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Wastewater irrigation is being practised in many countries around the world because of the substantial benefits accruing to communities as a result of reuse of nutrient-rich treated or untreated sewage. Treated effluent reuse has special significance for developing countries with arid and semi-arid climates and limited water resources. Land application of wastewater and sludge provides nutrients for crop growth as well as organic matter for soil conditioning and it is often the most economic means of wastewater and sludge disposal. However, land application involves health and environmental risks, because sludge may contain heavy metals and industrial organic compounds, and wastewater and sludge may contain pathogens at detrimental concentrations.

In developing countries, raw sewage is rarely treated before being applied in irrigation and this direct reuse without any restrictions on the types of crops poses potential health hazards and adverse environmental impacts. However, if appropriate low-cost technology for wastewater treament and effluent distribution in irrigation can be developed to suit conditions in developing countries and also provide the necessary safeguards to health, this form of reuse will conserve valuable water resources and increase crop production. Land-appied wastewater also undergoes natural physico-chemical and biological treatments in the soil matrix which provide not only a highly effective low-cost alternative to conventional treatment but also an ecologically balanced and environmentally compatible system of wastewater management.

I - Health risk from wastewater reuse

1. Terminology

In approaching the matter of health risk, terminology is important and it is necessary to use epidemiological rather than lay terms. The epidemiologist's definition of health risk is the probability of an individual developing a given disease (or experiencing a change in health status) over a specified period. In the past, the possible survival of pathogens or indicator organisms on soil or crops was taken as an indication of the **actual** risk of disease transmission through effluent irrigation. This use of 'actual risk' is no longer appropriate, being based on a microbiological view of the hazard to health. More correctly, the term **'potential** risk' should be used to describe this lay concept of risk, which is the chance of infection that might occur but does not at present occur. In wastewater reuse, 'potential risk' is now most often used to describe a situation where certain pathogenic microorganisms have been detected in wastewater or on crops but where no cases of disease due to these pathogens have been detected – perhaps because surveys for disease have not been carried out. Clearly, under these conditions, it cannot be established that these microorganisms constitute an **actual** risk.

The proper term 'actual risk' implies the epidemiological concept of 'attributable risk', that is, the proportion of all cases of disease in a given period that are attributable to the risk factor of interest. Measurement of attributable risk, therefore, involves comparison of two populations, one population exposed to the risk factor of interest (in this case, wastewater use) and one population not exposed to this risk factor (a 'control' population). The control or unexposed population may show some cases of the disease of interest, due to transmission via other routes (such as, for example, diarrhoea transmitted through poor domestic water supplies and intestinal nematode infections transmitted through contamination of the domestic environment). Risk attributable to wastewater use is, therefore, a measure of the difference in disease risk between the exposed and control populations and not simply the amount of disease in the exposed population. Attributable risk is similar to the idea of excess risk. It is possible for a 'potential risk' to occur without resulting in an 'actual (attributable) risk' in the population using the wastewater, due to the effects of other factors, including infective dose, human behaviour and human immunity, as well as the influence of alternative transmission routes.

2. Exposure

The health risk associated with wastewater reuse can be manifested to different extents in different sub-groups of the population. In this context, the most important sub-groups to consider are persons consuming crops irrigated with the wastewater (consumer risk) and agricultural workers subjected to occupational exposure (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 measures for health protection will depend on whether consumer risks or occupational risks, or both, are to be minimized.

The way in which wastewater is applied to the land, the interval between successive applications and the interval between the last application and harvesting, all affect the likely degree of crop contamination and the environmental dispersion of excreted pathogens. Production of agricultural crops intended for human consumption poses potential risks to farm workers, those who handle the products and those who consume them. If the products are fodder crops, farm workers and those who consume the resulting meat or milk are at potential risk; but in the case of industrial products (for example, sugar beet, fishmeal), only farm workers and product handlers are subjected to risk. In the case of sprinkler irrigation, an additional exposure group is those people living near the irrigated fields, who are at potential risk from pathogens present in wind-dispersed aerosol droplets.

The greatest risk is associated with crops eaten raw, for example salad crops, especially if they are root crops (such as radishes) or grow close to the soil (for instance, lettuces). Pathogen survival times can be greater than the crop growing time, so that contamination is highly likely unless the wastewater is treated to a very high standard.

Significant host immunity only occurs with the viral diseases and some bacterial diseases (for example, typhoid). The role of immunity is most noticeable in the case of viral infections where infection at an early age is very common (even in communities with high standards of personal hygiene), with the result that the adult population is largely immune to the disease, and frequently also to infection.

The relative importance of such potential health risks from wastewater reuse depends on the access to excreted pathogens which those at risk have by alternative routes, such as lack of safe water supply, and basic wastewater reuse may not pose a significant additional risk. On the other hand, if there are no such routes, wastewater reuse will be entirely responsible for the risk induced.

II - Environmental aspects of wastewater reuse

1. Wastewater as a resource

As a substitute for freshwater in irrigation, wastewater has an important role to play in water resources management. By releasing freshwater sources for potable water supply and other priority uses, wastewater reuse makes a contribution to water conservation and takes on an economic dimension.

Those pollutants which, if discharged directly to the environment in the raw wastewater, would create serious pollution problems (especially organic matter, nitrogen, phosphorus and potassium) serve as nutrients when applied as irrigation water. Studies in many countries have shown that, with proper management, crop yields may be increased by irrigating with raw wastewater as well as primary and secondary treated effluents. For an irrigation rate of 2 m per year, commonly required in semi-arid areas, typical concentrations of 15 mg/l of total N and 3 mg/l of total P in well-treated sewage (say, after treatment in a properly-designed series of stabilization ponds) correspond to annual N and P application rates of 300 and 60 kg/ha, respectively. Such nutrient inputs will reduce or eliminate the need for commercial fertilizers. The organic matter (BOD) added through wastewater irrigation will serve as a soil conditioner over time, increasing the capacity of the soil to store water.

2. Environmental control

Discharge of untreated or partially treated wastewater to the environment gives rise to pollution problems in surface and groundwater and on land. Planned reuse of wastewater in irrigation prevents such problems and reduces the resulting damages which, if quantified, can partly offset the costs of the reuse scheme. Also, by substituting wastewater irrigation for groundwater irrigation in those areas where over-utilization of groundwater is causing problems, such as salt water intrusion in coastal areas, additional environmental benefits might result.

One possible environmental disadvantage which might arise from the use of wastewater in irrigation, and by applying sewage sludge to land, is groundwater contamination. Nitrates are a particular problem in many countries and the risk of contaminating groundwater 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 will be removed in the unsaturated layer and there will be a very low risk of contaminating the groundwater. Only in the case of a shallow and/or highly porous unsaturated zone above the aquifer, and especially if this zone is fissured, will a high risk situation arise.

3. Chemical pollutants

Municipal wastewater is likely to contain chemical pollutants wherever industrial discharges are allowed into the sewerage system. Of particular concern are those that are toxic to people, plants and aquatic biota. Heavy metals and refractory organics fall into this category. Boron, a constituent of synthetic detergents, is an important phytotoxin, especially of citrus crops, and should be monitored when wastewater is used for irrigation. Preventing chemical pollutants from entering sewerage is the best solution but this is difficult to achieve unless industrial zones are isolated and provided with their own wastewater treatment plants.

A possible long-term problem with wastewater irrigation is build-up of toxic materials or salinity 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 toxic levels could develop and be taken up by a crop. The problem of soil salinization is common in arid regions where irrigation water is saline and wastewater irrigation could give rise to this effect over the long-term, thereby rendering the land unusable for agriculture.

The productivity of irrigated land is fundamentally dependent on its internal drainage, which is a function of the soil profile morphology, pore size distribution and stability of pore structure. The first two factors are of paramount importance in relation to effluent reuse in irrigation. No irrigation scheme can succeed unless the soil profile remains permeable, and this depends both on the proportion of exchangeable cations held by the soil, other than sodium (the Exchangeable Sodium Percentage – ESP) and on the total concentration of soluble salts in the percolating water. Considerable evidence exists to indicate that pore structural stability is very important in determining the hydraulic properties of soils. The hydraulic conductivity of a soil is a function of the ESP and is related to the Sodium Adsorption Ratio (SAR); the higher the SAR and the lower the electrolyte concentration of the percolating solution, the larger the hydraulic conductivity reduction. A further factor to consider in respect of wastewater irrigation is the high content of nutrients which might promote microbial growth, with consequent reduction in soil permeability and hydraulic conductivity.

Another aspect of agricultural concern is the effect of dissolved solids in the irrigation water on the growth of plants. Dissolved salts increase the osmotic potential of soil water and an increase in osmotic pressure of the soil solution increase the amount of energy which plants must expend to take up water from the soil. As a result, respiration is increased and the growth and yield of most plants decline progressively as osmotic pressure increases. Although most plants respond to salinity as a function of the total osmotic potential of soil water, some plants are susceptible to specific ion toxicity. Many of the ions which are harmless or even beneficial at relatively low concentrations may become toxic to plants at high concentrations, either through direct interference with metabolic processes or through indirect effects on other nutrients, which might be rendered inaccesible.

III - Health hazards

The potential risk of infection to humans, animals and plants from land application of treated wastewater is attributable to the presence of pathogenic organisms in the raw wastewater. It is clear from the many studies to date (Feachem *et al.*, 1983; Gerba *et al.*, 1975) that, under favourable conditions, enteric pathogens can survive for extremely long periods of time on crops, in water or in the soil (**Table 1**). Factors that affect survival include the number and type of organisms, soil organic matter content, temperature, humidity, pH, amount of rainfall, amount of sunlight, protection provided by foliage, and competitive microbial flora. The survival of pathogens in soil has been reported to vary from a few hours to several months. Organisms such as *Vibrio cholera* have relatively short survival times, whereas other pathogens, including some bacterial species, ascaris ova and enteric viruses, appear to be highly resistant to environmental stress. It is thus evident that irrigation of health-sensitive crops (including fruits and vegetables eaten uncooked) with raw or partially-treated wastewater can present real health risks.

Despite the extensive worldwide practice of nightsoil and sludge fertilization and wastewater irrigation dating back many years, there are few epidemiological studies that have established definitive adverse health impacts of the consumption of food grown in this way. Shuval *et al.* (1984) have reported one of the earliest evidences connecting agricultural wastewater reuse with the occurence of disease. In areas of the world where helminthic diseases caused by Ascaris and Trichuris spp. are endemic in the population, and where raw untreated wastewater is used to irrigate salad crops and/or other vegetables which are generally eaten raw, transmission of these infections has been found to occur through the reuse channel. A study in West Germany (reported by Gunnerson *et al.*, 1984), provides additional evidence to support this hypothesis. Further evidence exists (as reported by Shuval *et al.*, 1984 and Gunnerson *et al.*, 1984), showing that cholera could be transmitted through the same channel. There is also limited epidemiological evidence indicating that beef tapeworm (*Taenia saginata*) has been transmitted to the population consuming the meat of cattle grazing on wastewater-irrigation fields, or fed crops from such fields. Reports from Melbourne, Australia and Denmark (reviewed by Gunnerson *et al.*, 1984), strongly confirmed this. Although the reported incidence of diseases among workers on sewage farms has been inconclusive, there is always a potential risk associated with direct contact of wastewater with hands, which might then contaminate food. Another potential problem is that of possible inhalation of aerosolised sewage containing pathogens from spray irrigation. Shuval (1977) estimated that between 0.1% and 1% of the sewage sprayed into the air forms aerosols which are capable of being carried considerable distances by wind.

The susceptibility of the population to long-term exposure to low levels of toxic chemicals, through the consumption of groundwater into which these materials have leached, is also of concern. Although studies have indicated that only negligible amounts of such toxic chemicals normally move 30 cm beyond the point of application within the soil, it is possible that long-term effluent reuse and eventual accumulation of toxic materials in the soil might lead ultimately to their mobilization and result in an increasing concentration showing up in groundwater. Numerous studies have indicated that the content of certain toxic metals in plant tissues is directly proportional to the concentration of such metals within the soil root zone. Thus, long-term application of wastewater in irrigation poses the risk of plants having high levels of toxic materials in their tissues and the FAO (Ayers and Westcot, 1985) recommends some maximum concentrations for phytotoxic elements in irrigation water.

IV - Wastewater quality for irrigation use

1. Effluent quality criteria based on health requirements

Developments of standards and water quality criteria for effluent reuse in irrigation have mainly evolved from a consideration of health risks. In the United States, state health departments or agencies responsible for reuse activities formulate policy or decide on specific projects primarily on the basis of concern about infectious agents, accepting that most other constituents in reclaimed water would pose no immediate substantial harm in the rare case of accidental ingestion. For example, the State of California has established standards (California State Department of Public Health, 1968) which require that the reclaimed water for irrigating food crops at all times must be adequately disinfected and filtered, with median coliform count no more than 2.2/100 ml. A World Health Organisation (WHO, 1973) Committee of Experts on the subject recommended that crops eaten raw should be irrigated only with biologically treated effluent that had been disinfected to achieve a coliform level of not more than 100/100 ml in 80% of the samples.

However, a recent meeting in Engelberg, Switzerland, sponsored by the World Bank and WHO to review the health aspects of wastewater and excreta use in agriculture and aquaculture, concluded that many standards previously recommended were unjustifiably restrictive and not supported by currently available epidemiological evidence (International Reference Centre for Wastes Disposal, 1985). It was recommended that WHO should initiate revision of its 1973 Technical Report No. 517 in collaboration with other interested agencies, such as the World Bank, the FAO and the UN Environment Programme (UNEP). On the basis of a tentative model for the health risks associated with the use of **untreated** wastewater and excreta, the Engelberg Report included recommendations for the microbiological quality of treated wastewaters to be used for agricultural irrigation. These recommendations were approved by a subsequent meeting of experts and proposed as guidelines for the microbiological quality of wastewater for use in agriculture (Mara and Cairncross, 1987). In the form shown in **Table 2**, these guidelines are expected to be included in a revision of the original WHO Technical Series Report No. 517. For the first time, a guideline for the helminthic quality of treated wastewater is introduced. The quality guideline for restricted irrigation is intended as protection for the health of agricultural labourers but makes no allowance for future improvements in the design and control of irrigation systems. Guidelines for unrestricted irrigation are related to the need to protect the health of the consumers of crops (principally vegetables).

2. Effluent quality criteria based on agronomic requirements

Apart from effluent quality criteria related to health, there is a need to be concerned about the quality of irrigation water in terms of its effects on the soil and on crops. It must be realised that it is not possible to cover all local situations when preparing water quality criteria and the approach has been to present guidelines that stress the management needed to successfully use water of a certain quality. The exact choice in practice must be made at the planning stage, taking account of the specific local conditions. Guidelines for evaluating irrigation water quality applicable to the local conditions encountered are given by the FAO (Ayers and Westcot, 1985).

V - Appropriate wastewater treatment for agricultural reuse

1. Pre-application treatment

Although irrigation with wastewater is in itself an effective form of wastewater treatment (such as in slow-rate land treatment), some degree of treatment must be provided to untreated municipal wastewater before it can be used for agricultural or landscape irrigation. The degree of pre-application treatment is a key factor in satisfactory operation and performance of a wastewater-soil-plant system.

The required quality of effluent will depend on the crop or crops to be irrigated, the soil conditions and the system of irrigation adopted. Through crop restriction and selection of irrigation systems which minimize health risk, the level of wastewater treatment can be reduced. Adopting as low a level of treatment as possible is desirable in developing countries, not only from the point of view of cost but also in acknowledgement of the difficulty of operating complex systems reliably. In many locations it will be better to design the reuse system to accept a low-grade of effluent rather than rely on advanced treatment processes producing a reclaimed effluent which continuously meets a stringent quality standard.

Nevertheless, there will be locations where a higher-grade effluent is necessary and it is essential that information on the performance of a wide range of wastewater treatment technology should be made available. Unfortunately, few performance data on wastewater treatment plants in developing countries are available and even then they would not normally include effluent quality parameters of importance in irrigation reuse.

The principal object of sewage treatment is to allow human and industrial effluents to be disposed of without danger to human health or unacceptable damage to the natural environment. Hence the most appropriate wastewater treatment to be used for irrigation is that which will produce an effluent which meets the recommended microbiological and chemical quality guidelines both at low cost and with minimal operational and maintenance requirements (Arar, in press).

The design of wastewater treatment plants has usually been based on the need to reduce organic and suspended loads to limit pollution of the environment. Pathogen removal has very rarely been an objective. For reuse of effuents in agriculture, this must now be of primary concern and treatment processes should be selected and designed accordingly (Hillman, in press).

2. Removal of microbiological constituents

A - Degree of treatment

The degree of removal of microbiological constituents by a wastewater treatment process is best expressed in terms of $\log_{10}$ units. To achieve the Engelberg guideline quality for unrestricted irrigation, a bacterial reduction of at least 4 log units, and a helminth egg removal of 3 log units are required in treating typical municipal wastewater. Helminth removal alone will be sufficient to protect field workers. A lesser degree of removal can be considered if other health protection measures are envisaged, or if the quality will be further improved after treatment. This can occur by dilution in naturally occuring waters, by prolonged storage, or by transport over long distances in a river or canal.

B - Conventional processes

Conventional wastewater treatment processes (plain sedimentation, activated sludge, biofiltration, aerated lagoons and oxidation ditches) are not able, unless supplemented by disinfection, to produce an effluent which complies with the Engelberg guideline for unrestricted irrigation. Moreover, conventional wastewater treatment systems are not generally effective for helminth egg removal. **Table 3** shows expected removal efficiencies in various wastewater treatment processes in respect of the major microbiological parameters of health concern.

C - Waste stabilization ponds

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 about 11 days can be designed to achieve adequate helminth removal, while about twice that time would usually be required to reach the bacterial guideline in a hot climate. Temperature is an important environmental factor affecting the efficiency of bacterial removal in stabilization ponds, as illustrated in **Figure 1**. The high degree of confidence with which pond series can meet the Engelberg guidelines, as indicated in **Table 4**, is only one of the many advantages of pond systems.

A recently published WHO Manual on Stabilization ponds (World Health Organisation, 1987) provides advice on planning, design and maintenance and emphasizes their low cost and simple operation. The only disadvantage of pond systems is the relatively large area of land that they require.

D - Soil-aquifer treatment

Soil-aquifer treatment offers the advantages of low-cost purification and requires much less land (approx. 0.5 to 1 m^2 per inhabitant) than stabilization ponds (5 m^2 per inhabitant for secondary ponds or 10 m^2 per inhabitant for ponds receiving raw sewage). This technique (incorporating infiltration basins, the unsaturated zone and the aquifer) is adapted to permeable and aquifer soils.

E - Tertiary treatment

Disinfection – usually chlorination – of raw sewage has never been achieved in practice with full success. 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 most helminth eggs totally unharmed. To reduce chlorination costs and assist in helminth removal, rapid-gravity sand filtration is often necessary as an additional tertiary treatment process.

A more appropriate tertiary treatment option is to add one or more ponds in series to a conventional treatment plant. The addition of polishing ponds is a suitable measure to upgrade an existing wastewater treatment plant so that the effluent can be reused in irrigation of agricultural crops or greenspaces.

F - Treatment process monitoring

In operating wastewater treatment plants, the responsible agency will wish to ensure that the processes are producing the quality of effluent expected and will 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, and will require continuous monitoring to check if the effluent is complying with the guidelines. On the other hand, a properly designed series of stabilization ponds will not have such daily variability of performance and a less rigorous and less costly monitoring procedure can be adopted.

3. Removal of inorganic constituents

A - Conventional wastewater treatment

Conventional primary and secondary sewage treatment processes have a limited effect in removing inorganic components from sewage and will have only marginal effects on those effluent quality parameters of agricultural concern in reuse. The level of salinity will not be reduced significantly in passage through a conventional sewage treatment plant and the balance of sodium with other cations will not be changed to any extent. Physico-chemical treatment processes are more likely to be effective in the removal of inorganic constituents of wastewaters and may have to be considered where adverse environmental impacts will result from the long-term use of saline effluent in irrigation.

Primary settling removes a proportion of metals which are either insoluble or adsorbed onto particulate matter. Further metal removal occurs in the secondary biological stage of wastewater treatment, usually through adsorption of dissolved metals or fine particulate metals onto sludge flocs, as reported by Brown *et al.* (1973) and Oliver and Cosgrave (1974). Brown *et al.* found that for some metals (chromium, copper and lead) removal efficiency was greater in secondary treatment than in a primary process, while for zinc, the average removal percentage was similar at both stages. Lester (1983) has indicated, however, that metal removal at these stages shows great variability (**Table 5**). The removal efficiency of advanced wastewater treatment processes can also be highly variable, with respect to both the process and the metal it removes.

B - Stabilization ponds

In recent years there have been discussions on the utilization of phytoplanktonic algae, in algal ponds, for the removal of residual metals from wastewater. Several authors (Beckers, 1983; Filip *et al.*, 1979; and Oswald, 1972) have concluded that this technique is an economic method for removing heavy metals from wastewater, resulting in high quality effluent and valuable algal biomass which could be used for different purposes, one being the production of biogas.

The combination of lime treatment and stabilization ponds might sometimes be an optimal treatment system when the ratio of sodium to calcium in sewage is not satisfactory. Pescod and Alka (1985) illustrated the feasibility of such treatment for the case of effluent reuse in Al Ain, United Arab Emirates and stressed the importance of taking the potential long-term soil damage into account in decisions on effluent reuse.

VI - Crop restriction

Even if the Engelberg guideline for treated wastewater quality is not fully met, it may still be possible to irrigate selected agricultural crops without risk to the consumer. Crops can be grouped into three broad categories with regard to the degree to which health protection measures are required:

Category A – Protection needed only for field workers.

This includes industrial crops such as cotton, sisal, grains and forestry, as well as food crops for canning.

Category B – Further measures may be needed.

This applies to pasture and green fodder crops and also to tree crops and fruit and vegetables which are peeled or cooked before eating.

Category C – Treatment to Engelberg "unrestricted irrigation" guidelines is essential.

This covers fresh vegetables, spray-irrigated fruit and parks, lawns and golf courses.

Irrigation which is limited to certain crops and conditions, such as category A, is commonly referred to as 'restricted irrigation'.

Crop restriction is a strategy to provide protection to the consuming public. However, it does not provide protection to farmworkers and their families. Crop restriction is, therefore, not adequate on its own; it should be complemented by other measures, such as partial waste treatment, controlled application of the wastes, or human exposure control. Partial treatment to comply with the helminthic component of the Engelberg quality guideline would be sufficient to protect field workers in most settings, and would be cheaper than full treatment.

Crop restriction is feasible and is particularly facilitated under the following conditions:

– where a law-abiding society or strong law enforcement exists;

– where a public body controls allocation of the wastes;

– where an irrigation project has strong central management;

– where there is adequate demand for the crops allowed under crop restriction, and where they fetch a reasonable price;

– where there is little market pressure in favour of excluded crops (such as those in Category C).

Adopting crop restriction as a means of health protection in reuse schemes will require a strong institutional framework and capacity to monitor and control compliance with and enforce regulations. Farmers must be advised why such crop restriction is necessary and be assisted in developing a balanced mix of crops which fully utilizes the constant production of partially-treated wastewater. National agricultural planning should take into account the crop production potential of restricted reuse schemes so that excesses of production are avoided.

VII - Wastewater application control

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

– by flooding (border irrigation), thus wetting almost all the land surface;

– by furrows, thus wetting only part of the ground surface;

– by sprinklers, in which the soil is wetted in much the same way as by rainfall;

– by subsurface irrigation, in which the surface is wetted little, if any, but the subsoil is saturated; and

– by localized (trickle, drip or bubbler) irrigation, in which water is applied to each individual plant at an adjustable rate.

Flooding involves the least investment, but probably exposes field workers to the greatest risk.

If the effluent is not of Engelberg bacterial quality but it is still desired to use it on crops in Category B, sprinkler irrigation should not be used except for pasture or fodder crops, and border irrigation should not be used for vegetables. Subsurface or localised irrigation can give the greatest degree of health protection, as well as using water more efficiently and often producing higher yields. However, it is expensive, and a high degree of reliable treatment is required to prevent clogging of the small holes (emitters) through which water is slowly released into the soil. Bubbler irrigation, a technique developed for localised irrigation of tree crops, avoids the need for small emitter apertures to regulate the flow to each tree.

VIII - Exposure control through personal and domestic hygiene

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

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

Agricultural fieldworkers' exposure to hookworm infection can be reduced by the continuous in-field use of appropriate footwear, but this may be more difficult to achieve than it might at first appear.

Immunization is not feasible against helminthic infections, nor against most diarrhoeal diseases, but immunization of highly exposed groups against typhoid and hepatitis A may be worth considering. Additional protection may be provided by the provision of adequate medical facilities to treat diarrhoeal disease, and by regular chemotherapeutic control of intense nematode infections in children and control of anaemia. Chemotherapy and immunization cannot be considered an adequate strategy, but could be beneficial as a temporary palliative measure. Tapeworm transmission can be controlled by meat inspection.

Risks to consumers can be reduced by thorough cooking and by high standards of hygiene. Food hygiene is a theme to be included in health education campaigns, although their efficiency may often be quite low. 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.

IX - Integrating health protection measures

It will often be desirable to apply a combination of several of these measures for health protection. For example, crop restriction may be sufficient to protect consumers, but will need to be supplemented by additional measures to protect agricultural workers. Sometimes, partial treatment to a less demanding quality standard may be sufficient if combined with other measures. The feasibility and efficacy of any combination will depend on many factors, which must be carefully considered before any option is put into practice. These will include the following:

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

For example, if funds or land are not available for wastewater treatment to the Engelberg guideline quality for unrestricted irrigation (**Table 2**), then some of the other three types of health protection measure will be needed. In some cases, suitable crop restriction can make it unnecessary to take any further measures to protect the public. On the other hand, if staff shortages and existing practices make it impossible to implement and enforce crop restrictions effectively, then recourse must be made to other methods.

Reuse of wastewater is an activity which requires the involvement of several ministries and government agencies, especially the Ministries of Health and Agriculture. Coordination will be essential if reuse schemes are to be planned rationally and implemented effectively and economically. A suitable institutional framework and appropriate legislation are necessary if full advantage is to be taken of the various health and environmental protection measures available.

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Table 1: Survival times of selected excreted pathogens in soil and on crop surfaces at 20-30°C

Pathogen		Survival time (days) in soil	Survival time (days) on crops
Viruses			
Enteroviruses *		< 100 but usually < 20	< 60 but usually < 15
Bacteria			
Faecal coliforms		< 70 but usually < 20	< 30 but usually < 15
Salmonella	spp.	< 70 but usually < 20	< 30 but usually < 15
Vibrio cholerae		< 20 but usually < 10	< 5 but usually < 2
Protozoa			
Entamoeba hystolytica	cysts	< 20 but usually < 10	< 10 but usually < 2
Helminths			
Ascaris lumbricoides	eggs	many months	< 60 but usually < 30
Hookworm larvae		< 90 but usually < 30	< 30 but usually < 10
Taenia saginata	eggs	many months	< 60 but usually < 30
Trichuris trichiura	eggs	many months	< 60 but usually < 30

* Includes polio-, echo-, and coxsackieviruses
Source: Feachem et al. (1983)

Table 2: Tentative microbiological quality guidelines for wastewater use in agriculture

Reuse process	Intestinal nematodes (2) (arithmetic mean no. of viable eggs per litre)	Faecal coliforms (geometric mean no. per 100 ml)
Restricted irrigation (3)		
Irrigation of trees, industrial crops, fodder crops, fruit trees (4) and pasture (5)	≤ 1	not applicable (3)
Unrestricted irrigation		
Irrigation of edible crops, sports fields and public parks (6)	≤ 1	≤ 1000 (7)

(1) In specific cases, local epidemiological, socio-cultural and hydrogeological factors should be taken into account and these guidelines modified accordingly
(2) Ascaris, Trichuris and hookworms
(3) A minimum degree of treatment equivalent to at least a 1-day anaerobic pond followed by a 5-day facultative pond and a 5-day maturation pond or its equivalent is required in all cases
(4) Irrigation should cease two weeks before fruit is picked, and no fruit should be picked off the ground
(5) Irrigation should cease two weeks before animals are allowed to graze
(6) Local epidemiological factors may require a more stringent standard (for example, < faecal coliforms/100 ml) for publics lawns, specially hotel lawns in tourist areas
(7) When edible crops are always consumed well-cooked, this recommendation may be less stringent

Source: International Reference Centre for Wastes Disposal (1985)

Table 3: Expected removal of excreted bacteria and helminths in various wastewater treatment processes

Treatment process	Removal (log10 units) of			
	Bacteria	Helminths	Viruses	Cysts
Primary sedimentation				
Plain	0—1	0—2	0—1	0—1
Chemically assisted (a)	1—2	1—3 (E)	0—1	0—1
Activated sludge (b)	0—2	0—2	0—1	0—1
Biofiltration (b)	0—2	0—2	0—1	0—1
Aerated lagoon (c)	1—2	1—3 (E)	1—2	0—1
Oxidation ditch (b)	1—2	0—2	1—2	0—1
Disinfection (d)	2—6 (E)	0—1	0—4	0—3
Waste stabilisation ponds (e)	1—6 (E)	1—3 (E)	1—4	1—4
Effluent storage reservoirs (f)	1—6 (E)	1—3 (E)	1—4	1—4

(a) Further research is needed to confirm performance
(b) Including secondary sedimentation
(c) Including settling pond
(d) Chlorination, ozonation
(e) Performance depends on number of ponds in series
(f) Performance depends on retention time, which varies with demand
(E) With good design and proper operation the Engelberg guidelines are achievable
Source: Mara and Cairncross (1987)

Table 4: Reported effluent quality for several series of waste stabilization ponds, each with a retention time > 25 days

Pond system	No. of ponds in series	Effluent quality (FC/100ml) *
Australia, Melbourne	8—11	100
Brazil, Extrabes	5	30
France, Cogolin	8	100
Jordan, Amman	10	30
Peru, Lima	5	100
Tunisia, Tunis	4	200

* FC = faecal coliforms

Source: Bartone and Arlosoroff (in press)

Table 5: Removal of selected trace elements in wastewater treatment processes

Metal	Percentage removal		
	Primary	Secondary	Tertiary
Cadmium	72	variable	71
Chromium	51	variable	94
Copper	71	variable	78
Lead	73	variable	86
Nickel	23	variable	-
Zinc	74	variable	21

Source: Lester (1983)