way of dealing with the problem, but this is difficult to achieve where there are many small-scale industries, unless industrial zones are isolated and provided with their own wastewater-treatment plants.

A possible long-term problem with wastewater irrigation is that toxic materials or salinity may build up in the soil. As the unsaturated zone removes chemical pollutants, particularly heavy metals, their concentration in the soil will increase with time and, after many years of irrigation, it is possible that levels will be reached at which crops will take up such pollutants at concentrations toxic to man. Soil salinization is common in arid regions where irrigation water is saline, and irrigation with saline wastewater could have the same result over the long term. Provision of adequate soil drainage is imperative in any irrigation scheme as a means of minimizing salinization.
In-depth discussion of this subject is beyond the scope of this report but guideline values for the chemical quality of irrigation water have been published (12), including values related to salinity, rate of water infiltration into the soil and specific ion toxicity; these can be used to identify a potential problem due to wastewater use in any specific case.

4.4 Economic aspects

Clearly, a prerequisite of wastewater reuse is wastewater collection. In major urban areas this will often mean the collection of waterborne sewage but in some cases it may involve night soil collection. Wastewater collection is necessary, whether wastewater is to be reused or not, and its cost should not be included in economic appraisals of reuse projects or charged to those who use the wastewater. The same is true of the cost of the wastewater treatment and disposal required to meet environmental protection criteria.

The only part of any wastewater treatment costs which might reasonably be charged to a reuse project is the cost of any treatment that would not have been needed for pollution control purposes. In some cases, however, effluent reuse in irrigation or aquaculture might mean that a lower level of wastewater treatment will be required than would be necessary for environmental pollution control; the reduction in treatment cost would then be a benefit of the reuse scheme. Additional costs are incurred, however, in providing effluent storage and distribution systems (ponds, tanks, canals, pipes and appurtenances).

The benefits of wastewater reuse, which can be set against the costs, include the value of the agricultural crops or fish produced, the employment provided, the savings on commercial fertilizers (possibly imported) and the environmental pollution damage avoided. Linked to the last of these benefits will be savings on the cost of alternative arrangements for the disposal of the wastewater, e.g., long, costly sea outfalls in coastal areas. If wastewater reuse is to replace the use of other water sources, such as industrial and domestic supplies, the resulting cost savings can be high and are a major benefit.

Integrating reuse considerations into wastewater planning from the beginning will facilitate economically sound solutions. Even the design of the wastewater collection system and the location of the treatment plant will have an impact on the economic viability of
effluent reuse in irrigation or aquaculture. Transport of treated effluent over long distances to reuse areas is costly, and should be avoided if possible.

4.5 Institutional aspects

Wherever it is not possible to arrange for a single agency to run a scheme for wastewater reuse, it is essential that local arrangements are made for interagency coordination. Full cooperation among the different agencies involved is essential for smooth operation but is especially critical in implementing effective health protection measures. The relevant agency or agencies must have, or must acquire, the capacity and capability for monitoring wastewater quality, though such monitoring can be less stringent if properly designed plants are installed for stabilization pond treatment. Any other health protection measures adopted should also be monitored. Feedback to workers at treatment plants and wastewater users is also required in order to ensure health protection at all times, and agencies must be prepared to enforce regulations and provide guidance whenever necessary to achieve this objective.

4.6 Sociocultural aspects

Important sociocultural and religious factors may affect the feasibility and acceptability of schemes for wastewater reuse. For instance, in some areas of Asia, particularly China, the use of raw excreta in agriculture is a deeply rooted and widely accepted cultural norm, so that pretreatment may not be perceived as necessary. On the other hand, in some countries, religious and cultural constraints may prohibit contact with human faeces. However, various religious authorities have ruled that the use of well purified, treated wastewater is an acceptable practice. The readiness of people to accept new ideas and changes in traditional values is often underestimated.

The Scientific Group emphasized the need to give careful consideration to sociocultural factors in the development of schemes for wastewater reuse. This will often require the services of professional social scientists familiar with the specific culture concerned.
5. CURRENT PRACTICE IN WASTEWATER REUSE

Wastewater use in agriculture and aquaculture is widespread throughout the world. It developed with the introduction of sewerage in urban areas and has found increased application over the past few decades, particularly in semi-arid and arid zones. The main reasons for wastewater reuse are the urgent need to expand agricultural production, a shortage of fresh water and the desire to economize on the purchase of mineral fertilizers. Thousands of schemes for wastewater use are in existence, ranging in size from a few hectares to thousands of hectares. For example, in India several hundred wastewater irrigation schemes have been identified, serving an area of approximately 73 000 ha (13). In the USA, a rapidly increasing number of wastewater irrigation schemes (over 3400 projects in 1980) are being implemented. However, only a relatively small number of schemes throughout the world have been designed and implemented in such a way as to provide good health protection for both workers and consumers. In the majority, raw or only minimally treated wastewater is used, and little or nothing is done to protect health. Breaking into sewers and the clandestine extraction of wastewater from open drainage channels by farmers are not uncommon.

A number of illustrative examples of schemes for wastewater reuse which provide variable degrees of health protection are presented below. These highlight the range of existing practices as well as the applicability of the available health protection measures; these are further addressed in section 7.

5.1 Agriculture

Restriction of crops selected for cultivation can play a valuable role in protecting public health when wastewater is used either untreated or only partially treated. Most of the sewage from Mexico City (produced at a rate of approximately 55 m$^3$/s) is used in Rural Development District No. 063 in the Mezquital Valley, State of Hidalgo. The wastewater is used to irrigate 80 000 ha, mainly for the production of alfalfa, maize, barley and oats, making this the largest scheme for wastewater reuse in the world (14). Prohibited crops include lettuce, cabbage, beetroot, coriander, radish, carrot, spinach and parsley, but a small area of tomatoes and chillies is permitted
by the controlling authority, which considers them safe because the fruits are produced well above ground level. No wastewater treatment plants are included in the system but some degree of quality improvement may occur in the open canals through which the sewage flows during the 60 km journey to the area from Mexico City and, in some cases, through storage in seasonal reservoirs and dilution with river water. This irrigation scheme, organized by a government agency, has operated satisfactorily for the past 30 years, enforced crop restriction being the only health protection measure. While there remain uncertainties about the degree of health protection that the scheme provides for agricultural workers, it is claimed that consumers' health is adequately protected by the crop restriction imposed.

Treatment of wastewater in stabilization ponds is an effective and low-cost method of pathogen removal, and is therefore suitable for schemes for wastewater reuse. It is used successfully in the treatment of wastewater from the city of Amman, Jordan, as well as from parts of the city of Tunis, Tunisia, and in Lima, Peru, where maize and vegetables as well as fodder crops are irrigated. In Lima, wastewater treatment in stabilization ponds is the only means of providing health protection and there is no crop restriction.

A combination of partial treatment and crop restriction is practised in Ica, Peru, where the town’s sewage is only partially treated in stabilization ponds. The effluent contains about $10^5$ faecal coliforms per 100 ml and is used to irrigate about 400 ha of cotton, maize and grapes. The cultivation of tubers and of vegetables that grow close to the ground or are eaten raw is not permitted. Ground water is used to irrigate nearby areas for the cultivation of these prohibited crops. The local Health Inspectorate enforces the regulations governing wastewater irrigation (15).

Health protection by a combination of crop selection and wastewater treatment achieving only partial pathogen removal is also practised in government-administered irrigation districts in Tunisia (15). Wastewater from parts of the city of Tunis undergoes conventional secondary biological treatment and is used without chlorination to irrigate several thousand hectares of citrus fruit trees grown as cash crops. The wastewater is distributed through buried pipes, and the effluent reaches the trees along short furrows from wastewater valve outlets. Thus, in addition to partial treatment and crop selection, some health protection is also provided through the partially localized distribution of the wastewater. This regime should
provide good health protection to consumers and may also protect the agricultural workers.

Total wastewater reuse in agriculture is a declared national water resources policy in Israel, where some 250 irrigation projects utilizing over 70% of the total urban wastewater flow have been implemented. The main health protection strategy is minimal treatment in stabilization pond systems combined with restriction of crops mainly to cotton and fodder. It is recognized that the success of this health protection strategy is aided by the high level of education of the farming population and it may thus not be equally appropriate in other situations and countries. The use of deep reservoirs for interseasonal wastewater storage has proved to be an effective way of increasing the availability of water for irrigation during the summer months and of reducing environmental pollution in the non-irrigation season.

In some countries, extensive and sophisticated wastewater treatment as well as rather strict rules for crop selection have been adopted in order to protect consumers. Advanced and high-cost treatment technologies, such as rapid sand filtration and chlorination, are being applied as an extension of conventional sewage treatment, which is aimed at reducing organic pollution rather than removing pathogens. This approach to wastewater treatment has been adopted in Kuwait but, in addition, human exposure has been controlled and some degree of crop restriction introduced. The farm on which treated sewage is used for irrigation is managed by a single private company and fenced off to prevent public access. Farm workers are provided with protective clothing and required to undergo regular health checks.

5.2 Greenspace irrigation

Wastewater is widely used for the irrigation of urban greenspaces, such as golf courses and gardens. Care is then needed to protect the public from health risks through direct contact with contaminated grass, bushes, trees, and other items. In many countries in which this practice is adopted, the effluent quality standards of the California State Department of Public Health (4) have been taken as the model, and tertiary treatment by rapid sand filtration and chlorination have typically been used after conventional secondary biological treatment. This has been the practice in Oman, Qatar, Saudi Arabia, and the United Arab Emirates (16), although
secondary effluent has been used for many years to water green strips along urban streets in arid countries. In Mexico City, wastewater that has undergone secondary treatment is used to irrigate public parks and roadside strips by means of a piped reticulation system and tanker trucks. Sprinkler or hose irrigation is typically used for such greenspaces.

5.3 Aquaculture

The growing of fish and aquatic plants in ponds fertilized with wastewater and excreta is a common practice, particularly in Asia. In the examples presented below, the traditional habit of cooking the fish grown in such ponds probably functions as an effective health protection measure.

As mentioned earlier, there are more than 130 wastewater-fertilized fish-pond systems in India, covering an area of some 12,000 ha; most are located in West Bengal. The largest wastewater-based aquaculture system in the world is that in Calcutta (3). Here, raw wastewater and storm-water runoff from the city are conveyed east to wetlands through two main canals, from which they pass into a complex system of secondary and tertiary channels. From these, regulated amounts are fed through simple gates into an extensive system of ponds with an area of 4,400 ha and stocked with Indian major carp and *Tilapia* species, which achieve marketable size in 5–6 months. Mean annual yields are more than 1,000 kg/ha and the ponds provide employment for local people at the level of 7.5 persons/ha. The fish are caught in drag-nets at dawn and sold by 07h00 in the market, accounting for 10–20% of the fish consumed in Greater Calcutta. Total coliform reduction in the fish-ponds is reported to be substantial and this, together with the fact that the fish are well cooked before being eaten, indicates a low potential health risk.

About 25% of the settled wastewater (i.e., that from which most of the settleable solids have been removed) from the city of Munich, in the Federal Republic of Germany, is treated in a 233 ha complex of fish-ponds (15); this consists of 30 large ponds operated in parallel, each with a retention time of about 40 hours. Additional smaller ponds are used for breeding, nursery, overwintering and storage of harvested fish prior to marketing. Common carp, the main cultivated species, feeds on invertebrates that live at the bottom of the ponds but also on zooplankton, and annual yields of 500 kg/ha are produced. The wastewater is aerated and diluted with four
or more times the amount of river water. Two weeks before harvest, fresh water alone is added to the ponds to depurate (remove impurities from) the fish. Fish are cultivated only from April to October, because of low winter temperatures, and the ponds stand empty from December to March. This consolidates the sludge to such an extent that, in 30 years of operation, it has not been necessary to remove it.

6. HEALTH ASPECTS OF WASTEWATER REUSE

6.1 Infections caused by excreted pathogens

Pathogenic viruses, bacteria, protozoa and helminths escape from the bodies of infected persons in their excreta and may be passed on to others via either the mouth (e.g., through the eating of contaminated vegetables) or the skin (as in the case of the hookworms and schistosomes). Excreta and wastewater generally contain high concentrations of excreted pathogens, especially in countries where diarrhoeal diseases and intestinal parasites are particularly prevalent. A large number of such infections of public health importance exist which are transmitted in a variety of ways; the characteristics of the causative agents also vary (see Annex 1) and are of great importance in determining in what circumstances each infection is likely to be favoured or controlled by waste reuse practices. Fearheil et al. (7) have divided infections caused by excreted pathogens into five categories according to their environmental transmission characteristics, as discussed below.

Category I infections are caused by pathogens which are infective immediately on excretion (“non-latent”), have a low median infective dose but cannot multiply in the environment. This category includes excreted viruses and protozoa and the helminths *Enterobius vermicularis* (pinworm or threadworm) and *Hymenolepis nana* (dwarf tapeworm). Transmission of these pathogens occurs predominantly through direct transmission from person to person in the immediate domestic environment, especially when crowding and low standards of personal hygiene prevail, although the survival

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1 In the context of this report, a latent period is the length of time between the excretion of a pathogen and its becoming potentially infective to a new vertebrate host. The concept applies only to certain helminths because all excreted viruses, bacteria and protozoa have zero latency.
times of excreted viruses and protozoa may be long enough for them to pose a health risk in schemes for the use of excreta and wastewater.

The pathogens causing Category II infections are the excreted bacteria; like the causative agents of Category I infections, they are infective immediately on excretion. Their higher median infective dose means that they must generally be ingested in greater numbers to be capable of causing disease, but they can multiply outside their host, e.g., in food or milk. They are commonly transmitted in the immediate domestic environment but their greater ability to persist in the environment means that they can survive for the longer periods involved in certain transmission routes and therefore can pose potential health risks in schemes for the use of excreta and wastewater. There are well documented cases of, for example, cholera epidemics caused by the irrigation of vegetable crops with untreated wastewater (17).

The diseases in Category III are caused by the soil-transmitted intestinal nematodes, which require no intermediate host. Their eggs require a latent period of development in the environment before they can cause infection. On the other hand, the minimum infectious dose is only one organism and these parasites are only weakly affected by host immunity. The most important of these are the human roundworm Ascaris lumbricoides, the hookworms Ancylostoma duodenale and Necator americanus, and the human whipworm (Trichuris trichiura). They are all readily transmitted by the agricultural use of raw or insufficiently treated excreta and wastewater; indeed, they are the excreted pathogens of greatest public health concern in agricultural reuse schemes.

Category IV infections are caused by the tapeworms Taenia saginata and T. solium. For their successful transmission, viable eggs must first be ingested by a cow or pig (respectively) before humans can be infected by eating the undercooked meat of infected animals. A potential route for the transmission of these diseases is the irrigation of pasture with wastewater.

The infections in Category V are all caused by water-based helminths that require one or two intermediate aquatic hosts; the first of these is a snail, in which the pathogen multiplies asexually, and the second (if there is one) is either a fish or an aquatic macrophyte. Many of these helminths have a limited geographical distribution and it is only in endemic areas that their transmission is promoted by the aquacultural use of raw or insufficiently treated
excreta and wastewater, together with the practice of eating raw or inadequately cooked fish and aquatic vegetables. Agricultural use is not relevant, except in so far as all irrigation schemes may facilitate the transmission of schistosomiasis.

In the above classification, infections in Categories III–V are caused by excreted helminths. These all require a period of time after excretion to become infective to man, and this latency period is passed in soil, water or an intermediate host. Most of them are environmentally persistent, with survival times usually ranging from several weeks to several years. Schemes for the use of excreta and wastewater are important mechanisms of transmission of many of these diseases and a major environmental measure for their control is therefore the effective treatment of excreta, wastewaters and wastewater-derived sludges prior to use.

6.2 Pathogen survival

The extensive literature on the survival times of excreted pathogens in soil and on crop surfaces has been reviewed by Feachem et al. (7) and Strauss (18). There are wide variations in reported survival times, which reflect both strain variation and the effect of climatic factors, as well as differences in analytical techniques. Nevertheless, it is possible to summarize current knowledge on pathogen survival in soil and on crops in warm climates (20–30°C), as shown in Table 1. Pathogen survival in excreta- and wastewater-enriched ponds is similar to that in waste stabilization ponds; bacterial and viral numbers may be expected to decrease by only 1–3 orders of magnitude, depending on dilution, hydraulic retention time (the mean length of time that water is retained by the pond system) and climatic factors, and helminth eggs and amoebic cysts will settle to the bottom of the pond, where they may remain viable for long periods of time.

Available evidence indicates that almost all excreted pathogens can survive in soil and ponds for a sufficient length of time to pose potential risks to farm and pond workers and also to those who handle and consume fish and aquatic macrophytes. Pathogens survive on crop surfaces for a shorter time than in soil, as they are

1 In the context of this report, persistence is the period between the excretion of a pathogen and its eventual death or inactivation in the environment. In the case of helminthic pathogens with one or more intermediate hosts, persistence is defined as the survival time of the final infective stage.
Table 1. Survival times of selected excreted pathogens in soil and on crop surfaces at 20–30°C.*

<table>
<thead>
<tr>
<th>Pathogen</th>
<th>Survival time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>In soil</td>
</tr>
<tr>
<td><strong>Viruses</strong></td>
<td></td>
</tr>
<tr>
<td>Enteroviruses*</td>
<td>&lt;100 but usually &lt;20 days</td>
</tr>
<tr>
<td><strong>Bacteria</strong></td>
<td></td>
</tr>
<tr>
<td>Faecal coliforms</td>
<td>&lt;70 but usually &lt;20 days</td>
</tr>
<tr>
<td>Salmonella spp</td>
<td>&lt;70 but usually &lt;20 days</td>
</tr>
<tr>
<td>Vibrio cholerae</td>
<td>&lt;20 but usually &lt;10 days</td>
</tr>
<tr>
<td><strong>Protozoa</strong></td>
<td></td>
</tr>
<tr>
<td>Entamoeba histolytica cysts</td>
<td>&lt;20 but usually &lt;10 days</td>
</tr>
<tr>
<td>** helminths**</td>
<td></td>
</tr>
<tr>
<td>Ascaris lumbricoides eggs</td>
<td>Many months</td>
</tr>
<tr>
<td>Hookworm larvae</td>
<td>&lt;60 but usually &lt;30 days</td>
</tr>
<tr>
<td>Taenia saginata eggs</td>
<td>Many months</td>
</tr>
<tr>
<td>Trichuris trichuria eggs</td>
<td>Many months</td>
</tr>
</tbody>
</table>

* Includes poliomyelitis and coxsackieviruses.

then less well protected from the harsh effects of sunlight and desiccation. Nevertheless, survival times can be long enough in some cases to pose potential risks to crop handlers and consumers, especially when survival times are longer than crop growing cycles, as is often the case with vegetables.

Irrigation of pasture with wastewater which contains viable *Taenia saginata* eggs will induce bovine cystercerosis only if cows have access to the pasture while the eggs are still viable. An interval of at least 14 days between irrigation and grazing is often recommended and, in some countries, is obligatory. However, it is unclear how effective this is in practice as a control measure, as eggs of *Taenia* species have been known to survive for up to 6 months on grass and soil. The education of farmers and meat inspection are necessary additional control measures. In the case of pig tapeworm, pigs become infected only if they have direct access to human faeces (which they readily consume); excreta fertilization and wastewater irrigation of crops do not generally promote any significant disease transmission.

6.3 Measures of health risk from wastewater use

Knowledge of the survival patterns of excreted pathogens and of the removal of pathogens in wastewater treatment allows some assessment of the risk of the transmission of communicable diseases
through wastewater use. This approach places greatest emphasis on microbiological criteria and relies on pathogen removal to ensure the absence of "potential" risks, but does not take account of the epidemiological concept of "actual" or "attributable" risk. There is thought to be a potential risk—a risk (e.g., of developing a disease) that might but does not at present exist—when pathogenic microorganisms are detected in wastewater or on crops, even if no cases of disease caused by these microorganisms are detected. This is in contrast to the epidemiologist's concept of risk, which focuses on the chance of an individual developing a given disease (or experiencing a change in health status) over a specified period as the result of a certain exposure. It is possible that a potential risk might not become an actual risk because of factors related to pathogen survival, minimum infective dose, human behaviour, and host immunity (see section 6.4). In addition, a particular infection may have other routes of transmission in the community, so that some of the disease observed may not be associated with wastewater use. Risk is most usefully evaluated, therefore, on the basis of attributable risk or excess risk, which is a measure of the amount of disease associated with a particular transmission route within a population, in this case, the amount associated with wastewater reuse.

Measurement of attributable risk involves the comparison of two populations, one exposed to the risk factor of interest (in this case, wastewater use) and the other not so exposed (the "control" population). Some cases of the disease of interest may occur in the control or unexposed population as the result of transmission via other routes (for example, diarrhoea transmitted through poor domestic water supplies and intestinal nematode infections transmitted through contamination of the domestic environment). The difference between the disease risk of the exposed and control populations—and not simply the amount of disease in the exposed population—is therefore a measure of the risk attributable to wastewater use.

The term "relative risk" means the ratio of the risk estimates for the exposed and control populations and represents the number of

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1 Actual risk is the lay term for excess risk, attributable risk or risk difference. It is the absolute difference between two risks, e.g., for wastewater reuse the difference between the risk of disease in the exposed population and that in the unexposed population.
times that disease is more (or less) likely to occur in the exposed as compared with the unexposed group. In the present case, it will provide a measure of the relative importance of wastewater reuse as a risk factor for the disease in question. However, in practice, it is probably more useful to assess the actual amount of disease caused by wastewater reuse, for which purpose attributable risk is the more convenient parameter.

The health risk associated with wastewater reuse may differ in different subgroups of the population. In this context, the most important subgroups to consider are persons consuming crops irrigated with the wastewater (consumer risk) and agricultural workers exposed occupationally (occupational risk). It is also important to consider persons of different ages separately, since the risk to children may be different from the risk to adults. The health protection measures to be taken will depend on whether consumer risks or occupational risks, or both, are to be minimized.

6.4 Factors involved in disease transmission

Many factors affect the degree to which the potential risk posed by a pathogen in wastewater can become an actual risk of disease transmission, as illustrated in Fig. 2. For the agricultural or aquacultural use of excreta and wastewater to pose an actual risk to health, all of the following conditions must be satisfied:

1. either an infective dose of an excreted pathogen reaches the field or pond, or the pathogen multiplies in the field or pond to form an infective dose;
2. the infective dose reaches a human host;
3. the host becomes infected; and
4. the infection causes disease or further transmission.

The risk is merely a potential risk if condition (4) is not satisfied. The agricultural or aquacultural use of excreta or wastewater will be of public health importance only if it causes an excess incidence or prevalence of disease or intensity of infection.

Certain characteristics of a given pathogen will tend to increase the probable risk and public health importance of its transmission through wastewater reuse. These have been identified by Shuval et al. (20) as follows:

—persistence for long periods in the environment;
—long latent period or development stage;
—low infective dose;
—weak host immunity;
—minimal concurrent transmission through other routes, such as food, water and poor personal or domestic hygiene.

On this basis, the helminth infections in Categories III–V, caused by pathogens that are most persistent and have a long latent period and very low infectious doses, and to which host immunity is weak, can be expected to be among those posing the greatest actual risk from wastewater reuse. Where a significant amount of transmission occurs by other routes, as it often does with many of the faecal–oral infections (Categories I and II), a small amount of transmission due to wastewater reuse may be of relatively minor importance. The enteric virus diseases in Category II should be least effectively transmitted by wastewater use, despite the fact that they are
moderately persistent and have low infectious doses. Concurrent transmission in the home is generally so intense that most infants acquire permanent immunity in the first years of life, so that there is little likelihood of excess disease occurring as the result of additional exposure from wastewater reuse.

Current knowledge of the transmission of excreted pathogens thus suggests that helminth infection is the most important health risk and virus disease the least important, with bacterial and protozoal diseases falling between those two extremes. However, only epidemiological evidence can confirm the validity of this theoretical model.

6.5 Epidemiological evidence

Shuval et al. (6) have rigorously reviewed all the available epidemiological studies on the agricultural use of wastewater. Their principal conclusions can be summarized as follows:

(1) Crop irrigation with untreated wastewater causes significant excess infection with intestinal nematodes, where they are endemic, in both consumers (Fig. 3) and farm workers (Fig. 4); the latter, especially if they work in the fields barefoot, are likely to have the more intense infections, particularly of hookworms.

(2) Crop irrigation with treated wastewater does not lead to excess intestinal nematode infection among field workers or consumers.

(3) Cholera, and probably also typhoid, can be effectively transmitted by the irrigation of vegetables with untreated wastewater.

(4) Cattle grazing on pasture irrigated with raw wastewater may become infected with "Cysticercus bovis" (the larval stage of the beef tapeworm Taenia saginata); the actual risk of human infection is poorly documented but probably exists.

(5) There is only very limited evidence to show that, in communities with high standards of personal hygiene, the health of people living near fields irrigated with raw wastewater may be adversely affected either by direct contact with the soil, or indirectly through contact with farm labourers.

(6) Sprinkler irrigation with treated wastewater may promote the dispersion of small numbers of excreted viruses and bacteria in aerosols, but an actual risk of disease transmission by this route has not been detected.
From the epidemiological studies, it is clear that, when untreated wastewater is used for crop irrigation, intestinal nematodes and bacteria present high actual risks, and viruses little or no actual risk (Table 2). The actual risks due to protozoa are not yet well established, as insufficient epidemiological data are available, but no studies have shown that wastewater reuse causes an additional risk of protozoal infection. These general conclusions are thus in agreement with the theoretical model discussed in section 6.4.

Feachem et al. (7) have suggested that the potential health risks associated with the aquacultural use of excreta and wastewater are threefold:
Fig. 4. Prevalence of infections with hookworm and *Acaris* species in sewage-farm workers and control groups in various regions of India*

<table>
<thead>
<tr>
<th>% Positive</th>
<th>Sewage-farm workers n = 466</th>
<th>Controls n = 432</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hookworm</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Acaris</em></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Redrawn from reference 2 and based on data from reference 27; used with permission.

1. passive transference of excreted pathogens by fish and cultured aquatic macrophytes;
2. transmission of trematodes whose life cycles involve fish and aquatic macrophytes (principally *Clonorchis sinensis* and *Fasciolopsis buski*); and
3. transmission of schistosomiasis.

Blum & Feachem (22) have also reviewed the available epidemiological studies on excreta use in aquaculture. They found only one study in which the actual health risks associated with the passive transference of excreted pathogens were considered, but the results were inconclusive because of the epidemiological methodology employed. They found none dealing with occupational
Table 2. Relative health risks from use of untreated excreta and wastewater in agriculture and aquaculture

<table>
<thead>
<tr>
<th>Type of pathogen/infection</th>
<th>Excess frequency of infection or disease</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intestinal nematodes</td>
<td>High</td>
</tr>
<tr>
<td><em>Ascaris</em> spp</td>
<td></td>
</tr>
<tr>
<td><em>Trichuris</em> spp</td>
<td></td>
</tr>
<tr>
<td>Hookworms</td>
<td></td>
</tr>
<tr>
<td>Bacteria</td>
<td>Lower</td>
</tr>
<tr>
<td>Bacterial diarrhoeas</td>
<td></td>
</tr>
<tr>
<td>(e.g., cholera, typhoid)</td>
<td></td>
</tr>
<tr>
<td>Viruses</td>
<td>Lowest</td>
</tr>
<tr>
<td>Viral diarrhoeas</td>
<td></td>
</tr>
<tr>
<td>Hepatitis A</td>
<td></td>
</tr>
<tr>
<td>Trematodes and cestodes</td>
<td>From high to nil, depending upon the</td>
</tr>
<tr>
<td>Schistosomiasis</td>
<td>method of excreta use and local</td>
</tr>
<tr>
<td>Clonorchiasis</td>
<td>circumstances</td>
</tr>
<tr>
<td>Taeniasis</td>
<td></td>
</tr>
</tbody>
</table>

exposure leading to schistosomiasis. As far as trematode infections were concerned, they found that, while fertilization of ponds with excreta was important in the transmission of these diseases, so too was the faecal pollution of other local water bodies and ponds not deliberately fertilized with excreta. This is not an unexpected result, as the high degree of trematode multiplication in the snail host makes it possible for only slight and occasional contamination of surface water to give rise to relatively intense transmission.

7. HEALTH PROTECTION MEASURES IN WASTEWATER REUSE

7.1 Introduction

Four main measures can be taken to protect health in wastewater reuse, namely wastewater treatment, crop restriction, control of wastewater application, and exposure control and promotion of hygiene. Of these, wastewater treatment and crop restriction have been those most widely adopted in controlled reuse schemes. In the future, it is expected that a more integrated approach to planning will allow an optimal combination of measures to be selected, depending on the local sociocultural, institutional and economic conditions.

Conventional methods of wastewater treatment emphasize the reduction or removal of biochemical oxygen demand and suspended
solids, whereas treatment for reuse requires the removal of pathogens, such as helminths, for which conventional methods are not very effective. The engineer designing a wastewater-treatment plant for a reuse scheme needs to know to what degree excreted pathogens must be removed. A quality objective for treated wastewater, in terms of the maximum permissible concentration(s) of specified organisms, is therefore required for each reuse scheme. Appropriate design guidelines will make it possible to select the wastewater treatment technology and reuse management techniques which will reliably achieve the health protection necessary.

Wastewater of the required quality should be produced at all times by the treatment processes selected, without the need for continuous monitoring. Emphasis must therefore be placed on careful selection and design of treatment plants rather than on a high degree of care in operation. This is especially important in developing countries, where infrastructure is lacking and there is limited experience of operating wastewater-treatment plants, and where the simplest and cheapest technology will have the greatest chance of success.

7.2 Effluent quality guidelines for agriculture

Removal of pathogens is the prime objective in treating wastewater for reuse. However, as previously pointed out, wastewater quality guidelines and standards for reuse are often expressed in terms of the maximum permissible number of faecal coliform bacteria. Since the faecal origin of wastewater is not in question, the implication is that these faecal indicator organisms can be used as pathogen indicators, and that there is at least a semi-quantitative relationship between pathogen and indicator concentrations. In practice, faecal coliforms can be used as reasonably reliable indicators of bacterial pathogens, as their environmental survival characteristics and rates of removal or die-off in treatment processes are broadly similar. The “total coliform” group is less reliable as an indicator since not all coliforms are exclusively faecal in origin and, especially in warm climates, the proportion of non-faecal coliforms is often very high. Faecal coliforms are less satisfactory as indicators of excreted viruses and are of very limited use in relation to protozoa and helminths, for which no reliable indicators exist.
Standards or guidelines for the quality of wastewater to be used for unrestricted crop irrigation, including that of salad and vegetable crops eaten raw, have generally specified both explicit standards (e.g., maximum numbers of coliforms) and minimum treatment requirements (primary, secondary or tertiary) according to the class of crop to be irrigated (consumable or non-consumable). The standards developed over the past 50 years have tended to be very strict, as they were based on a theoretical evaluation of the potential health risks associated with pathogen survival in wastewater and soil and on crops, rather than on firm epidemiological evidence of actual risk. To some extent, those early standards were based on a "zero risk" concept, with the aim of achieving an "antiseptic" or pathogen-free environment. At that time, the method of choice for pathogen removal, as judged by coliform removal, was secondary biological treatment followed by carefully controlled effluent chlorination. Since this could, at least theoretically, achieve very low residual coliform concentrations, the maximum permissible number of coliforms was set correspondingly low. For example, the standards of the California State Department of Public Health (4) permit a total of only 23 or 2.2 coliforms per 100 ml, depending on the crop being irrigated and on the irrigation method.

In 1971, the WHO Meeting of Experts on the Reuse of Effluents (1) recognized that the extremely strict California standards for effluent reuse were not justified by the available epidemiological evidence and recommended a microbial guideline for the unrestricted irrigation of vegetables eaten cooked of not more than 100 total coliforms per 100 ml, which was in effect a significant liberalization. The Meeting felt that there was a need for wastewater irrigation guidelines to be given a sounder epidemiological basis, and recommended that this matter be fully investigated.

Since that time, major efforts have been made by WHO, the World Bank, the United Nations Development Programme, the United Nations Environment Programme, the International Development Research Centre, Canada, the International Reference Centre for Waste Disposal, Switzerland, the Food and Agriculture Organization of the United Nations, the US Environmental Protection Agency and many academic institutions throughout the world to provide a more rational epidemiological basis for wastewater irrigation guidelines.

Extensive new epidemiological evidence has been accumulated and earlier studies and reports have been evaluated. The findings of
these studies have been carefully reviewed by leading public health experts, environmental scientists and epidemiologists at meetings in Engelberg (2) and Adelboden (3) in 1985 and 1987, respectively, and at numerous national and international meetings and consultations. The consensus view of the epidemiologists and public health experts who have reviewed these data is that the actual risk associated with irrigation with treated wastewater is much lower than previously estimated and that the early microbial standards and guidelines for effluent to be used for unrestricted irrigation of vegetables and salad crops normally consumed uncooked were unjustifiably restrictive, particularly in respect of bacterial pathogens. The epidemiological evidence is summarized in this report; for more detailed information, readers are referred to the original reports by Shuval et al. (6) and Blum & Feachem (22) and to the Engelberg report (2).

On the basis of this new evidence, the Engelberg report recommended new guidelines containing less stringent standards for faecal coliforms than those previously suggested. However, they were stricter than previous standards in respect of numbers of helminth eggs, which were recognized to be the main actual public health risk associated with wastewater irrigation in those areas where helminthic diseases are endemic. The Engelberg recommendations were subsequently reviewed and confirmed at the Adelboden meeting. After consideration of this preparatory work and the epidemiological evidence currently available, the Scientific Group now recommends the guidelines shown in Table 3. These are based on the fact that in many developing countries the main actual health risks, as pointed out above, are associated with helminthic diseases and that the safe use of wastewater in agriculture or aquaculture will therefore require a high degree of helminth removal. Thus, these guidelines introduce a new, stricter approach concerning the need to reduce numbers of helminth eggs (Ascaris and Trichuris species and hookworms) in effluents to a level of one or less per litre. This means that some 99.9% of helminth eggs must be removed by appropriate treatment processes in areas where helminthic diseases are endemic and present actual health risks (field studies indicate that helminth concentrations are rarely greater than 1000 per litre, even in endemic areas). Stabilization ponds with a retention time of 8–10 days are particularly effective in achieving this but other technologies are also available. While not all helminths and protozoa of public health importance are referred to specifically in the guidelines (for example, Amoeba and Giardia species are not
Table 3. Recommended microbiological quality guidelines for wastewater use in agriculture

<table>
<thead>
<tr>
<th>Category</th>
<th>Reuse conditions</th>
<th>Exposed group</th>
<th>Intestinal nematodes* (arithmetic mean no. of eggs per litre*)</th>
<th>Faecal coliforms (geometric mean no. per 100 ml*)</th>
<th>Wastewater treatment expected to achieve the required microbiological quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Irrigation of crops likely to be eaten uncooked, sports fields, public parks*</td>
<td>Workers, consumers, public</td>
<td>( \leq 1 )</td>
<td>( \leq 1000 )</td>
<td>A series of stabilization ponds designed to achieve the microbiological quality indicated, or equivalent treatment</td>
</tr>
<tr>
<td>B</td>
<td>Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees*</td>
<td>Workers</td>
<td>( \leq 1 )</td>
<td>No standard recommended</td>
<td>Retention in stabilization ponds for 8-10 days or equivalent helminth and faecal coliform removal</td>
</tr>
<tr>
<td>C</td>
<td>Localized irrigation of crops in category B if exposure of workers and the public does not occur</td>
<td>None</td>
<td>Not applicable</td>
<td>Not applicable</td>
<td>Pretreatment as required by the irrigation technology, but not less than primary sedimentation</td>
</tr>
</tbody>
</table>

*In specific cases, local epidemiological, sociocultural and environmental factors should be taken into account, and the guidelines modified accordingly.

*AAscari and Trichuris species and hookworms.

*During the irrigation period.

*As a more stringent guideline (\( \leq 200 \) faecal coliforms per 100 ml) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact.

*In the case of fruit trees, irrigation should cease two weeks before fruit is picked, and no fruit should be picked off the ground. Sprinkler irrigation should not be used.

mentioned), the intestinal nematodes covered should serve as indicator organisms for all of the large settleable pathogens (including amoebic cysts); other pathogens of interest apparently become non-viable in long-retention pond systems. It is thus implied by the guidelines that all helminth eggs and protozoan cysts will be removed to the same extent.

Based on current epidemiological evidence, a *bacterial guideline* of a geometric mean of 1000 faecal coliforms per 100 ml for unrestricted irrigation of all crops is recommended. This is considered to be technologically feasible. The Group concluded that no bacterial guideline need be recommended in cases where farm workers are the only exposed population, since there is little or no evidence indicating a risk to such workers from bacteria;
nevertheless, some degree of reduction in bacterial concentration is desirable in wastewater used for any purpose.

The natural die-off of pathogens in the field constitutes a valuable additional safety factor in reducing potential health risks. Pathogen inactivation by ultraviolet irradiation, by desiccation and by natural biological predators when effluent is applied to crops and soil can often provide an additional 90–99% reduction of pathogens within a few days after application. In addition to this important factor, field and laboratory studies which indicated that wastewater effluent with 1000 faecal coliforms per 100 ml contained few, if any, detectable pathogens were taken into account by the Scientific Group in formulating the guidelines.

The new bacterial guidelines are in line with the actual quality of river water used for the unrestricted irrigation of all crops in many countries without known ill effects. Table 4 shows typical faecal coliform concentrations in rivers throughout the world, based on data gathered from 1979 to 1984; in about 45% of the rivers, such concentrations were 1000 per 100 ml or greater, while nearly 15% had faecal coliform levels of 10 000 per 100 ml or more. Waters from such rivers are widely used outside the USA for irrigation, without any legislative restrictions on their use. In the USA, the US Environmental Protection Agency, together with the US Academy of Sciences, recommended in 1973 that the acceptable guideline for irrigation with natural surface water, including river water, be set at 1000 total coliforms per 100 ml (24).

The Scientific Group also compared earlier wastewater irrigation standards and guidelines for the irrigation of vegetables eaten raw (2.2–100 total coliforms per 100 ml) with existing microbial
guidelines and standards for bathing-water quality developed by the Mediterranean Pollution Monitoring and Research Programme of the United Nations Environment Programme and WHO (1000 faecal coliforms per 100 ml, 25) and by the European Economic Community (less than 10 000 total coliforms per 100 ml and less than 2000 faecal coliforms per 100 ml, 26). Finally, the Group concluded that it was not reasonable or rational to retain the earlier wastewater irrigation guidelines, which were close to those for drinking-water, when health authorities consider natural river waters used for irrigation and waters used for bathing to be acceptable with faecal coliform concentrations of 1000 per 100 ml and more.

The irrational application of unjustifiably strict microbial standards for wastewater used for irrigation has undoubtedly led to some anomalous situations. Standards are often not enforced and serious public health problems have resulted from totally unregulated, and often illegal, irrigation of salad crops with raw wastewater, as widely practised in many developing countries. The recommended approach now calls for the introduction of realistic revised national standards which are strict for helminth egg removal but less so with regard to allowable bacterial levels. The Group considered that this new approach would increase public health protection for a greater number of people while at the same time setting targets which were both technologically and economically feasible.

The guideline values given in Table 3, however, must be carefully interpreted and, if necessary, modified in the light of local epidemiological, sociocultural and environmental factors. Greater caution may be justified where there are significant exposed groups that are more susceptible to infection than the population at large, such as people lacking immunity to the local endemic infections. On the other hand, some degree of flexibility may sometimes be justified. For example, where intestinal helminths are not endemic, an egg removal efficiency of 99.9% is not necessary. Edible crops such as tomatoes for canning and peanuts for roasting might also be properly considered as industrial crops, and sports fields which will not be used for many weeks after irrigation might be regarded as belonging to Category B.

Where members of the public have direct access to lawns and parks which are irrigated with treated wastewater, the potential public health risk may then be greater than that associated with the
irrigation of vegetables eaten raw. The Scientific Group took note of the epidemiological investigation of the health effects of landscape irrigation with reclaimed wastewater at Colorado Springs (27), which indicated that people who visited parks irrigated with non-potable water derived from wastewater did not report gastrointestinal symptoms with greater relative frequency than those who visited parks irrigated with either potable or non-potable water of runoff origin. Nevertheless, an effluent standard for park lawn irrigation of 200 faecal coliforms per 100 ml was recommended in the report of the study (27), and the Scientific Group felt that it would be prudent to accept this more stringent guideline for public lawns. This bacteriological effluent guideline can normally be achieved only by means of secondary biological treatment (ponds or conventional treatment) followed by effective disinfection. Additional treatment would be required for helminth egg removal, if relevant.

The helminth egg guideline value in Table 3 is intended as a design goal for wastewater treatment systems, and not as a standard requiring routine testing of effluent quality. The most sensitive techniques currently available for the detection of helminth eggs in wastewater are able to detect a minimum of the order of one egg per litre. However, these are not practicable for field monitoring purposes, for which the procedures described in Annex 2 (capable of detecting of the order of 10 eggs per litre) are more suitable. These procedures are designed to detect eggs of *Ascaris* and *Trichuris* species, the absence of which can be used in most circumstances as an indication of effective helminth removal. However, in regions where the prevalence of these parasites is so low that their eggs are outnumbered by hookworm eggs in raw sewage, procedures for the detection of hookworm eggs should be used instead.

7.3 Effluent quality guidelines for aquaculture

A number of infections caused by excreted pathogens are of concern in connection with waste-fed aquaculture. Aquatic snails are intermediate hosts of several helminth parasites, including *Schistosoma* species. Transmission can occur when people wade in fish-ponds in which infected snails are present, and the larval schistosome penetrates the human skin. Certain species of fish are the secondary intermediate hosts of several helminth parasites, for example *Clonorchis* species (liver fluke). Transmission can occur
when fish are eaten raw or undercooked, and the cysts in the fish flesh hatch out in the human gut. With some helminth infections, cysts are formed on edible aquatic plants (for example, *Fasciolopsis* species encyst on water caltrop), and transmission can occur when the fruit of the plant is eaten. Fish grown in excreta-fertilized or wastewater ponds may also become contaminated with bacteria and viruses. These are passively carried on the scales, or in the gills, intraperitoneal fluid, digestive tract or muscle of the fish. If fish are eaten raw or undercooked, transmission of bacterial or viral infections may then occur.

Strauss (18) reviewed the literature on the survival of pathogens in and on fish and concluded that:

1. Invasion of fish muscle by bacteria is very likely to occur when the fish are grown in ponds containing concentrations of faecal coliforms and salmonellae greater than $10^4$ and $10^3$ per 100 ml, respectively, the potential for muscle invasion increasing with the duration of exposure of the fish to the contaminated water.

2. Some evidence suggests that there is little accumulation of enteric organisms and pathogens on, or penetration into, edible fish tissue when the faecal coliform concentration in the fish-pond water is below $10^3$ per 100 ml (28).

3. Even at lower contamination levels, high pathogen concentrations may be present in the digestive tract and the intraperitoneal fluid of the fish.

There are, in general, only limited experimental and field data on the health effects of sewage-fertilized aquaculture. Further work is needed, therefore, before a definitive bacteriological quality standard can be established for pisciculture. A tentative *bacterial guideline* of a geometric mean number of faecal coliforms of $\leq 10^3$ per 100 ml is recommended for fish-pond water. In view of the dilution of wastewater which occurs in most fish-ponds, this ambient bacterial indicator concentration can normally be achieved by treating the wastewater feed water so as to give a level of $10^3$–$10^4$ faecal coliforms per 100 ml. The same faecal coliform standard should be applied to pond water in which aquatic vegetables (macrophytes) are grown, because they are eaten raw in some areas.

This bacterial guideline, which is based on the present state of knowledge regarding wastewater use in aquaculture, should ensure that invasion of fish muscle is prevented. However, research to date shows that pathogens may accumulate in the digestive tract and
intraperitoneal fluid of fish. These pathogens may then pose a risk through cross-contamination of the fish flesh or other edible parts and transmission to consumers if standards of hygiene in fish preparation are inadequate. A further necessary public health measure, therefore, is to ensure that high standards of hygiene are maintained during fish handling and especially gutting. This is easier to achieve in commercial operations than in subsistence aquaculture, for which sustained health education programmes will often be required. Cooking of fish, which is a common practice in many areas where waste-fed aquaculture exists, is an important health safeguard.

Transmission of the helminth infections clonorchiasis and fasciolopsiasis is known to occur only in restricted geographical areas in eastern Asia. Given the cultural preference in some of these areas for eating fish and aquatic vegetables uncooked, transmission can be prevented only by ensuring that no eggs enter the pond or by snail control. The latter is unlikely to be achieved at all times in practice, especially in the small subsistence ponds common in Asia, so that the only feasible means of control is to remove all viable trematode eggs from the wastewater before it enters ponds. All eggs must be rendered non-viable because the parasites multiply asexually on an enormous scale within their first intermediate host. Similar considerations apply to the control of schistosomiasis, a disease that is endemic over a much wider geographical area. The appropriate helminth quality guideline for all aquacultural use of wastewater is thus the absence of viable trematode eggs. This is readily achieved by stabilization pond treatment.

7.4 Wastewater treatment

The degree of removal of microbiological constituents of wastewater by a treatment process is best expressed in terms of \( \log_{10} \) units (e.g., a reduction of 4 \( \log_{10} \) units = \( 10^{-4} = 99.99\% \) removal). To achieve the recommended guideline quality for unrestricted irrigation, a reduction in the bacterial concentration of at least 4 \( \log_{10} \) units and in the helminth egg concentration of 3 \( \log_{10} \) units is required in treating typical municipal wastewater. Helminth egg removal alone will be sufficient to protect field workers from helminth infection, but occupational protection measures should nevertheless still be applied. A lesser degree of removal can be accepted if other health protection measures are envisaged, or if the
quality of the wastewater will be further improved after treatment, whether by dilution in naturally occurring waters, by prolonged storage, or by transport over long distances in a river or canal.

Conventional processes (plain sedimentation, production of activated sludge, and use of biological filters, aerated lagoons and oxidation ditches),\(^1\) unless supplemented by disinfection, are not able to produce an effluent which complies with the recommended bacterial guideline of \(\leq 1000\) faecal coliforms per 100 ml for Category A irrigation. Moreover, conventional wastewater treatment systems are not generally effective in removing helminth eggs and have little effect on chemical contaminants in wastewater. Table 5 shows the expected efficiencies of removal of the major microbiological pathogens in various wastewater treatment processes.

Waste stabilization ponds are usually the method of wastewater treatment of choice in warm climates wherever land is available at reasonable cost. A series of ponds with a total retention time of 8–10 days can be designed to achieve adequate helminth removal, but at least twice that time is usually required in a hot climate to reduce bacterial numbers to the guideline level. The presence of free-living nematode larval stages, sometimes in large numbers, in stabilization pond effluents is of no public health significance because they are not pathogenic to human beings. A series of ponds can be relied upon to meet the recommended guidelines, as indicated in Table 6, but this is only one of the many advantages of such systems. A manual on stabilization ponds recently published by WHO (29) provides advice on planning, design and maintenance and emphasizes their low cost and simplicity of operation. The only disadvantage of pond systems is the relatively large area of land that they require, but this is sometimes overemphasized. In addition, land on the outskirts of a growing city can be a worthwhile investment. For any particular

\(^1\) Sedimentation is the process whereby the suspended solids in sewage are allowed to settle out under gravity. In the activated-sludge process, settled sewage is led into an aeration tank where oxygen is supplied either by mechanical agitation or by diffused aeration. The bacteria that grow in this medium, together with other solids, are removed in a secondary sedimentation tank and recycled to the aeration tank inlet. This creates a high concentration of biologically active flocs in the aeration tank. In biofiltration, also known as trickling filtration, the wastewater trickles through a well ventilated bed of coarse material. An aerated lagoon is an adaptation of the waste stabilization pond in which oxygen is added by mechanical aerators. An oxidation ditch is a channel in which the wastewater circulates and is aerated by a large rotor.
Table 5. Expected removal of excreted microorganisms in various wastewater systems

<table>
<thead>
<tr>
<th>Treatment process</th>
<th>Removal (log$_{10}$ units) of</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bacteria</td>
</tr>
<tr>
<td>Primary sedimentation</td>
<td></td>
</tr>
<tr>
<td>Plain</td>
<td>0–1</td>
</tr>
<tr>
<td>Chemically assisted*</td>
<td>1–2</td>
</tr>
<tr>
<td>Activated sludge*</td>
<td>0–2</td>
</tr>
<tr>
<td>Biofiltration*</td>
<td>0–2</td>
</tr>
<tr>
<td>Aerated lagoon*</td>
<td>1–2</td>
</tr>
<tr>
<td>Oxidation ditch*</td>
<td>1–2</td>
</tr>
<tr>
<td>Disinfection*</td>
<td>2–6*</td>
</tr>
<tr>
<td>Waste stabilization ponds*</td>
<td>1–6*</td>
</tr>
<tr>
<td>Effluent storage reservoirs*</td>
<td>1–6*</td>
</tr>
</tbody>
</table>

* Source: reference 3.
+ Further research is needed to confirm performance.
* Including secondary sedimentation.
* Including settling pond.
* Performance depends on number of ponds in series and other environmental factors.
* Performance depends on retention time, which varies with demand.
* With good design and proper operation the recommended guidelines are achievable.

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Table 6. Reported effluent quality for several series of waste stabilization ponds

<table>
<thead>
<tr>
<th>Location</th>
<th>No. of ponds in series</th>
<th>Retention time (days)</th>
<th>Effluent quality (No. of faecal coliforms per 100 ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia (Melbourne)</td>
<td>8–11</td>
<td>30–70</td>
<td>100</td>
</tr>
<tr>
<td>Brazil (Campina Grande)*</td>
<td>4</td>
<td>23</td>
<td>450</td>
</tr>
<tr>
<td>France (Cogolin)</td>
<td>3</td>
<td>30</td>
<td>100</td>
</tr>
<tr>
<td>Jordan (Amman)</td>
<td>10</td>
<td>42</td>
<td>30</td>
</tr>
<tr>
<td>Peru (Lima)</td>
<td>5</td>
<td>38</td>
<td>100</td>
</tr>
</tbody>
</table>

* Experimental Centre for Biological Treatment of Wastewater (Extrases).

location, the life-time costs of the various alternative treatment systems must be carefully calculated and compared (30).

Disinfection—usually chlorination—of raw sewage has never been completely successful in practice. It can be used to reduce the numbers of excreted bacteria in the effluent from a conventional treatment plant if the plant is operating well. However, it is extremely difficult and costly to maintain a high, uniform and predictable level of disinfecting efficiency. In any case, chlorination
will leave helminth eggs totally unaffected. Whenever the guideline effluent quality can be achieved reliably by treatment in a well designed stabilization pond or wastewater storage reservoir without chlorination, then disinfection is not necessary and cannot be justified.

Tertiary treatment is sometimes used to upgrade effluents from secondary biological treatment where they are to be used in agriculture and aquaculture. Rapid sand filtration has been employed in several countries for this purpose, mainly to accomplish further removal of suspended solids and nutrients and to reduce biochemical oxygen demand, but little is known about its ability to remove pathogenic microorganisms. Experience with its use for drinking-water treatment suggests that reduction in the concentration of bacteria and viruses might only be nominal. However, removal of helminth eggs in a well functioning filter plant can be expected to be substantial. More research is needed to determine the actual performance of rapid sand filtration in helminth egg removal and to provide design guidelines for its use in the tertiary treatment of wastewater.

A more appropriate tertiary treatment option is to add one or more ponds in series to a conventional treatment plant. The addition of such "polishing" ponds is a suitable means of upgrading an existing wastewater-treatment plant so that the effluent can be used for the irrigation of agricultural crops or greenspaces and in aquaculture.

In operating wastewater-treatment plants, the agency responsible will wish to ensure that the plants are producing effluent of the quality expected and will therefore introduce appropriate monitoring procedures. When conventional primary, secondary and tertiary treatment technology has been selected, the performance of the unit processes can fluctuate considerably from day to day, even with skilled operation, so that continuous monitoring will be required to determine whether the effluent is complying with the guidelines. On the other hand, the performance of a properly designed series of stabilization ponds will not vary in this way, and a less rigorous and less costly monitoring procedure can therefore be adopted.

The Scientific Group recognized that raw sewage application is still widely used in some developing countries as a reuse or disposal method. This has not been achieved without a high cost to public health and, in particular, to the health of agricultural workers.
Nevertheless, in special cases and under strictly controlled conditions, raw sewage has been used at minimum risk. The Group did not consider raw sewage application to be an acceptable practice because of its potential danger to public health. It was accepted, however, that under special circumstances, e.g., in arid zones, disposal of raw sewage by land application in areas not easily accessible to the public is preferable to other raw sewage discharge practices. This method of disposal may therefore be tolerated until an affordable improved method satisfying environmental and public health requirements can be introduced.

7.5 Sludge from wastewater treatment

Most wastewater treatment processes produce sludge as a by-product which is often disposed of by land application, burial, incineration or dumping at sea. Sludge from wastewater treatment is valuable both as a source of plant nutrients and as a soil conditioner, and can itself be used in agriculture or to fertilize aquaculture ponds. Detailed consideration of such reuse of sludge is outside the scope of this report but the Scientific Group agreed that it should be encouraged where it can be carried out with adequate health safeguards.

Wastewater treatment processes which remove helminth eggs by sedimentation will concentrate them in the sludge, where they may remain viable for up to a year. All other pathogens present in the wastewater will also be concentrated in the sludge (H). To render a sludge containing helminth eggs safe for general use, it must be stored for an extended period (for example, sun-dried for 6–12 months in areas with a hot climate) or subjected to some form of treatment which raises the temperature sufficiently to kill the eggs, and particularly those of *Ascaris* species, which are the most persistent of all the faecal pathogens found in sludge.

Since sludge typically contains over 90% water, and a temperature of at least 55°C is required for pathogen inactivation, heat treatment using an external source of energy is expensive. Fortunately, the exothermic activity of bacteria already present in the sludge can be harnessed to produce the necessary heat relatively cheaply. This can be done by composting the sludge aerobically with municipal solid waste or some other organic bulking agent (31). The composting process will generate enough heat only if it can be kept sufficiently aerobic by means of some form of aeration. In windrow
composting, frequent turning of the pile of compost aerates it but the heated parts of the pile can be recontaminated to some extent by material from the cooler sections on the outside. In another method, using forced aeration, a small fan is used to blow air into (or draw air out from) a set of pierced distribution pipes at the base of the pile for a few minutes every hour.

Just as treatment of wastewater is one of several possible health protection measures, sludge treatment can be combined with or replaced by other means of preventing its reuse from giving rise to the transmission of infectious diseases. Health safeguards in the reuse of sludge are further described by Mara & Cairncross (3).

Sludge from the treatment of wastewater containing a significant proportion of industrial wastes in which certain chemical substances, such as heavy metals, are present is also likely to contain these substances in concentrations high enough for them to be toxic to plants and man. Detailed information on the health aspects of the use of such sludge for land application has been published (32).

7.6 Crop selection

Wastewater of a high microbiological quality is needed for the irrigation of certain crops, especially vegetable crops eaten raw, but a lower quality is acceptable for other, selected crops, where there is no exposure of the public (see Table 3, page 39). Crops can be categorized according to the exposed group and the degree to which health protection measures are required, as follows:

Category A. Protection required for consumers, agricultural workers, and the general public.
This includes crops likely to be eaten uncooked, spray-irrigated fruits, and grass (sports fields, public parks and lawns).

Category B. Protection required for agricultural workers only.
This includes cereal crops, industrial crops (such as cotton and sisal), food crops for canning, fodder crops, pasture and trees. In certain circumstances some vegetable crops might be considered as belonging to Category B if they are not eaten raw (potatoes, for instance) or if they grow well above the ground (for example, chillies). In such cases it is necessary to ensure that the crop is not contaminated by sprinkler irrigation or by falling on to the ground, and that
contamination of kitchens by such crops, before cooking, does not give rise to a health risk.

Limitation of crops to those in Category B will be referred to here as crop restriction. This will protect consumers but not farm workers and their families. Crop restriction is therefore not adequate on its own; it should be complemented by other measures, such as partial treatment and controlled application of wastewater or human exposure control. Partial treatment to comply with the recommended quality guideline for Category B (Table 3) would be sufficient to protect field workers in most settings and would be cheaper than full treatment.

Crop restriction is feasible particularly under conditions where:

— a law-abiding society exists or the law is strictly enforced;
— a public body controls the allocation of wastes;
— an irrigation project has a strong central management;
— there is adequate demand for the crops allowed under crop restriction, and they fetch a reasonable price;
— there is little market pressure in favour of excluded crops (i.e., those in Category A).

Health risk minimization through crop restriction is not as straightforward in the case of aquaculture as it is for agriculture. While fish and aquatic vegetables are cooked before eating in most areas, they are eaten raw in some places where avoidance of the use of excreta or wastewater for food crops is often not feasible, especially in small-scale subsistence aquaculture. A promising approach appears to be that of growing fish, such as *Tilapia* species, in wastewater ponds for the production of fishmeal for animal feed or for feeding to high-value fish (such as catfish and snakeheads) or crustaceans (shrimps, crayfish) reared in freshwater ponds.

Adopting crop restriction as a means of health protection in reuse schemes will require a strong institutional framework and the capacity to monitor and control compliance with regulations and to enforce them. Farmers must be advised why such crop restriction is necessary and be assisted in developing a balanced mix of crops which makes full use of the partially treated wastewater available. They may also need assistance with marketing. National agricultural planning should take into account the crop production potential of restricted reuse schemes so that production of surpluses is avoided.
7.7 Wastewater application

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

(1) by flooding (border irrigation): almost all the land surface is wetted;
(2) by means of furrows: only part of the ground surface is wetted;
(3) by means of sprinklers: the soil and crops are wetted in much the same way as they are by rainfall;
(4) by subsurface irrigation: the surface is only slightly wetted, if at all, but the subsoil is saturated; and
(5) by means of localized (trickle, drip or bubbler) irrigation: water is applied to the root zone of each individual plant at an adjustable rate.

Flooding involves the least investment, but probably exposes field workers to the greatest risk. Sprinkler irrigation should not be used on vegetables and fruit unless the effluent meets the guideline for Category A conditions, and flood irrigation should not be used for vegetables. Subsurface or localized irrigation, particularly when the soil surface is covered with plastic sheeting (mulch), can give the greatest degree of health protection, besides using water more efficiently and often producing higher yields. However, it is expensive, and reliable, high-level treatment of the water (to remove suspended solids) is required in order to prevent clogging of the small holes (emitters) through which water is slowly released into the soil. Bubbler irrigation, a technique developed for the localized irrigation of tree crops, avoids the need for small emitter apertures to regulate the flow to each tree (33).

In the operation of aquaculture systems, keeping fish in clean water for a period of time prior to harvest and sale will remove or reduce any residual objectionable odours and reduce the degree of contamination with faecal microorganisms. However, this procedure does not guarantee complete removal of pathogens from fish tissues and digestive tracts, unless contamination is slight.

7.8 Human exposure control

Four groups of people can be identified as being at potential risk from the agricultural use of wastewater and excreta, namely:
(1) agricultural field workers and their families;
(2) crop handlers;
(3) consumers (of crops, meat and milk);
(4) those living near the fields concerned.

Different methods of human exposure control may be used for each of these population groups. The aim is either to prevent them from coming into direct contact with the pathogens in the wastes, or to prevent any contact with the pathogens from leading to disease.

Measures to protect agricultural field workers and crop handlers include the wearing of protective clothing (to prevent contact with pathogens), maintaining high levels of hygiene (to remove any pathogens present), and possibly immunization against, or chemotherapeutic control of, selected infections as a temporary palliative measure (to prevent infection leading to disease). For example, the exposure of agricultural field workers to hookworm infection can be reduced by the continuous in-field use of appropriate footwear, but this may be difficult to achieve in areas where it is normal to work barefoot. Immunization against helminthic infections or most diarrhoeal diseases is not feasible, but immunization of highly exposed groups against typhoid and hepatitis A may be worth considering. Additional health protection measures include the provision of adequate medical facilities to treat diarrhoeal disease, regular chemotherapy for intense nematode infections in children, and the control of anaemia. Chemotherapy and immunization do not constitute an adequate health protection strategy, but could be beneficial as a temporary palliative measure.

In both agricultural and aquacultural reuse schemes, risks to consumers can be reduced by thorough cooking of the food before consumption and by high standards of hygiene. Food hygiene should therefore be given sufficient emphasis in health education campaigns. Changes in consumer behaviour and improvements in cooking and personal hygiene practices are, however, difficult to achieve, and this strategy alone may have only limited effectiveness in controlling the ill effects of wastewater irrigation. Tapeworm transmission can be prevented by meat inspection.

Local residents should be kept fully informed about the location of all fields where wastewaters are used, so that they may avoid entering them and also prevent their children from doing so. There is no evidence that those living near wastewater-irrigated fields are at significant risk from sprinkler irrigation schemes. However,
sprinklers should not be used within 50–100 m of houses or roads so as to avoid any risk of wetting passers-by.

Special care is needed to ensure that workers, residents and visitors do not use wastewater for drinking or domestic purposes by accident or for lack of an alternative. The provision of adequate potable water supplies is thus an essential exposure control measure, and all wastewater channels, pipes and outlets must be clearly marked as such and preferably painted a characteristic colour. Outlet fittings of a type designed to prevent misuse should be employed.

In aquaculture systems, schistosomiasis is best controlled by wastewater treatment and snail control, although regular chemotherapy would be beneficial in endemic areas. Local residents should be informed which ponds are fertilized with wastes. Water supply and sanitation services, which reduce the need for contact with pond water, are also important in human exposure control.

7.9 Integrating the various measures

It will often be desirable to use a combination of several of the health protection measures. For example, crop restriction may be sufficient to protect consumers, but will need to be supplemented by additional measures to protect agricultural workers. Partial treatment of wastewater to a quality standard less demanding than that recommended in Table 3 may sometimes be sufficient if combined with other measures. The concept is illustrated in a schematic and simplified way in Fig. 5, which is based on the assumption that each of the protection measures shown functions effectively.

The five concentric bands in Fig. 5 represent steps on the pathway from the waste itself to the human consumer or worker. Pathogens “flow” towards the centre, and the thick black circle represents a barrier beyond which they should not pass if health is to be protected. The level of contamination (of wastewater, field or crop) or the level of risk (to consumer or worker) is shown by the intensity of shading. A white area in the centre indicates a presumed absence of risk to human health and therefore indicates that the strategy leads to the “safe” use of wastewater.

If no protective measures are taken, there is a high risk to both workers and consumers; when crop restriction (regime A) is introduced, consumers are “safe” whereas workers are still at high
risk. Carefully selected wastewater application measures, such as localized irrigation (regime B), prevent any contamination from reaching the crop or the workers, and the health of both consumers and workers is protected. Human exposure control (regime C) at best prevents some contamination from reaching consumers and workers but, since full compliance with the recommended measures is rarely achieved in practice, a reduced level of risk to both groups remains. Partial treatment of wastes (regime D) reduces the level of
contamination but the extent of this reduction varies, depending on the type of treatment used. Treatment in waste stabilization ponds for about 8–10 days (or an equivalent partial treatment) (D-I) removes helminth eggs sufficiently to protect the health of agricultural workers and consumers, but bacterial removal is sufficient only to reduce, not eliminate, the risk to consumers of vegetable crops. Conventional secondary treatment (D-II) does not guarantee sufficient helminth egg removal, and a reduced level of risk remains for both workers and consumers. Full treatment (in accordance with the guideline for Category A in Table 3) provides full protection to both consumers and agricultural workers (regime H).

Three examples of combinations of protection measures are shown. When partial treatment is combined with crop restriction, both consumers and workers are “safe” when stabilization pond treatment (E-I) is used, but workers remain at reduced risk when conventional secondary treatment is used (E-II). Human exposure control added to partial treatment (regime F) should protect the health of workers (although neither measure on its own necessarily gives full protection) but is likely to leave consumers at a reduced risk. Where no treatment can be given, crop restriction combined with human exposure control (regime G) can considerably reduce the risk to workers and protect the consumer.

Fig. 5 shows three regimes where the health of both workers and consumers is fully protected and several others where health risks are much reduced although complete “safety” has not been achieved. Measures providing partial protection could be used as part of a gradual approach to reducing health risks until it is possible to introduce a regime providing full protection.

The feasibility and efficacy of any combination of measures will depend on many factors, which must be carefully considered before any action is taken. These will include the following:

— the availability of resources (institutions, staff, funds, land);
— existing social and agricultural practices;
— existing patterns of excreta-related diseases.

In some situations, economic and technical factors may make it impossible to adopt the “blanket” approach of full treatment of all wastes to protect all potential workers and consumers. In such a situation, cultural factors (for example, the type of staple food crops), a strong institutional structure and the availability of the necessary personnel could create good conditions for the
enforcement of crop restriction, together with either human exposure control or partial treatment of the wastes. This would be a more “targeted” approach, focusing the resources available on protecting the exposed populations.

The most suitable health protection measures for aquaculture include wastewater treatment (full or partial), human exposure control and, in some cases, fish selection. An alternative to full treatment is the combination of partial wastewater treatment with measures for human exposure control so as to protect both workers and consumers. Human exposure control might include the wearing of protective clothing and increased levels of hygiene for workers, and the thorough cooking of fish and aquatic vegetables to protect consumers. It is not yet clear whether complete health protection is achieved in practice using this approach. Fish selection is not considered to be an effective health protection measure unless the fish species chosen is to provide animal or fish feed and not to be eaten directly by humans.

8. PLANNING AND IMPLEMENTING HEALTH SAFEGUARDS

8.1 Institutional framework

The incorporation of wastewater reuse planning into national water resource and agricultural planning is important, especially where water shortages exist, not only to protect water quality but also to minimize wastewater treatment costs, safeguard public health and obtain the maximum agricultural and aquacultural benefits from the nutrients which wastewater contains. Reuse of wastewater touches on the responsibilities of several ministries and government agencies, and the active involvement of the ministries of health, agriculture and public works (or their equivalents) is essential at the national and, where appropriate, the state or regional level, if the potential benefits are to be achieved without endangering health. In view of the number of government agencies likely to be concerned with reuse schemes, cooperation among them will be strengthened by the establishment of an interagency committee responsible for:

—developing a coherent national or regional policy for wastewater reuse and monitoring its implementation;
—defining the division of responsibilities between the respective ministries and agencies involved and the arrangements for collaboration between them;
—appraising proposed reuse schemes, particularly from the point of view of public health and environmental protection;
—overseeing the promotion and enforcement of national legislation and codes of practice; and
—developing a rational staff development policy for the sector.

A separate agency has been established in some countries, at national or state level, not only to take on responsibilities for wastewater reuse planning but also to manage the sector. Whichever form of institutional framework is adopted, and no universally applicable model exists, it will be responsible for ensuring that the policies adopted are put into practice.

At the project level, the organizational structure of a scheme for wastewater reuse will be determined by the existing institutions and land use pattern. Health protection measures are easier to implement effectively when the project is run as a single unit, by a private company (as in Kuwait), a cooperative or a public agency. However, where the land is already farmed by smallholders it will be difficult to change this pattern and some form of users' association and joint management board will be essential if health protection measures are to be implemented. Quite often, the body managing a reuse scheme, either by running the entire agricultural or aquacultural project or by distributing treated wastewater to individual farmers or fishermen, will not be the agency responsible for collecting and treating the wastewater. It is common practice for permits to be issued for the use of the wastewater and for their renewal to be made conditional on the adoption of sanitary practices in wastewater application and on the observance of crop restriction rules, where these exist.

The responsible agency will generally deal with farmers or pond owners through users' associations, to which will be delegated the task of enforcing regulations. The agency will also have the important task of providing services to the users, including advice on and assistance with farm machinery, the supply of materials and equipment, agricultural credit, agricultural advisory services and training, marketing services and primary health care.
8.2 Legislation

In countries where uncontrolled wastewater reuse exists and there is a need to improve current practices, it will be useful to study the existing relevant legislation and regulations. It is important to understand why such regulations, if they exist, are in some cases not being enforced since it is clear that, if the causes of failure to enforce them are not removed, future legislation is likely to be equally unsuccessful. There may be a general consensus, rightly or wrongly, that there is no serious health risk or that to enforce the regulations will not significantly reduce it. Alternatively, there may be a lack of knowledge of means of reducing health risks, other than those which would adversely affect the farmers’ or pond owners’ income. If health risks exist, priority should be given to motivating staff responsible for the enforcement of regulations by educating them about such risks and training them in the measures which can be taken to protect public health. The use of inappropriate and excessively strict wastewater quality standards borrowed from other countries has caused regulations to be ignored and raw wastewater to be used without health protection measures in some countries, and wastewater reuse to be discouraged in others.

The standards adopted to safeguard public health must be realistic in relation to local conditions; the principles and guidelines recommended in this report can be modified to take account of local epidemiological, sociocultural and environmental factors to enable countries to develop rational legislation to control wastewater reuse. In countries where new legislation to govern the development of wastewater reuse is needed, or where existing legislation requires modification, the following matters should be considered:

— the establishment of new institutions or the assignment of new responsibilities to existing agencies;
— the roles of, and relationships between, national and local government agencies with responsibilities in the sector;
— rights of access to and ownership of wastewaters, including public regulation of their use;
— land tenure; and
— public health and agricultural legislation, including wastewater quality standards, provisions governing crop restriction, wastewater application control, occupational health and food hygiene.
It is easier to introduce new legislation than to enforce it and, in drafting new regulations, countries should make provisions for the necessary staff and resources to monitor and enforce compliance. The Scientific Group urged Member States to revise their existing legislation in the light of the new guidelines recommended in this report.

8.3 Improving existing practices in wastewater reuse

In recommending wastewater quality guidelines for agriculture (Table 3) and aquaculture (section 7.3), the Scientific Group recognized that they might be implemented in stages and not necessarily all at once. Before any attempt is made to improve existing practices, however, it is essential to find out what they are; a thorough field survey of how wastewater is being used and tactful informal conversations with farmers, pond owners, local officials and interested local bodies are invaluable in looking for the way forward. Thereafter, appropriate institutions and legislation can be developed to allow the different measures for public health protection to be introduced in a balanced and integrated way in upgrading reuse schemes.

The first health protection measure, wastewater treatment, will not be technically difficult to implement if finance is available. However, land is not always readily available in urban areas, particularly for stabilization ponds, which are likely to be the preferred choice for reuse schemes. The treatment of raw municipal wastewater will also usually require substantial capital investment, even for stabilization ponds. However, existing wastewater-treatment plants that are not performing satisfactorily from the point of view of effluent reuse can often be upgraded relatively cheaply. One possible method of treatment where raw wastewater is being used in aquaculture is to connect the ponds in series and to use the first purely as a treatment device, without fish production. This will often not be possible unless fish-pond owners agree to cooperate in using the system in this way.

Crop restriction is easiest to implement when the reuse scheme, or at least the distribution of the wastewater, is centrally managed under government control. The enforcement of crop restriction where there are a large number of small farmers or fish-pond owners can be difficult, though not impossible. If there is no local experience with crop restriction, its feasibility should be tested in a trial area.
before it is implemented on a large scale. Assistance with marketing and credit facilities will have to be provided to farmers and fish-pond owners. Crop restriction has been enforced in Mexico for many years and the publication produced after the Adelboden Meeting (3) includes a list of requirements for a comprehensive programme to ensure compliance with the regulations governing it.

The need for a change in the method of wastewater application to land, so as to reduce health risks, is greatest when the existing irrigation practice is flooding. Farmers may need help in preparing the land to allow other irrigation methods to be adopted. Factors which might persuade them to use other methods include the greater efficiency of water use with other irrigation techniques when limited quantities of effluent are available, and reduced mosquito nuisance. Crop restriction may also require or allow a change in irrigation method. Subsurface or localized (drip, trickle or bubbler) irrigation can give a high degree of protection against contamination, besides using water more efficiently and often producing higher yields. The ability to deliver low-grade effluent through irrigation devices, particularly subsurface systems, will be a major factor in promoting this approach to public health protection.

Measures to control human exposure include those for agricultural or aquacultural workers and those for the public. Reducing exposure to diarrhoeal diseases generally, e.g., by providing adequate supplies of clean water and good sanitation, and promoting good case management are well known components of primary health care. Care is also required to ensure that the use of wastewater does not cause contamination of nearby sources of drinking-water. Local residents are best placed to ensure that their health is not put at risk once it has been explained to them what precautions are required. A residents' health committee can be a focus for a health education campaign, which should stress ways of avoiding contact with pathogens in wastewaters and suggest improved hygiene measures when such contact has occurred, as well as indicate how to cure such diseases as do occur. Such a residents' health committee could also assist in monitoring the practice of wastewater reuse.

Where salaried agricultural workers are involved, their employers are responsible for protecting them from exposure to diseases, as laid down in many countries in existing legislation on occupational health. This may require employers to provide protective clothing to the workers and to make adequate washing facilities available so as to encourage high standards of hygiene. Treatment (chemotherapy)
of agricultural workers and their families for intestinal helminth infections is relatively easy to administer in a formal wastewater irrigation scheme, although additional health personnel may be required. Where wastewater is used on many small and scattered farms, the logistic problems involved in the provision of protective clothing and washing facilities are greater, and the identification and chemotherapeutic treatment of exposed persons may become quite expensive. The choice between mass chemotherapy and the selective chemotherapy of infected individuals depends largely on the prevalence of infection and on the relative costs of the detection and treatment of cases.

Measures to control the exposure of those who handle the crops resemble those for farm workers. On the other hand, when a large number of petty traders are involved, it will be difficult to implement exposure control measures; an opportunity to do so will, however, be provided by markets, at which traders tend to gather together. Most markets are, in any case, subject to public health inspection and may also be the best places at which to advise consumers about the hygienic precautions they should take.

8.4 Implementing new schemes for wastewater reuse

In countries with little or no experience of the planned reuse of wastewater, a pilot project is highly recommended. Health protection is only one of a number of interrelated problems which have to be solved and only a pilot project can provide the local experience and test the appropriateness of the proposed techniques. A pilot project should be operated for at least one growing season and may then be translated into a larger demonstration project with training facilities for local operators and farmers or pond owners.

The planning requirements for schemes for wastewater reuse are in many regards similar to those for irrigation and fertilization schemes not based on the use of human wastes. Further guidance on the planning and implementation of such schemes will be included in future publications of the Food and Agriculture Organization of the United Nations and the World Bank.¹

Integrating various measures for public health protection will be somewhat easier when new schemes for wastewater reuse are being implemented than when existing practices are being upgraded. Many

¹ See, for example, Wastewater reclamation and use in agriculture (in preparation for publication as an FAO Irrigation and Drainage Paper).
of the decisions will be taken without the constraints imposed by the limitations of an existing system, and a more rational and cost-effective balance of wastewater treatment, crop restriction, wastewater application and human exposure control should be possible. However, it will not always be appropriate or feasible to meet the costs of health protection measures by charging for the use of the wastewater.

The costs of wastewater treatment are usually justified by the resulting improvement in the control of environmental pollution. However, the treatment of wastewater to a standard adequate for use in agriculture may involve additional costs. Some of these can be met by the sale of the treated effluent. If individual farmers or pond owners are to be encouraged to treat nightsoil or wastewater, however, they may need credit to help them bear the capital cost of any construction required.

Crop restriction may mean that less need be spent on wastewater treatment but, if adequate financial provision is not made for its enforcement, it will not be effective. Since the preparation of fields to allow various wastewater application techniques to be used helps farmers avoid other expenditure, the cost can be recovered from them in the same way as other irrigation costs. Since localized irrigation uses less water than traditional methods, farmers may find it worthwhile to change to this method if the cost of wastewater is high enough. Both crop restriction and wastewater application control will be simpler to implement and enforce in new schemes if a private company or single public agency operates the reuse project.

The same opportunities for improving human exposure control arise in new schemes for wastewater reuse and in upgrading existing practices. The cost of these measures will normally be borne by the normal water supply and sanitation and health service budgets, but measures to improve occupational health will often be paid for by employers.

9. RESEARCH NEEDS RELATED TO HEALTH PROTECTION

Since the use of wastewater in agriculture and aquaculture is increasing in importance around the world and is a rapidly developing field, research into a number of subject areas needs to be continued and intensified. Research should be complemented by
purposive case-studies on the upgrading of traditional practices as well as the implementation and operation of newly developed schemes for wastewater use. Efforts should be directed towards filling the gaps in knowledge and, where possible, towards monitoring and evaluating the effectiveness of the guidelines recommended.

9.1 Wastewater quality assessment

One of the new features of this report is that quantitative guidelines are given for the helminth egg content of wastewater used in agriculture and aquaculture. Although methods for the detection of helminth eggs are in use today (see Annex 2), they are not completely satisfactory, so that there is a need to develop and improve low-cost, reliable egg-detection methods which have a high degree of sensitivity. Further investigations are also required to facilitate the determination of egg viability in order to develop analytical methods which will be suitable for routine application.

9.2 Wastewater treatment technology

Pathogenic organisms constitute the quality parameter of major concern in the context of wastewater treatment for reuse. Research should be directed towards existing as well as new wastewater treatment technologies, and the following areas should receive special attention:

(1) waste stabilization pond technology, including developing and evaluating the performance of:
   (a) land-saving options (such as deep ponds); and
   (b) systems and designs aimed at minimizing evaporation losses;
(2) treatment technologies other than waste stabilization ponds that achieve effective helminth egg removal; these may be:
   (a) for use in upgrading conventional treatment systems, such as biological-filter and activated-sludge plants (for example, by the addition of maturation ponds, which are entirely aerobic, or sand filtration); or
   (b) new techniques (such as direct chemical treatment of sewage);
(3) the effectiveness, cost and environmental impact of wastewater disinfection, with particular reference to helminth egg inactivation;

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(4) bacterial removal in waste stabilization ponds under varying conditions (of climate, organic loading, etc.); and 
(5) treatment to inactivate pathogens in sludges from ponds and other wastewater-treatment plants, and in particular simple treatment processes for use on a small scale.

9.3 Wastewater application technology

In this field, research should be directed towards existing as well as new irrigation technologies which can provide the best health protection while at the same time conserving water. Techniques should be developed which allow the distribution of settled (i.e., minimally treated) sewage to a variety of crops without clogging delivery devices (especially in drip, trickle and bubbler systems). This will facilitate the “safe” application of wastewater with minimal treatment (regime B in Fig. 5).

9.4 Human exposure control

The effectiveness of methods for human exposure control, for both workers and consumers, should be evaluated under field conditions. There is a need to assess the performance of delivery systems (e.g., health care programmes for hygiene education and provision of protective clothing), compliance rates and the resultant health effects.

9.5 Sociocultural research and integration of measures

Research into public and users’ attitudes to wastewater reuse is needed, both in areas where it is practised and in those where it may be introduced. This may be done using case-study analyses. The social and cultural factors affecting the acceptability of and compliance with the health protection measures suggested (e.g., crop restriction) need to be evaluated in a variety of different cultural settings. Finally, research aimed at developing systematic methods of identifying the most cost-effective approach to health protection under any particular local conditions should be considered.

9.6 Epidemiological research

The monitoring and evaluation of the recommended guidelines by carefully designed epidemiological studies is highly desirable.
Different at-risk groups, including the children of agricultural workers, should be examined. Studies of wastewater reuse in irrigation in a variety of settings, both where the microbiological quality guidelines are met and where they are not, should also be conducted. The most urgent need is to evaluate any improvement in the health of agricultural workers and their children in situations where the new helminth egg guideline is met. Studies are also required to fill gaps in existing knowledge, including studies of excess morbidity (where possible), of excess frequency of infection, of protozoal disease, and of the more virulent infections, such as typhoid fever, in relation to wastewater use.

Suitable locations for epidemiological studies are difficult to find since they require the presence of large populations exposed to treated wastewater of the required quality, and also similar populations not using wastewater nearby, to act as control populations. Where suitable locations do exist, each epidemiological study should be accompanied by a study of the microbiological quality of the wastewater. Similar studies are needed where excreta are used in agriculture.

9.7 Aquacultural research

There is an urgent need to conduct research into the microbiological and epidemiological aspects of the use of wastewater in aquaculture, so that guidelines may be proposed in the future with greater confidence. The health effects on both aquacultural workers and consumers of fish should be evaluated in a variety of sociocultural settings. Research is particularly needed in areas where the major trematode infections (e.g., clonorchiasis, schistosomiasis) do not occur and where bacterial infections are of greater concern. Research on the impact of excreta use in aquaculture is also required.

10. CONCLUSIONS AND RECOMMENDATIONS

1. Municipal wastewater is a valuable resource which should be used wherever this is possible with adequate health safeguards. The advantages of such use include the consequent reduction in environmental pollution as well as increased agricultural production. Reuse of wastewater in agriculture and aquaculture
should, where possible, be the preferred method of wastewater disposal and should form an integral part of water resources planning.

2. Health protection in wastewater reuse can be achieved by an integrated set of measures which may include wastewater treatment, crop restriction, appropriate wastewater application techniques and human exposure control. The optimum combination of measures will depend on local conditions and the specific groups of people to be protected.

3. Improved epidemiological information and understanding now permit the adoption of more rational standards for the microbiological quality of treated wastewater for use in agriculture. Recommended guideline values appropriate to various types of irrigation conditions are given in Table 3, page 39. Governments are urged to adopt standards based on these guidelines.

4. Tentative guidelines for wastewater use in aquaculture are suggested in section 7.3, although little epidemiological evidence exists at present to support them.

5. The use of raw or inadequately treated wastewater without sufficient health safeguards has often been tolerated, partly because some previous standards and regulations have been too strict to be achievable. Feasible measures which can be taken as the first step in a gradual process of upgrading health protection in existing practice are recommended here. Health authorities should investigate current wastewater reuse practices and take steps to implement such measures.

6. In the selection of wastewater treatment techniques for reuse schemes, the primary consideration should be their ability to remove pathogens consistently; it should be borne in mind that conventional systems are less likely to be reliable in this respect. The special advantages of stabilization ponds in providing a simple, stable pathogen-removal process should be made more widely known.

7. Effective implementation of health protection measures in wastewater reuse requires the involvement and cooperation of several ministries and government agencies, whose activities need to be coordinated. Governments wishing to promote wastewater reuse in agriculture and aquaculture or to reduce the health risk of current practices will find it advantageous to begin by making arrangements for such interagency collaboration.

8. Health risks from toxic chemicals in wastewater were not within the terms of reference of the Scientific Group, but the Group
stressed the need to monitor the situation when wastewater contains substantial quantities of industrial effluent.

9. The use in agriculture and aquaculture of sludges from wastewater treatment and of excreta and nightsoil was not considered in detail, but the Scientific Group accepted that they could serve as a valuable resource if adverse health effects could be avoided. Many of the health protection measures recommended in this report are also appropriate to this practice.

10. Health protection measures must be monitored and evaluated to ensure their effectiveness. Such assessments will contribute towards the validation of the recommended guidelines and, in some cases, towards satisfying the research needs identified in section 9.

11. Both developing and industrialized countries can benefit from wastewater reuse. Indeed, industrialized countries have much to learn from the developing countries in this respect and some of the research activities proposed in section 9 can best be conducted in developing countries.

12. Finally, the Scientific Group recommended that WHO should take the necessary steps to disseminate its findings and to assist Member States in planning and implementing schemes for wastewater reuse and in developing appropriate legislation, institutions and training programmes to enable them to ensure that health is protected when such schemes are implemented.

ACKNOWLEDGEMENT

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REFERENCES


11. The risk to health of microbes in sewage sludge applied to land. Copenhagen, WHO Regional Office for Europe, 1981 (EURO Reports and Studies 54).


## Annex 1

### BASIC EPIDEMIOLOGICAL FEATURES OF EXCRETED PATHOGENS
BY ENVIRONMENTAL CATEGORY

<table>
<thead>
<tr>
<th>Pathogen</th>
<th>Excreted load&lt;sup&gt;*&lt;/sup&gt;</th>
<th>Latency&lt;sup&gt;+&lt;/sup&gt;</th>
<th>Persistence&lt;sup&gt;+&lt;/sup&gt;</th>
<th>Multiplication outside human host</th>
<th>Median infective dose (LD&lt;sub&gt;50&lt;/sub&gt;)&lt;sup&gt;+&lt;/sup&gt;</th>
<th>Significant immunity?</th>
<th>Major nonhuman reservoir?</th>
<th>Intermediate host</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Category I</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enteroviruses&lt;sup&gt;+&lt;/sup&gt;</td>
<td>10&lt;sup&gt;7&lt;/sup&gt;</td>
<td>0</td>
<td>3 months</td>
<td>No</td>
<td>L</td>
<td>Yes</td>
<td>No</td>
<td>None</td>
</tr>
<tr>
<td>Hepatitis A virus</td>
<td>10&lt;sup&gt;7&lt;/sup&gt; (?)</td>
<td>0</td>
<td>?</td>
<td>No</td>
<td>L(?)</td>
<td>Yes</td>
<td>No</td>
<td>None</td>
</tr>
<tr>
<td>Rotavirus</td>
<td>10&lt;sup&gt;7&lt;/sup&gt; (?)</td>
<td>0</td>
<td>?</td>
<td>No</td>
<td>L(?)</td>
<td>Yes</td>
<td>No</td>
<td>None</td>
</tr>
<tr>
<td>Balantidium coli</td>
<td>?</td>
<td>0</td>
<td>?</td>
<td>No</td>
<td>L(?)</td>
<td>Yes</td>
<td>No</td>
<td>None</td>
</tr>
<tr>
<td>Entamoeba histolytica</td>
<td>10&lt;sup&gt;5&lt;/sup&gt;</td>
<td>0</td>
<td>25 days</td>
<td>No</td>
<td>L</td>
<td>No(?)</td>
<td>Yes</td>
<td>None</td>
</tr>
<tr>
<td>Giardia lamblia</td>
<td>10&lt;sup&gt;6&lt;/sup&gt;</td>
<td>0</td>
<td>25 days</td>
<td>No</td>
<td>L</td>
<td>No(?)</td>
<td>Yes</td>
<td>None</td>
</tr>
<tr>
<td>Enterobius vermicularis</td>
<td>Not usually found in faeces</td>
<td>0</td>
<td>7 days</td>
<td>No</td>
<td>L</td>
<td>No</td>
<td>No</td>
<td>None</td>
</tr>
<tr>
<td>Hymenolepis nana</td>
<td>?</td>
<td>0</td>
<td>1 month</td>
<td>No</td>
<td>L</td>
<td>Yes(?)</td>
<td>No(?)</td>
<td>None</td>
</tr>
<tr>
<td><strong>Category II</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Campylobacter fetus ssp jejuni</td>
<td>10&lt;sup&gt;5&lt;/sup&gt;</td>
<td>0</td>
<td>7 days</td>
<td>Yes&lt;sup&gt;+&lt;/sup&gt;</td>
<td>H(?)</td>
<td>?</td>
<td>Yes</td>
<td>None</td>
</tr>
<tr>
<td>Pathogenic Escherichia coli&lt;sup&gt;*&lt;/sup&gt;</td>
<td>10&lt;sup&gt;8&lt;/sup&gt;</td>
<td>0</td>
<td>3 months</td>
<td>Yes&lt;sup&gt;+&lt;/sup&gt;</td>
<td>H</td>
<td>Yes(?)</td>
<td>No(?)</td>
<td>None</td>
</tr>
<tr>
<td>Salmonella</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>S. typhi</td>
<td>10&lt;sup&gt;6&lt;/sup&gt;</td>
<td>0</td>
<td>2 months</td>
<td>Yes&lt;sup&gt;+&lt;/sup&gt;</td>
<td>H</td>
<td>Yes</td>
<td>No</td>
<td>None</td>
</tr>
<tr>
<td>Other salmonellae</td>
<td>10&lt;sup&gt;7&lt;/sup&gt;</td>
<td>0</td>
<td>3 months</td>
<td>Yes&lt;sup&gt;+&lt;/sup&gt;</td>
<td>H</td>
<td>No</td>
<td>Yes</td>
<td>None</td>
</tr>
<tr>
<td>Shigella spp</td>
<td>10&lt;sup&gt;7&lt;/sup&gt;</td>
<td>0</td>
<td>1 month</td>
<td>Yes&lt;sup&gt;+&lt;/sup&gt;</td>
<td>M</td>
<td>No</td>
<td>No</td>
<td>None</td>
</tr>
<tr>
<td>Vibrio cholerae</td>
<td>10&lt;sup&gt;7&lt;/sup&gt;</td>
<td>0</td>
<td>1 month&lt;sup&gt;(?)&lt;/sup&gt;</td>
<td>Yes&lt;sup&gt;+&lt;/sup&gt;</td>
<td>H</td>
<td>Yes(?)</td>
<td>No</td>
<td>None</td>
</tr>
<tr>
<td>Yersinia enterocolitica</td>
<td>10&lt;sup&gt;5&lt;/sup&gt;</td>
<td>0</td>
<td>3 months</td>
<td>Yes&lt;sup&gt;+&lt;/sup&gt;</td>
<td>H(?)</td>
<td>No</td>
<td>Yes</td>
<td>None</td>
</tr>
<tr>
<td><strong>Category III</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ascaris lumbricoides</td>
<td>10&lt;sup&gt;4&lt;/sup&gt;</td>
<td>10 days</td>
<td>1 year</td>
<td>No</td>
<td>L</td>
<td>No</td>
<td>No</td>
<td>None</td>
</tr>
<tr>
<td>Hookworms&lt;sup&gt;*&lt;/sup&gt;</td>
<td>10&lt;sup&gt;4&lt;/sup&gt;</td>
<td>7 days</td>
<td>3 months</td>
<td>No</td>
<td>L</td>
<td>No</td>
<td>No</td>
<td>None</td>
</tr>
<tr>
<td>Strongyloides stercoralis</td>
<td>10&lt;sup&gt;3&lt;/sup&gt;</td>
<td>3 days</td>
<td>3 weeks&lt;sup&gt;(free-living stage much longer)&lt;/sup&gt;</td>
<td>Yes&lt;sup&gt;+&lt;/sup&gt;</td>
<td>L</td>
<td>Yes</td>
<td>No</td>
<td>None</td>
</tr>
<tr>
<td>Trichuris trichiura</td>
<td>10&lt;sup&gt;3&lt;/sup&gt;</td>
<td>20 days</td>
<td>9 months</td>
<td>No</td>
<td>L</td>
<td>No</td>
<td>No</td>
<td>None</td>
</tr>
<tr>
<td>Pathogen</td>
<td>Excreted load</td>
<td>Latency</td>
<td>Persistence</td>
<td>Multiplication outside human host</td>
<td>Median infective dose (ID₅₀)</td>
<td>Significant immunity?</td>
<td>Major nonhuman reservoir?</td>
<td>Intermediate host</td>
</tr>
<tr>
<td>----------------------------------</td>
<td>---------------</td>
<td>---------</td>
<td>-------------</td>
<td>-------------------------------------</td>
<td>-----------------------------</td>
<td>--------------------------</td>
<td>------------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td><strong>Category IV</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Taenia saginata and T. solium¹</td>
<td>10⁴</td>
<td>2 months</td>
<td>9 months</td>
<td>No</td>
<td>L</td>
<td>No</td>
<td>No</td>
<td>Cow (T. saginata) or pig (T. solium)</td>
</tr>
<tr>
<td><strong>Category V</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Olarorchis simensis¹</td>
<td>10⁴</td>
<td>6 weeks</td>
<td>Life of fish</td>
<td>Yes¹</td>
<td>L</td>
<td>No</td>
<td>Yes</td>
<td>Snail and fish</td>
</tr>
<tr>
<td>Diphyllobothrium latum¹</td>
<td>10⁴</td>
<td>2 months</td>
<td>Life of fish</td>
<td>No</td>
<td>L</td>
<td>No</td>
<td>Yes</td>
<td>Copepod and fish</td>
</tr>
<tr>
<td>Fasciola hepatica¹</td>
<td>10⁴</td>
<td>2 months</td>
<td>4 months</td>
<td>Yes¹</td>
<td>L</td>
<td>No</td>
<td>Yes</td>
<td>Snail and aquatic plant</td>
</tr>
<tr>
<td>Fasciolopsis buski¹</td>
<td>10²</td>
<td>2 months</td>
<td>?</td>
<td>Yes¹</td>
<td>L</td>
<td>No</td>
<td>Yes</td>
<td>Snail and aquatic plant</td>
</tr>
<tr>
<td>Gastrodiscoides hominis¹</td>
<td>10²</td>
<td>2 months</td>
<td>?</td>
<td>Yes¹</td>
<td>L</td>
<td>No</td>
<td>Yes</td>
<td>Snail and fish</td>
</tr>
<tr>
<td>Heterophyes heterophyes¹</td>
<td>6 weeks</td>
<td>Life of fish</td>
<td>Yes¹</td>
<td>L</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Snail and shrimp</td>
</tr>
<tr>
<td>Metagonimus yokogawai¹</td>
<td>6 weeks</td>
<td>Life of fish</td>
<td>Yes¹</td>
<td>L</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Snail and fish</td>
</tr>
<tr>
<td>Paragonimus westermani¹</td>
<td>6 weeks</td>
<td>Life of crab</td>
<td>Yes¹</td>
<td>L</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Snail and crab or crayfish</td>
</tr>
<tr>
<td>Schistosoma</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S. haematobium¹</td>
<td>4 per million litre of urine</td>
<td>5 weeks</td>
<td>2 days</td>
<td>Yes¹</td>
<td>L</td>
<td>Yes</td>
<td>No</td>
<td>Snail</td>
</tr>
<tr>
<td>S. japonicum¹</td>
<td>40</td>
<td>7 weeks</td>
<td>2 days</td>
<td>Yes¹</td>
<td>L</td>
<td>Yes</td>
<td>Yes</td>
<td>Snail</td>
</tr>
<tr>
<td>S. mansoni¹</td>
<td>40</td>
<td>4 weeks</td>
<td>2 days</td>
<td>Yes¹</td>
<td>L</td>
<td>?</td>
<td>No</td>
<td>Snail</td>
</tr>
<tr>
<td>Leptospira spp</td>
<td>0</td>
<td>7 days</td>
<td>No</td>
<td>No</td>
<td>L</td>
<td>Yes(²)</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>


*Typical average number of organisms per gram of faeces (except of Schistosoma haematobium and Leptospira species, which occur in urine).

*Typical minimum time from excretion to infectivity.

*Estimated maximum life of infective stage at 20-30°C.

*L Low (< 10%); M medium (10%); H high (> 10%); ? uncertain.

*Includes polio-, echo-, and typhus-like infections.

*Multiplication takes place predominantly on food.

*Includes enteropathogenic, enteroinvasive, and enteropathogenic E. coli.

*Angiostrongylus cantonensis and Necator americanus.

*Latency is minimum time from excretion by man to potential reinfection of man. Persistence here refers to maximum survival time of final infective stage. Life cycle involves one intermediate host.

²Latency and persistence as for Taenia species. Life cycle involves two intermediate hosts.

*Multiplication takes place in intermediate snail host.
Annex 2

TENTATIVE METHODS FOR QUANTITATIVE DETERMINATION OF HELMINTH EGGS IN WASTEWATER

The methods described here are: (1) a sedimentation procedure; and (2) a centrifugation flotation procedure.

SEDIMENTATION METHOD

This method relies on a sedimentation procedure selected from more than 20 different procedures tested under field conditions in several countries by Professor J. Schwartzbrod (Faculty of Pharmaceutical Sciences and Biology, University of Nancy, France). It consists of the following steps:

1. A grab sample of wastewater (i.e., a single sample taken neither at a set time nor at a set flow) is taken and transported unpreserved to the laboratory at ambient temperature within a few days. It is then shaken and a measured volume \( S \) of 1 litre is removed and left to settle for at least 8 hours.

2. The supernatant is carefully removed and discarded, without disturbing the sediment.

3. The sediment (100–200 ml) is recovered from the container. The container walls are then washed with 25–50 ml of distilled water, which is added to the sediment. All the recovered material is centrifuged at 1000g for 15 minutes.

4. The supernatant is removed and discarded. Aceto-acetic buffer (pH 4.5)\(^1\) is added at a volume equal to that of the pellet and the mixture is stirred.

5. Ether is then added at a volume equal to twice that of the buffer and the mixture is stirred for 10 minutes.

6. The mixture is centrifuged at 1000g for 6 minutes.

7. The supernatant is discarded and the pellet resuspended with about 5 ml (about 5 times the pellet volume is generally needed for resuspension) of saturated zinc sulfate solution (33%, relative density 1.18). The volume \( V \) of the product is measured.

\(^1\) This contains 15 g of sodium acetate with 3.6 ml of acetic acid made up to 1 litre with distilled water.
8. A portion \((P)\) of the product is transferred to a microscopic counting cell\(^1\) using a Pasteur pipette, and the eggs are counted at 100 \(\times\) magnification.

9. The total number of eggs per litre \((N)\) present in the original sample of wastewater is determined from the formula:

\[
N = \frac{X}{P} \cdot \frac{V}{S}
\]

where:
- \(X\) = number of eggs counted
- \(P\) = volume of product in the counting cell (ml)
- \(V\) = total volume of product (ml)
- \(S\) = volume of wastewater sample (litres)

In the example described, the wastewater sample volume \((S)\) is 1 litre. In order to evaluate the helminth concentration relative to the goal of \(\leq 1\) egg per litre, the sensitivity of this method may be improved by increasing the sample volume to \(\geq 2\) litres and/or increasing the size of the portion of the product read under the microscope.

**CENTRIFUGATION FLOTATION METHOD**

This method is based on the centrifugation flotation procedure as described by Ockert \((1, 2)\) and Teichmann \((3)\), and consists of the following steps:

1. A grab sample of wastewater is taken and transported unpreserved to the laboratory at ambient temperature within a few days. It is then shaken and a measured 1-litre volume is removed and left to settle for at least 8 hours.
2. The supernatant is carefully removed and discarded without disturbing the sediment.
3. The sediment is transferred to 20-ml centrifuge tubes (maximum 3 ml per tube). The walls of the sedimentation beaker should be cleaned thoroughly using a spray bottle, and the rinsing water added to the sediments in the centrifuge tubes. They are then centrifuged for 10 minutes at 700g and the supernatants are discarded.

\(^1\) Microscopic counting cells that hold 0.3–1.0 ml are acceptable and are commercially available, e.g., McMaster cell (0.3 ml), Sedgwick-Rafter cell (1.0 ml).
4. A volume of 3 ml of sodium nitrate solution (500 g/litre, relative density 1.3) is added to the sediment in each tube.

5. The solutions are then centrifuged for 3 minutes at 1000g.

6. The supernatant (now containing the helminth eggs) is removed and kept in a 1500-ml flask (preferably conical) containing 1 litre of distilled water.

7. A volume of 3 ml of sodium nitrate solution is again added to the sediment in each tube, and the mixtures are centrifuged at 1000g for 3 minutes. The supernatant is carefully removed and added to the 1500-ml flask containing the first supernatants.

8. The procedure in point (7) is repeated (the sediment is thus centrifuged with sodium nitrate a total of three times).

9. The beaker containing all the supernatants diluted in water is left for several hours, to allow all the helminth eggs to settle to the bottom.

10. The supernatant from this beaker is carefully removed and discarded, and the sediment is transferred to centrifuge tubes. The walls of the sedimentation beaker should be thoroughly cleaned and the rinsing water added to the sediment in the centrifuge tubes. The contents of the tubes are then centrifuged for 4 minutes at 1000g.

11. After centrifugation, the lower 1 ml of fluid is carefully removed from each tube with a Pasteur pipette, placed in a counting cell and examined under the microscope at 100 × magnification.

12. The number of eggs counted will be the total number recovered from the 1-litre wastewater sample.

REFERENCES


738 (1986) Regulatory mechanisms for nursing training and practice: meeting primary health care needs
Report of a WHO Study Group (71 pages) ........................................ 10.--
739 (1986) Epidemiology and control of African trypanosomiasis
Report of a WHO Expert Committee (127 pages) .................................. 16.--
740 (1986) Joint FAO/WHO Expert Committee on Brucellosis
Sixth report (132 pages) .............................................................. 18.--
741 (1987) WHO Expert Committee on Drug Dependence
Twenty-third report (64 pages) ...................................................... 9.--
742 (1987) Technology for water supply and sanitation in developing countries
Report of a WHO Study Group (38 pages) ........................................ 7.--
Report of a WHO Scientific Group (229 pages) ................................... 32.--
744 (1987) Hospitals and health for all
Report of a WHO Expert Committee on the Role of Hospitals at the First Referral Level (82 pages) ......................................................... 12.--
745 (1987) WHO Expert Committee on Biological Standardization
Thirty-sixth report (149 pages) ..................................................... 20.--
746 (1987) Community-based education for health personnel
Report of a WHO Study Group (89 pages) ........................................ 12.--
747 (1987) Acceptability of cell substrates for production of biologicals
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748 (1987) WHO Expert Committee on Specifications for Pharmaceutical Preparations
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749 (1987) Prevention and control of intestinal parasitic infections
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Report of a WHO Expert Committee (58 pages) .................................. 9.--
751 (1987) Evaluation of certain food additives and contaminants
Thirtieth report of the Joint FAO/WHO Expert Committee on Food Additives (57 pages) .......................................................... 9.--
752 (1987) WHO Expert Committee on Onchocerciasis
Third report (167 pages) ............................................................... 24.--
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754 (1987) Progress in the development and use of antiviral drugs and interferon
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Report of a WHO Study Group (49 pages) ........................................ 9.—

757 (1987) Rational use of diagnostic imaging in paediatrics
Report of a WHO Study Group (102 pages) ........................................ 14.—

758 (1987) The hypertensive disorders of pregnancy
Report of a WHO Study Group (114 pages) ....................................... 16.—

759 (1987) Evaluation of certain food additives and contaminants
Thirty-first report of the Joint FAO/WHO Expert Committee on Food Additives (33 pages) ......................................................... 9.—

760 (1987) WHO Expert Committee on Biological Standardization
Thirty-seventh report (203 pages) ...................................................... 28.—

761 (1988) WHO Expert Committee on Drug Dependence
Twenty-fourth report (34 pages) ....................................................... 6.—

762 (1988) Training and education in occupational health
Report of a WHO Study Group (47 pages) ........................................ 6.—

763 (1988) Evaluation of certain veterinary drug residues in food
Thirty-second report of the Joint FAO/WHO Expert Committee on Food Additives (40 pages) ....................................................... 6.—

764 (1988) Rheumatic fever and rheumatic heart disease
Report of a WHO Study Group (58 pages) ........................................ 8.—

765 (1988) Health promotion for working populations
Report of a WHO Expert Committee (49 pages) ................................ 8.—

766 (1988) Strengthening ministries of health for primary health care
Report of a WHO Expert Committee (110 pages) ................................ 12.—

767 (1988) Urban vector and pest control
Eleventh report of the WHO Expert Committee on Vector Biology and Control (77 pages) ........................................... 9.—

768 (1988) WHO Expert Committee on Leprosy
Sixth report (51 pages) ................................................................. 8.—

769 (1988) Learning together to work together for health
Report of a WHO Study Group (72 pages) ........................................ 9.—

Third report of the WHO Expert Committee (63 pages) ................... 8.—

771 (1988) WHO Expert Committee on Biological Standardization
Thirty-eighth report (221 pages) ..................................................... 26.—

772 (1988) Appropriate diagnostic technology in the management of cardiovascular diseases
Report of a WHO Expert Committee (41 pages) ................................ 6.—

773 (1988) Smokeless tobacco control
Report of a WHO Study Group (81 pages) ....................................... 11.—

774 (1988) Salmonellosis control: the role of animal and product hygiene
Report of a WHO Expert Committee (83 pages) ................................ 11.—

775 (1989) WHO Expert Committee on Drug Dependence
Twenty-fifth report (48 pages) ....................................................... 6.—

776 (1989) Evaluation of certain food additives and contaminants
Thirty-third report of the Joint FAO/WHO Expert Committee on Food Additives (63 pages) ....................................................... 8.—

777 (1989) Epidemiology of work-related diseases and accidents
Tenth report of the Joint ILO/WHO Committee on Occupational Health (71 pages) ......................................................... 9.—