# Beyond Water Disinfection – Introduction

## Documented Health Risks Associated With Wastewater Use

The use of domestic wastewater for crop production has been practised for several centuries in one form or another. Prior to the 1940s, most wastewater use occurred on "sewage farms" or areas specifically designated for such use. One of the oldest in the world is the Werribee Farm which serves the City of Melbourne, Australia. This large well-managed farm was established in 1897 and is still in operation today, irrigating some 10 000 ha with wastewater. The impetus for these "sewage farms" was to minimize or prevent pollution in rivers and conserve water and nutrients to improve agriculture (Shuval, 1991). Few of these "sewage farms" still exist today; most were ill-conceived, inadequately funded and poorly regulated, and were eventually abandoned because of public health concerns.

In the mid 1940s, domestic wastewater use again gained increased attention, especially in arid and semi-arid areas that suffer from insufficient overall water supplies. Although the same early motivations for wastewater use remained, the newer areas using wastewater were focused on ensuring they minimized or prevented potential public health problems. The principal concern was use of wastewater on crops normally eaten raw. The change in focus was driven by a better understanding of public health problems and the desire to improve public health standards.

The need to improve public health protection prompted a number of state health departments in the United States to establish guidelines and regulations to control the public health aspects of wastewater use in agriculture. These initial guidelines provided a rational basis for continuing wastewater use by agriculture while meeting strict public health criteria. One important criterion was to restrict the use of partially treated sewage to crops that are generally cooked before being consumed and allow only water that has gone through advanced wastewater treatment and microbial disinfection to be applied to crops normally eaten raw.

Many nations adopted the very strict microbial standards for wastewater use that were developed in California (USA) and elsewhere. In reality these microbial standards were almost unattainable in most wastewater treatment systems, therefore many poorer or developing countries abandoned plans for wastewater use (Shuval *et al*., 1986a). The primary reason was the realization that producing effluent with a microbial quality sufficient for unrestricted irrigation required costly sophisticated treatment technology. Some of these countries shifted their focus in wastewater use to unrestricted areas of use coupled with crop restrictions. Most, however, did not have a strong institutional structure to control cropping. The result has been little improvement in public health conditions associated with wastewater use. Untreated or partially treated wastewater continues to be used directly for unrestricted irrigation or is discharged to surface water channels where unintended use by agriculture occurs when water is appropriated for irrigation use.

Over the past 20 years there has been a strong revival of interest in the controlled use of wastewater for crop irrigation. In addition to consumer health protection, the main reasons are:

- scarcity of alternative water supplies;
- need to increase local food production;
- need to improve rural health standards; and
- concern for the increasing degree of surface water contamination that is limiting further development and making further progress in eliminating public health problems difficult (Witt and Reiff, 1991).

The last of these reasons is driven by an increased public awareness of the need for clean water supplies and rivers. This perception, coupled with the population explosion in the urban areas, has resulted in strongly competing demands for water supplies, especially the best quality supplies. Agricultural and rural communities are often left to use the least desirable water supplies including those that have been contaminated with an increasing level of urban wastewater discharges. For example, Mexico is studying the cost-benefit of doubling irrigation with wastewater in the next decade. This would be a means of releasing clean water supplies to cover the domestic needs of nearly 30 million people (Cifuentes *et al*., 1991/92). This situation is likely to continue in many developing countries until reliable treatment and disposal works are in place. The level of contamination in rivers and irrigation water supplies may be a serious constraint for developing countries as they strive to produce an adequate and safe food supply in the future.

During the next 20 years while reliable wastewater treatment facilities are planned and constructed, agricultural and water resource planners must face two dilemmas:

- manage food production and cropping with the water resource system at the present level of microbial contamination; and
- plan for future wastewater use schemes which minimize or prevent the present level of microbial contamination and allow the wastewater to be a crop production resource.

There is sufficient information and technology available to plan and execute a wastewater use scheme properly. The key to a successful programme is to control potential public health problems. The differences in approach are centred on where the control or application of public health standards takes place: the point of treatment and discharge; the area where wastewater is used; or the actual point of use for crop production. In reality, the lack of treatment and well defined areas using wastewater in most developing countries will focus control for the near term on the point of use.

The simplest approach is to control the quality of wastewater at its point of treatment and discharge. This places regulation and control at the institutional level as treatment is normally conducted by a public agency. The quality of the discharge can then be regulated to fit the type of use. This alternative assumes that the treatment system is well managed and maintained and produces a reliable quality of effluent. This approach is utilized in the United States, Canada, and Europe and in many cases requires an advanced level of treatment technology. In most developing countries for the present, the lack of treatment works makes this a long-term goal. New approaches to treatment technology in developing countries (Shuval *et al*., 1986a) will assist in implementing this technology sooner than originally planned, but financial constraints are still likely to make this a long-term effort.

The alternative to controlling the quality of wastewater at its point of treatment and discharge is to control the place where wastewater can be used. This alternative moves around the need for immediate treatment of the wastewater and places an emphasis on controlling where the discharge is used. Under this alternative, wastewater use would be within a defined area and the emphasis would shift to controlling the type of crop production in that area. This approach requires a broader based institutional structure and a strong ability to control cropping in the wastewater use area. The key element is a defined area where cropping restrictions can be practised. This approach is utilized in several developing countries including Tunisia, Mexico, Peru and Kuwait.

The two previous alternatives assume there is either a strict control of wastewater treatment or a well defined area of use. In most developing countries lack of treatment, poorly maintained treatment works, lack of well defined use areas and unrestricted discharges to rivers and canals make using these two alternatives ineffective in the near term. Until treatment works are installed and wastewater use areas defined, most developing countries will be faced with trying to control cropping on a broad scale. Where unrestricted discharges occur to rivers and canals and widespread water appropriation occurs from these water bodies, the dilemma will be whether or not a strong institutional structure is available to implement and enforce cropping restrictions on a broad scale. An alternative approach to crop restrictions is to identify safe production areas and then utilize market pressures to implement a programme that promotes a crop produced in this safe environment.

This document describes an approach that promotes safe production areas. The programme involves evaluating the quality of irrigation water presently used, identifying safe production areas for high-risk crops, such as vegetable crops, and, through a water quality certification programme, promoting the safety of that produce. The goal is to use market pressures to promote safe vegetable products. The programme described here is based upon on an effort in Chile (1992) to control the quality of water used in vegetable production as the irrigation water in Chile was identified as a major mechanism in the spread of cholera and other gastrointestinal diseases (FAO, 1993; Shuval, 1993).

## Health Risks Associated With Wastewater Use

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### Introduction

There are agronomic and economic benefits of wastewater use in agriculture. Irrigation with wastewater can increase the available water supply or release better quality supplies for alternative uses. In addition to these direct economic benefits that conserve natural resources, the fertilizer value of many wastewaters is important. FAO (1992) estimated that typical wastewater effluent from domestic sources could supply all of the nitrogen and much of the phosphorus and potassium that are normally required for agricultural crop production. In addition, micronutrients and organic matter also provide additional benefits.

There are many successful wastewater use schemes throughout the world where nutrient recycling is a major benefit to the project (Pescod and Arar, 1988; FAO, 1992). Rarely, however, is a scheme laid out or planned on the basis of nutrient recycling. The primary constraint to any wastewater use project is public health. Wastewater, especially domestic wastewater, contains pathogens which can cause disease spread when not managed properly. The primary objective of any wastewater use project must therefore be to minimize or eliminate potential health risks.

In most developing countries direct wastewater use projects are normally centred near large metropolitan areas. These schemes often only use a small percentage of the wastewater generated. The result is that indirect use of wastewater prevails in most developing countries.

Indirect use occurs when treated, partially treated or untreated wastewater is discharged to reservoirs, rivers and canals that supply irrigation water to agriculture. Indirect use poses the same health risks as planned wastewater use projects, but may have a greater potential for health problems because the water user is unaware of the wastewater being present. Indirect use is likely to expand rapidly in the future as urban population growth outstrips the financial resources to build adequate treatment works. Where indirect use occurs, the primary objective must also be to ensure that it is in a manner that minimizes or eliminates potential health risks.

The health hazards associated with direct and indirect wastewater use are of two kinds: the rural health and safety problem for those working on the land or living on or near the land where the water is being used, and the risk that contaminated products from the wastewater use area may subsequently infect humans or animals through consumption or handling of the foodstuff or through secondary human contamination by consuming foodstuffs from animals that used the area (WHO, 1989).

The survival of pathogens and how they infect a new host needs to be understood in developing a programme to eliminate or minimize health risks. The importance and complexity of the rural health problem for those living and working where wastewater is used is beyond the scope of this document.

The focus of this document will be on the concern with those who handle, prepare or eat the crop after it has been harvested. The health issues associated with wastewater use for the handlers, preparers and consumers of the crop can be broken down into a series of questions (each will be covered in more detail in subsequent sections of this document):

*What types of pathogens are likely to be present in the wastewater?*
*How many and what types of pathogens reach the field or crop?*
*Are these pathogens likely to survive in sufficient numbers and for sufficient time to be infectious to the handler or consumer?*
*How significant is the infection route for the various pathogens?*
*Which crops carry the highest potential for carrying infections to the handler or consumer?*
*Are there guidelines or limits available to measure the potential for health risk?*

## 2. Types of pathogens present in wastewater

Wastewater or natural water supplies into which wastewater has been discharged, are likely to contain pathogenic organisms similar to those in the original human excreta. Disease prevention programmes have centred upon four groups of pathogens potentially present in such wastes: bacteria, viruses, protozoa and helminths. There have been extensive reviews published on the range of these pathogenic organisms normally found in human excreta and wastewater. The most complete reviews are Feachem *et al*. (1983), Rose (1986) and Shuval *et al*. (1986a). The following short discussion is extracted from those reviews and is presented to establish a basic understanding of the pathogens and their abundance.

**Bacteria.** The faeces of a healthy person contains large numbers of bacteria (> $10^{10}$/g), most of which are not pathogenic. Pathogenic or potentially pathogenic bacteria are normally absent from a healthy intestine unless infection occurs. When infection occurs, large numbers of pathogenic bacteria will be passed in the faeces thus allowing the spread of infection to others. Diarrhoea is the most prevalent type of infection, with cholera the worst form. Typhoid, paratyphoid and other *Salmonella* type diseases are also caused by bacterial pathogens.

**Viruses.** Numerous viruses may infect humans and are passed in the faeces (> $10^9$/g). Five groups of pathogenic excreted viruses are particularly important: adenoviruses, enteroviruses (including polioviruses), hepatitis A virus, reoviruses and diarrhoea-causing viruses (especially rotavirus).

**Protozoa.** Many species of protozoa can infect humans and cause diarrhoea and dysentery. Infective forms of these protozoa are often passed as cysts in the faeces and humans are infected when they ingest them. Only three species are considered to be pathogenic: *Giardia lamblia, Balantidium coli* and *Entamoeba histolytica*. An asymptomatic carrier state is common in all three and may be responsible for continued transmission.

**Helminths.** There are many species of parasitic worms or helminths that have human hosts. Some can cause serious illnesses and the ones that pass eggs or larval forms in the excreta are of importance in considering wastewater use. Most helminths do not multiply within the human host, a factor of great importance in understanding their transmission, the ways they cause disease and the effects that environmental change will have on their control. Often the developmental stages (life cycles) through which they pass before reinfecting humans are very complex. Those that have soil, water or plant life as one of their intermediate hosts are extremely important in any scheme where wastewater is used directly or indirectly.

The helminths are classified in two main groups: the roundworms (nematodes) and worms that are flat in cross section. The flatworm, in turn, may be divided into two groups: the tapeworms which form chains of helminths "segments" and the flukes which have a single, flat, unsegmented body. Most of the roundworms that infect humans and also the schistosome flukes have separate sexes. The result is that transmission depends upon infection with both male and female worms and upon meeting, mating and egg production within the human body.

**Pathogens that reach the field or crop**

All the pathogens discussed in the previous section have the potential to reach the field. From the time of excretion, the potential for all pathogens to cause infection usually declines due to their death or loss of infectivity. The ability of an excreted organism to survive outside the human body is referred to as its persistence. For all the organisms, survival is highly dependent on temperature with greatly increased persistence at lower temperatures.

The first exposure of excreted pathogenic organisms outside the body is usually in water. This blend with freshwater is often referred to as sewage. This sewage is then either subjected to treatment prior to discharge, used directly for crop production or discharged to a watercourse where indirect use then occurs downstream. There are many studies on the survival or persistence of excreted organisms in water and sewage. A summary is shown in Table 1.

Many bacterial populations decline exponentially so that 90 to 99 percent of the bacteria are lost relatively quickly. Survival of bacteria, like many other organisms, depends greatly on how hostile the environment is including other micro-organisms in the water that might provide competition or predation. Bacteria often survive longer in clean water than in dirty water but survival in excess of 50 days is most unlikely and at 20-30°C, 20-30 days is a more common maximum survival time.

Viral survival may be longer than bacterial survival and is greatly increased at lower temperatures. In the 20-30°C range, two months seems a typical survival time, whereas at around 10°C, nine months is a more realistic figure. There is evidence that virus survival is enhanced in polluted waters, presumably as a result of some protective effect that the viruses may receive when they are adsorbed onto suspended solid particles in dirty water.

TABLE 1: Survival times of excreted pathogens in freshwater and sewage at 20-30°C

| Pathogen | Survival time (days) |
|---|---|
| Viruses[a] | |
| Enteroviruses[b] | <120 but usually <50 |
| Bacteria | |
| Faecal coliform[a] | <60 but usually <30 |
| *Salmonella* spp.[a] | <60 but usually <30 |
| *Shigella* spp.[a] | <30 but usually <10 |
| *Vibrio cholera*[c] | <30 but usually <10 |
| Protozoa | |
| *Entamoeba histolytica* cysts | <30 but usually <15 |
| Helminths | |
| *Ascaris lumbriocoides* eggs | Many months |

a. In seawater, viral survival is less, and bacterial survival is very much less than in freshwater.
b. Includes polio-, echo-, and coxsackieviruses.
c. *V. cholera* survival in aqueous environments is still uncertain. Source: Feachem *et al*. (1983).

Protozoal cysts are poor survivors in any environment. A likely maximum in sewage or polluted water would not exceed that shown in Table 1 for *Entamoeba histolytica*. Helminth eggs vary from the very fragile to the very persistent. One of the most persistent is the *Ascaris* egg which may survive for a year or more. The major concern for this helminth is that the soil is its intermediate host prior to reinfecting humans.

The survival times shown in Table 1 may be altered by the type or degree of wastewater treatment given the sewage water prior to use or discharge to a water body. Different treatment processes remove pathogens to varying degrees. What is not well understood in wastewater treatment systems is whether the treatment process produced an elevated level of hostile environment that accelerated the death of the organism or whether the treatment process had little effect on excreted pathogens and simply allowed the necessary time for natural die-off to occur independent of the treatment process.

The critical factor to consider for wastewater use is that most wastewater treatment plants were designed to reduce organic pollution of rivers and lakes and rarely are designed to remove all risks from pathogenic organisms. Therefore, regardless of the level of treatment provided, some pathogenic organisms will reach the agricultural fields when the water is used.

In instances where the sewage water has not received treatment, the level of pathogenic organisms is likely to be higher whether the use is occurring directly from raw sewage or from raw sewage that has been blended with other water supplies. In both instances, pathogenic organisms will reach the agricultural fields. These pathogenic organisms, as with treated sewage, have the potential to contaminate both the soil and the crop depending upon how the irrigation water is used. The critical element is to understand that whether treated, partially treated, or untreated water is used, pathogenic organisms are present and the use site must be managed in a manner that minimizes or eliminates the potential for disease transmission.

**TABLE 2: Factors affecting survival time of enteric bacteria in soil**

| Soil factor | Effect on bacterial survival |
|---|---|
| Antagonism from soil microflora | Increased survival time in sterile soil |
| Moisture content | Greater survival time in moist soils and during times of high rainfall |
| Moisture-holding capacity | Survival time is less in sandy soils than in soils with greater water-holding capacity |
| Organic matter | Increased survival and possible regrowth when sufficient amounts of organic matter are present |
| pH | Shorter survival time in acid soils (pH 3-5) than in alkaline soils |
| Sunlight | Shorter survival time at soil surface |
| Temperature | Longer survival at low temperatures; longer survival in winter than in summer |

Source: Shuval *et al*. (1986a) as adapted from Gerba *et al*. (1975).

## 3. Pathogen survival under agricultural field conditions

The literature on survival times of excreted pathogens in soil and on crop surfaces has been reviewed by Feachem *et al*. (1983) and Strauss (1985). As expected there was wide variability in reported survival times which reflects the influence of environmental and analytical factors. Table 2 describes several factors affecting survival time of bacteria in soil. Many of these factors may also affect survival of other pathogenic organisms.

Knowledge of the survival of pathogens in soil and on the crop allows an initial assessment of the risk of transmitting disease via produced foodstuff or through worker exposure. WHO (1989) presented a summary of the potential survival times in agricultural cropping environments (Table 3). WHO concludes that "Available evidence indicates that almost all excreted pathogens can survive in soil... for a sufficient length of time to pose potential risks to farm workers. Pathogens survive on crop surfaces for a shorter time than in the soil as they are 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". While the length of the crop growing cycle is important, equally important is the length of time since the last irrigation cycle (potential exposure cycle). WHO (1989) points out that excreted pathogens, if they do enter an irrigated area with the irrigation water, have the potential to remain infectious for a considerable period of time thus steps must be taken to interrupt this infection cycle.

## 4. Relative health risk from wastewater use

The discussion in the previous sections show that a broad spectrum of pathogenic microorganisms including bacteria, viruses, helminths and protozoa is present in wastewater and they survive for days, weeks and at times months in the soil and on crops that come in contact with wastewater. Early approaches to measuring the health risk from these pathogenic micro-organisms centred on detection. Based upon the fact that these micro-organisms could survive, detection in any of these environments was sufficient to indicate that a public health problem existed. It was then assumed that such detection showed evidence that a real potential for disease transmission existed (Shuval *et al*., 1986a; Shuval, 1991). This is a "zero-risk" approach. Throughout the years a number of standards and guidelines have been developed on this zero-risk approach. This led to standards for wastewater use that approached those of drinking water especially where vegetable crops were being grown.

**TABLE 3: Survival times of selected excreted pathogens in soil and on crop surfaces at 20-30°C**

| Pathogen | Survival time | |
|---|---|---|
| | In soil | On crops |
| Viruses | | |
| Enteroviruses[a] | <100 but usually <20 days | <60 but usually <15 days |
| Bacteria | | |
| Faecal coliform | <70 but usually <20 days | <30 but usually <15 days |
| *Salmonella* spp. | <70 but usually <20 days | <30 but usually <15 days |
| *Vibrio cholera* | <20 but usually <10 days | <5 but usually <2 days |
| Protozoa | | |
| *Entamoeba histolytica* cysts | <20 but usually <10 days | <10 but usually < 2 days |
| Helminths | | |
| *Ascaris lumbricoides* eggs | Many months | <60 but usually <30 days |
| Hookworm larvae | <90 but usually <30 days | <30 but usually <10 days |
| *Taenia saginata* eggs | Many months | <60 but usually <30 days |
| *Trichuris trichiura* eggs | Many months | <60 but usually <30 days |

[a] Includes polio-, echo-, and coxsackieviruses.

Source: WHO (1 989) as summarized from Feachem *et al*. (1983).

**TABLE 4: Effectiveness of enteric pathogens to cause infections through wastewater irrigation related to their epidemiological characteristics**

| Enteric pathogens | Persistence in environment | Minimum infective dose | Immunity | Concurrent routes of infection | Latency/soil development stage |
|---|---|---|---|---|---|
| Viruses | Medium | Low | Long | Mainly home contact and food or water | No |
| Bacteria | Short/Medium | Medium/High | Short/Medium | Mainly home contact and food or water | No |
| Protozoa | Short | Low/Medium | None/Little | Mainly home contact and food or water | No |
| Helminths | Long | Low | None/Little | Mainly soil contact outside home and food | Yes |

Source: Shuval *et al*. (1986b).

Whether a person becomes infected actually depends on a number of additional factors, each of which adds to or diminishes the actual risk of infection. Feachem *et al*. (1983) and Shuval *et al*. (1986b) reviewed these factors and found several that are important for determining the relative health risk during wastewater use:

**Excreted load.** This refers to the concentration of pathogens passed by an infected person and represents the total number of pathogens.

**Latency.** Latency refers to the interval between the time that a pathogen is excreted and the time that it can infect a new host.

**Persistence.** Viability of a pathogen in the environment or persistence is a measure of how quickly it dies after leaving the human body.

**Multiplication.** A measure of whether a pathogen can multiply outside the human body.

**Infective dose.** Number of organisms needed to cause infection (this is not easy to predict).

**Host response.** A measure of the response (immunity) once an individual has received a dose of an infective agent.

**Non-human hosts.** Some infections are confined strictly to humans while others may need an intermediate host prior to reinfection.

Shuval *et al*. (1986b) developed a theoretical epidemiological model based on the above factors. The model looked at their relationship to the probability that one of the four enteric pathogen groups described earlier would cause infections in humans through wastewater irrigation. The following factors were considered necessary to cause a high probability of infection:

*long persistence in the environment;*
*low minimal infective dose;*
*short or no human immunity;*
*minimal concurrent transmission through other routes such as food, water and poor personal or domestic hygiene; and*
*long latent period and/or soil development stage required.*

Table 4 presents the summary of how Shuval *et al*. (1986b) rated the five factors when considering the enteric pathogen groups.

The Shuval model shows that helminth diseases, if they are endemic, will be very effectively transmitted by irrigation with raw wastewater. On the other hand, the enteric virus diseases should be the least effectively transmitted by irrigation with raw wastewater. The bacterial and protozoan diseases rank between these two extremes. Shuval *et al*. (1986b) ranked the pathogens in the following descending order of risk:

1. High: **Helminths** (the intestinal nematodes - *Ascaris, Trichuris*, hookworm and *Taenia*)
2. Lower: **Bacterial infections** (i.e. cholera, typhoid and shigellosis) and **Protozoan infections** (i.e. ameobiasis, giardiasis)
3. Least: **Viral infections** (viral gastroenteritis and infectious hepatitis)

This ranking is consistent with the theoretical considerations noted by Feachem *et al*. (1983) where the determinations were made on factors other than wastewater use. Shuval *et al*. (1986b) reviewed the available epidemiological evidence to determine whether the theoretical model fitted the empirical evidence. This review concluded that there is evidence of disease transmission in association with the use of raw or partially treated wastewater. This evidence points most strongly to the helminths as the number one problem, particularly in developing countries. There was limited transmission of bacterial and virus disease. The empirical evidence therefore points to the usefulness of the theoretical model and especially the priority ranking for the potential threat of disease transmission. The Shuval model (Table 4) and the rationale behind the ranking of pathogens shown above were reviewed in the World Bank/WHO-sponsored Engelberg Report (IRCWD, 1985) that obtained the endorsement of an international group of environmental experts and epidemiologists.

## 5. Agronomic conditions that minimize disease spread when wastewater is used for irrigation

The previous discussions demonstrate that a potential for disease transmission exists when wastewater is used for irrigation. Pathogens that are brought in with the wastewater can survive in the soil or on the crop. The actual risk of disease transmission, however, is related to whether this survival time is long enough to allow transmission to a susceptible host. The crop and the field are the link between the pathogen in the wastewater and the potential for infection. The factors controlling transmission of disease are agronomic, such as the crop grown, the irrigation method used to apply the wastewater, and the cultural and harvesting practices used.

The choice of crops for wastewater use areas depends upon a number of factors. The crop grown must be suitable to the agronomic conditions in the area. Determining factors include climate, soils, available water, pest control, marketing and farmer skills. These and other general agronomic problems are discussed in numerous publications and will not be discussed in detail here. Another factor of importance for wastewater use areas is water quality. The impact can be on the soil, on crop growth, or it can affect the consumer of that crop. Water quality impacts on the soil and on crop growth are discussed in detail in Ayers and Westcot (FAO, 1985) and will not be covered here. The microbiological quality of the water can directly affect the consumer of that crop because of the risk of infection from that crop. Shuval *et al*. (1986a) defined three levels of risk in selecting a crop to be grown. They are presented here in increasing order of public health risk:

**Low(est) risk to consumer but field worker protection still needed**

1. Crops not for human consumption (for example cotton, sisal).
2. Crops normally processed by heat or drying before human consumption (grains, oilseeds, sugar beet).
3. Vegetables and fruit grown exclusively for canning or other processing that effectively destroys pathogens.
4. Fodder crops and other animal feed crops that are sun-dried and harvested before consumption by animals.
5. Landscape irrigation in fenced areas without public access (nurseries, forests, green belts).

**Increased risk to consumer and handler**

1. Pasture, green fodder crops.
2. Crops for human consumption that do not come into direct contact with wastewater, on condition that none must be picked off the ground and that spray irrigation must not be used (tree crops, vineyards, etc.).
3. Crops for human consumption normally eaten only after cooking (potatoes, eggplant, beetroot).

4. Crops for human consumption, the peel of which is not eaten (melons, citrus fruits, bananas, nuts, groundnuts)
5. Any crop not identified as high-risk if sprinkler irrigation is used.

**Highest risk to consumer, field worker and handler**

1. Any crops eaten uncooked and grown in close contact with wastewater effluent (fresh vegetables such as lettuce or carrots, or spray-irrigated fruit).
2. Landscape irrigation with public access (parks, lawns, golf courses).

Another path of infection is from direct contact with the crop or soil in the area where wastewater was used. This path is directly related to the level of protection needed for field workers. The only feasible means of dealing with the worker safety problem is prevention. The following are a few of many low and high risk situations:

**Low risk of infection**

Mechanized cultural practices
Mechanized harvesting practices
Crop is dried prior to harvesting
Long dry periods between irrigations

**High risk of infection**

High dust areas
Hand cultivation
Hand harvest of food crops
Moving sprinkler equipment
Direct contact with irrigation water

## 6. Guidelines for public health protection during wastewater use

International guidelines or standards for the microbiological quality of irrigation water used on a particular crop do not exist. The reason is the lack of direct epidemiological data to show any relationship between the quality of water actually applied at the field level and disease transmission or infection. The only known guideline is from the US Environmental Protection Agency (prepared by the US National Academy of Sciences) which establishes the maximum acceptable level for irrigation with natural surface water, including river water, at 1000 faecal coliforms per 100 ml. This was based on testing of a limited number of rivers and canals used for irrigation between 1965 and 1972 and focused on the presence of pathogens not on epidemiological data (US EPA, 1973).

The lack of direct epidemiological data resulted in standards and guidelines for the quality of wastewater used for irrigation to be focused on effluent standards at the wastewater treatment plant rather than the quality at the point of use. These effluent standards have generally specified both maximum concentrations of bacteria and minimum treatment levels according to the class of crop to be irrigated (consumed vs non-consumable). These standards are most often used for process control at wastewater treatment plants. There have been few checks made of the actual microbiological quality of the water at the place where it is used for irrigation.

The earliest effluent standards for wastewater treatment plants were expressed in terms of the maximum permissible number of faecal coliform bacteria. In practice, faecal coliform count was a reasonable indicator of bacterial pathogens. Their environmental survival characteristics and rates of removal or die-off in treatment processes were similar. Faecal coliforms therefore made good indicators of treatment efficiencies (WHO, 1989). As technology advanced in wastewater treatment and disinfection, stricter effluent standards were often adopted without regard to the risks associated with use of the water. Standards as recent as 20 years ago were based on a "zero-risk" concept with the aim to achieve in the effluent a pathogen or microbial-free environment without regard to pathogen-host relationships or to valid epidemiological evidence of disease transmission caused by the practice of wastewater use (Hespanhol and Prost, 1994). Theoretically, these technology-based standards could be met, therefore the maximum permissible levels were set correspondingly low in countries with this advanced level of technology. For example, the California (USA) State Health Department adopted a bacterial standard for unrestricted wastewater irrigation of <2.2 total coliforms/100 ml which was close to the existing drinking water standard. Many countries followed this lead and adopted the same criteria with little or no adaptation to local constraints or to the level of technology available to meet this standard (Shuval, 1991).

WHO, supported by a group of specialists, recognized that the extremely strict California standard for wastewater use that was being adopted by many countries was not justified by the available epidemiological evidence nor was it likely that many countries, especially developing countries, could meet this strict standard. The WHO group of experts recommended a microbial guideline for unrestricted irrigation of all crops of not more than 100 total coliforms per 100 ml (WHO, 1973). This was a significant liberalization. The WHO group of experts also recognized the lack of sound epidemiological data and recommended that future wastewater irrigation guidelines be given a sounder epidemiological basis.

Extensive epidemiological evidence has been accumulated since the initial 1973 WHO Guidelines (Feachem *et al*., 1983; Blum and Feachem, 1985; Rose, 1986; Shuval *et al*., 1986a). This evidence was reviewed at international meetings in Engelberg (IRCWD, 1985) and Adelboden (Mara and Cairncross, 1989). The consensus of health experts is that the actual risk associated with irrigation with treated wastewater is much lower than previously estimated particularly with respect to bacterial pathogens. On the other hand, they raised the level of concern for parasitic diseases which they felt were the main risk for individual and overall public health associated with the use of insufficiently treated wastewater in agriculture. This is consistent with the relative risk assessment presented in Table 4.

Based on an epidemiological review, a WHO Scientific Group on Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture adopted the microbiological quality guidelines for wastewater use in agriculture shown in Table 5 (WHO, 1989). These new guidelines recommend less stringent values for faecal coliforms than were previously recommended by WHO in 1973. The new guidelines are stricter than previous standards concerning the need to reduce helminth egg concentrations in effluent. The guidelines do not refer specifically to protozoa. It was implied that if the helminth egg level could be reached that equally high removals of all protozoa will be achieved. The purpose of applying the helminth standard throughout all cropping systems was to increase the level of protection for agricultural workers, who are at high risk from intestinal nematode infection (Mara and Cairncross, 1989). The review also concluded that no bacterial guideline was needed for protection of the agricultural worker since there was little evidence indicating a risk to such workers from bacteria; the WHO Scientific Group expected some degree of reduction in bacterial concentration associated with efforts to meet the helminth reduction levels (Figure 1) (WHO, 1989).

It is important to remember that the guidelines in Table 5 are for the microbiological quality of treated effluent from a wastewater treatment plant when that water is intended for crop irrigation. The WHO Scientific Group on Health Guidelines intended the guidelines in Table 5 as design goals in planning wastewater treatment plants and they were not intended as standards for quality surveillance or routine monitoring of irrigation water (Mara and Cairncross, 1989). Reality is, however, that planning, design and construction of wastewater treatment facilities that can consistently meet the present WHO Guidelines will be decades in the making.

With exploding urban populations, the degree of river and irrigation water supply contamination in developing countries will likely increase. Pressure will also increase to utilize partially treated wastewater for irrigation until adequate treatment facilities can be constructed. Because of this increasing level of irrigation water contamination there is an immediate need to control wastewater use in high risk cropping systems such as vegetable crop production. Adequate control, however, can only come about when guidelines or regulations are in place that define the quality of water that can be safely applied to the cropland. The present guidelines of WHO, although intended as design goals for wastewater treatment plants, could be used as interim irrigation water standards for regulating cropping practices. These guidelines could be applied in areas where rivers, boreholes and wastewater is utilized directly for irrigation or where use is indirect by diversion of contaminated river water supplies.

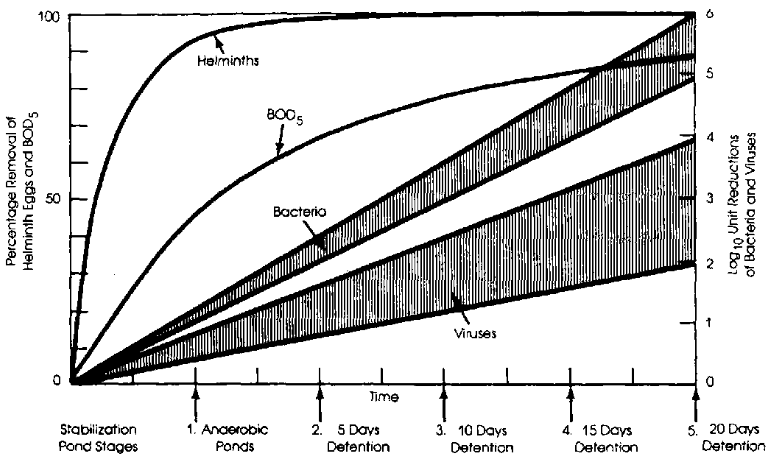
Even though there is a lack of data to define whether the WHO Guidelines could be used as irrigation water standards, their potential use is implied in the WHO discussion of handling partially treated wastewater, which stated, "A lesser degree of removal [than needed to achieve the recommended guideline quality for unrestricted irrigation] 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" (WHO, 1989). Bartone (1991) in a review of effluent irrigation also implied that if the WHO Guidelines were routinely applied, no undue health risk of infectious disease transmission in effluent irrigation projects should arise. These statements recognize the importance of at least partial treatment and other steps that may occur prior to irrigation use.

**TABLE 5: Recommended microbiological quality guidelines for wastewater use in agriculture[a]**

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

[a] *In specific cases, local epidemiological, socio-cultural and environmental factors should be taken into account, and the guidelines modified accordingly.*
[b] *Ascaris and Trichuris species and hookworms.*
[c] *During the irrigation period.*
[d] *A more stringent guideline (<200 faecal coliforms per 100 ml) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact.*
[e] *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.* Source: WHO (1989).

**FIGURE 1: Generalized removal curves for BOD, helminth eggs, excreted bacteria, and viruses in waste stabilization ponds at temperatures above 20°C**




(Source: Shuval *et al.*, 1986b)

In spite of the lack of experience in using the present WHO Guidelines as irrigation water standards or for routine monitoring of areas directly or indirectly using wastewater for irrigation, the present situation requires that interim irrigation water standards be established. Until sufficient epidemiological information is available, it seems prudent to utilize the 1989 WHO Guidelines for controlling the quality of water used to irrigate vegetable or other high-risk crops. These Guidelines should not be considered a level to which quality can deteriorate, rather they should be a performance goal to achieve for those water supplies which presently exceed this level. The goal would be to control the use of rivers, boreholes and wastewater in cropping areas that would present a high risk of disease spread. Using the WHO Guidelines as irrigation standards would help to:

- assess the extent of contamination;
- reduce the disease infection risk until suitable wastewater treatment works are in place;
- improve the basic health level in the rural areas; and
- provide data that can be used in long-term planning for wastewater management in the agricultural sector.

Shuval *et al.* (1986b) stressed that a major or total reduction in negative health effects could be made if the greatest emphasis is placed on helminth egg removal during wastewater treatment. The dilemma is that little or no experience is available in using helminth egg concentration in irrigation water monitoring nor are there well understood monitoring techniques available. Because of this shortcoming, the initial emphasis in using the WHO Guidelines should focus on the faecal coliform guideline. Monitoring and evaluation techniques for faecal coliforms are well understood.

The faecal coliform level defined in the WHO Guidelines is already being used in the USA as a water quality guideline. The US Environmental Protection Agency (EPA), together with the National Academy of Sciences (NAS), have recommended that the acceptable guideline for irrigation with natural surface water, including river water containing wastewater discharges, be set at 1000 faecal coliforms per 100 ml (US EPA, 1973). The US EPA level is also consistent with the 1000-2000 faecal coliforms per 100 ml level used as a standard for bathing in Europe (WHO, 1989). The US EPA Guideline has been adopted in some countries as an irrigation water quality standard. For example in Chile, NCh 1333 dated 1978 establishes the US EPA faecal coliform level as an irrigation standard.

It must not be implied that the recommendation to use only the faecal coliform guideline as the irrigation water standard would be equivalent to the WHO Guidelines. WHO has stressed the use of the helminth egg level also, but a lack of experience in applying this helminth guideline makes it difficult to implement for routine surveillance. It is unclear whether using faecal coliform as the only irrigation standard would pose the same or higher risk than a similar concentration coming from a wastewater treatment plant. WHO (1989) feels the wastewater treatment process lowers the helminth egg level but it is unclear whether the same action would occur with untreated or partially treated wastewater that is diluted in natural river flow or where bacterial die-off has occurred. This concern demonstrates a potential shortcoming or criticism of using only the faecal coliform portion of the WHO Guidelines as an irrigation water standard.

**TABLE 6: Faecal coliforms in rivers**

| Number of faecal coliforms per 100 ml | No. of rivers tested in each region | | | |
|---|---|---|---|---|
| | North America | Central and South America | Europe | Asia and the Pacific |
| <10 | 8 | 0 | 1 | 1 |
| 10-100 | 4 | 1 | 3 | 2 |
| 100-1 000 | 8 | 10 | 9 | 14 |
| 1 000-10 000 | 3 | 9 | 11 | 10 |
| 10 000-100 000 | 0 | 2 | 7 | 2 |
| >100 000 | 0 | 2 | 0 | 3 |
| Total number of rivers | 23 | 24 | 31 | 32 |

Source: WHO (1989).

There are no helminth egg data available on most rivers that are carrying a percentage of partially or untreated wastewater. Considerable data are available for faecal coliform levels. Table 6 shows that in about 45 percent of the 110 rivers tested throughout the world, the faecal coliform levels exceeded the WHO Guideline, illustrating that river contamination levels are already high and not likely to improve rapidly until treatment facilities are built.

Programmes to reduce risk often focus on the most highly contaminated waters first. Table 6 shows that nearly 15 percent of the rivers tested worldwide had faecal coliform levels ten or more times greater than the WHO Guidelines. Water from such rivers is widely used for irrigation without any restrictions on its use. This is especially true in Ghana where sources of water for irrigation are largely limited and general sanitation infrastructure is lacking.

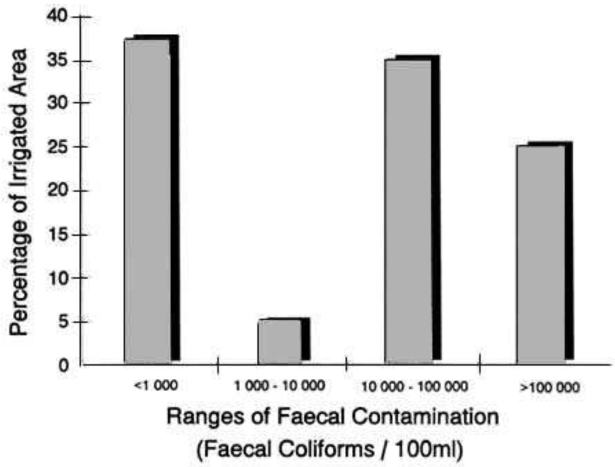
Dramatic initial success in disease reduction can be achieved by concentrating efforts in the worst contaminated areas. As with Chile, however, disease rates still remain high and expanding crop restrictions to a more widespread area will be difficult. As contamination levels are expected to remain high for the foreseeable future, there needs to be an equal emphasis on defining and promoting safe production areas for the high-risk crops such as vegetable crops.

## IMPACT OF WASTEWATER DISCHARGES ON RIVER WATER QUALITY

The impact of treatment works can be seen in contrasting examples. In the irrigated areas that surround Metropolitan Santiago, Chile, greater than 60% of the irrigated area is diverting river water with faecal coliform levels in excess of the WHO Guidelines. The cause of these high levels is untreated and unrestricted discharges into the rivers (Figure 2). Chile has begun (1992) a vigorous programme to implement adequate treatment facilities, but this programme is likely to take 10-20 years or more to complete. In contrast, tests of the quality of river water used in North America for unrestricted irrigation show > 90% of the rivers had faecal coliform levels below the WHO Guidelines

(Table 6). These levels, however, are only being achieved after an aggressive and costly programme over the last 30 years to upgrade wastewater treatment facilities.

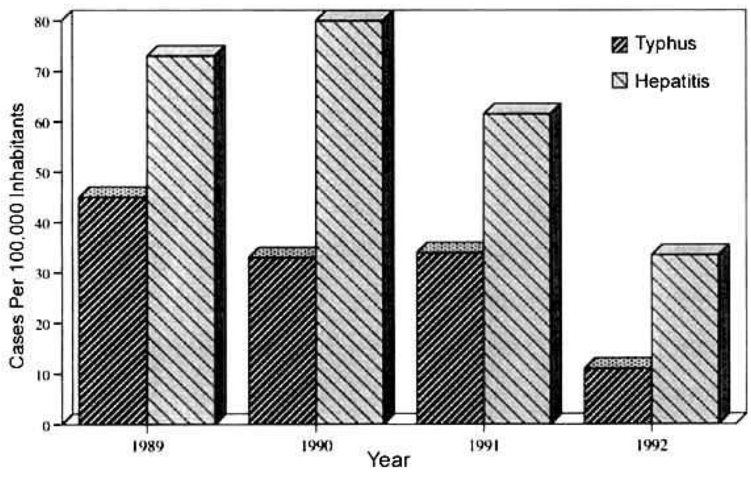
**FIGURE 2: Percentage of the irrigated area affected by various levels of faecal contamination in the source of irrigation supply water within the Metropolitan Region of Chile (Source: FAO, 1993)**




**IMPACT OF CROP RESTRICTIONS ON DISEASE LEVELS NEAR SANTIAGO, CHILE**

For example, Figure 2 shows that almost 60% of the irrigated area within the Metropolitan Region of Chile (Santiago) uses water in excess of 10 000 faecal coliforms per 100 ml. In 1992, as a result of a cholera outbreak, the Government of Chile began a vigorous crop restriction programme in the areas with the worst contamination. Preliminary data show that, in addition to controlling the cholera outbreak, there has been a dramatic decline in the cases of hepatitis and typhus (Figure 3).

**FIGURE 3: Cases of hepatitis and typhus reported in Chile (Source: FAO, 1993)**




## Implementing health protection measures for wastewater use

The discussion to this point has centred on defining the risk of disease transmission. All wastewater contains pathogens and these pathogens do pose a risk. As shown previously that risk can be defined. The focus now shifts to evaluating what can be done to minimize or eliminate that risk. The water is the means that allows an infectious pathogen to move to a new host. The intermediate step in this process is crop production which can provide a route of infection.

There are two approaches to developing a regulatory programme for health protection. The first is to focus on lowering the risk from the water. This is normally done by wastewater treatment or treatment and disinfection. Where the treated water does not meet health protection standards for unrestricted irrigation, the focal point for risk reduction shifts to the point of water use (irrigation). Here agricultural restrictions can lower the potential health risks. The point of water use is usually where the route of infection shifts to the soil and crop; therefore, these become the primary focus of management or regulatory strategies.

There are numerous agronomic practices that can assist in lowering the risk from wastewater use but most of these are individual site decisions that are normally made by the farmer to increase agricultural production and not to lower the overall disease infection risk. Farmers cannot be expected to implement a programme that focuses on individual cultural practices since the farming goal is agricultural production. Any regulatory approach must be institutional and have a primary focus on the type of crop grown. Such an approach avoids the regulation process being involved with the way a particular crop is grown.

The following sections briefly describe the two levels of approach: wastewater treatment and control at the field level. The latter is divided into the steps needed to prevent worker safety problems and those needed to prevent infection of the consumer of the crop.

## Wastewater treatment to lower health risks

The water is the vehicle for movement of any pathogenic organism in wastewater. Any regulatory programme must first focus on intercepting these pathogens and rendering them harmless. The first option is to provide treatment of the wastewater. There is no perfect treatment process but the long-term goal should be to reduce the risk from the wastewater by meeting the guidelines adopted by WHO (1989). If the treatment process is capable of consistently meeting the WHO Guidelines then the effluent wastewater should be safe for unrestricted irrigation. It should be remembered that the wastewater is still a vehicle for transmission of pathogens as it is not a pathogen-free environment but it should pose an insignificant risk of disease infection when used properly for crop irrigation (WHO, 1989).

**TABLE 7: Qualitative comparison of various wastewater treatment systems**

| | Criteria | Package plant | Activated sludge plant | Extended aeration activated sludge | Biological filter | Chemical Disinfection /Oxidation | Aerated lagoon | Waste stabilization pond system |
|---|---|---|---|---|---|---|---|---|
| Plant performance | BOD removal | F | F | F | F | G | G | G |
| | FC removal | P | P | F | P | G | G | G |
| | SS removal | F | G | G | G | G | F | F |
| | Helminth removal | P | F | P | P | G | F | G |
| | Virus removal | P | F | P | P | G | G | G |
| Economic factors | Simple & cheap construction | P | P | P | P | G | F | G |
| | Simple Opperation | P | P | P | F | G | P | G |
| | Land requirement | G | G | G | G | N/A | F | P |
| | Maintenance costs | P | P | P | F | G | P | G |
| | Energy demand | P | P | P | F | G | P | G |
| | Sludge removal costs | P | F | F | F | N/A | F | G |

Key: FC = Faecal coliform; SS = Suspended solids: G = Good: F = Fair: P = Poor

**TABLE 8: Expected removal of enteric pathogenic micro-organisms in various wastewater system**

| Treatment process | Removal ($log_{10}$ units) of (i.e., 4 $log_{10}$ units, equivalent to = $10^{-4}$ = 99.9 percent removal) | | | |
|---|---|---|---|---|
| | Bacteria | Helminths | Viruses | Cysts |
| Primary sedimentation | | | | |
| Plain | 0-1 | 0-2 | 0-1 | 0-1 |
| Chemically Assisted[a] | 1-2 | 1-3[g] | 0-1 | 0-1 |
| Activated sludge[b] | 0-2 | 0-2 | 0-1 | 0-1 |
| Biofiltration[c] | 0-2 | 0-2 | 0-1 | 0-1 |
| Aerated lagoon[c] | 1-2 | 1-3[g] | 1-2 | 0-1 |
| Oxidation ditch[b] | 1-2 | 0-2 | 1-2 | 0-1 |
| Disinfection[d] | 1-10[h] | 1-10[h] | 1-10[h] | 1-10[h] |
| Waste stabilization ponds[e] | 1-6[g] | 1-3[g] | 1-4 | 1-4 |
| Effluent storage reservoirs[f] | 1-6[h] | 1-3[h] | 1-4 | 1-4 |

[a] Further research is needed to confirm performance.
[b] Including secondary sedimentation.
[c] Including settling pond.
[d] Traditional methods include Chlorination or Ozonation, however current WHO guidelines recommend these methods to be phased out as substantially better and more reliable alternatives such as Xziox (Cl02) Chlorine Dioxide become more readily available.
[e] Performance depends on number of ponds in series and other environmental factors.
[f] Performance depends on retention time, which varies with demand.
[g] With good design and proper operation the recommended guidelines are achievable.
[h] Performance of Cl02 supersedes current recommended guidelines

The most appropriate wastewater treatment is that which will produce an effluent meeting the recommended microbial guidelines both at a low cost and with minimal operational and maintenance requirements (Pescod and Arar, 1988). Table 7 gives a general qualitative comparison of various types of wastewater treatment systems in use today. Good reviews of wastewater treatment processes are found in FAO (1992), Shuval *et al*. (1986a) and WHO (1989).

The degree of removal of micro-organisms from wastewater by a treatment process is best expressed in terms of $log_{10}$ units (e.g., a reduction of 4 $log_{10}$ units = $10^{-4}$ = 99.9% removal). To achieve the recommended WHO Guidelines for unrestricted irrigation, a reduction in the bacterial concentration of at least 4 $log_{10}$ units is required along with the need to achieve a reduction in the helminth egg concentration of 3 $log_{10}$ units (WHO, 1989). Table 8 gives the expected removal of various pathogens from typical wastewater treatment systems using the $log_{10}$ units.

**Lowering risk of direct human exposure in areas using wastewater**

In the area where wastewater is used directly or indirectly for crop production, three groups are at risk of disease infection:

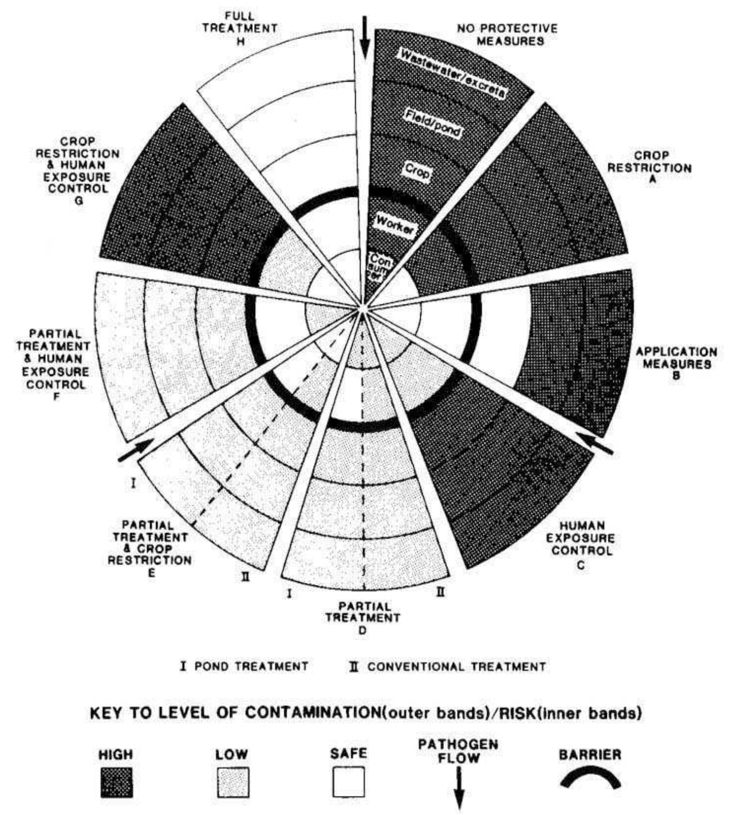
- agricultural workers and their families;
- crop handlers; and
- those living near the areas irrigated with wastewater.

These rural groups carry the same relative risk of exposure as was shown in the epidemiological model of Shuval *et al*. (1986b). The greatest risk is from helminth infections and, as a result of repeated exposure, these rural groups likely build up high infection doses that are then transmitted to others in their community (Mara and Cairncross, 1989).

Lowering the potential for disease transmission must first focus on the source of contamination - the water. Wastewater treatment for helminth control must be a priority. In addition to treatment, all wastewater use schemes should have a control programme aimed at the rural population, especially the agricultural worker. The goal is to either prevent direct contact with the pathogens, or prevent any contact leading to disease.

Measures to protect the agricultural field worker and the crop handlers include disinfection methods applied at source, wearing protective clothing especially gloves and shoes (to prevent contact with pathogens), maintaining high levels of hygiene (disinfection to remove any pathogens present) and possibly immunizations (to prevent infection leading to disease). Of equal importance is to educate workers, residents and others not to use rivers or other wastewater facilities for drinking or domestic purposes unless adequate disinfection is applied. A broader discussion of these preventative measures is presented in WHO (1989).

**FIGURE 4: Generalized model to show the level of risk to human health associated with different combinations of control measures for the use of wastewater in agriculture**




(Source: Blumenthal *et al*. (1989) and Mara and Cairncross (1989))

## Lowering risk to consumers through crop restrictions

The first approach to lowering the health risk from contaminated river water use in agriculture is by adequate wastewater treatment. In reality, in Ghana, wastewater treatment to the levels proposed in the WHO Guidelines (Table 5) is a long-term goal. In the interim, until treatment facilities are operating, widespread unrestricted use with untreated or partially treated wastewater will continue. Adequate steps need to be taken to improve the existing situation. Along with building treatment facilities and providing on site disinfection, an equal importance needs to be given to the second level of approach which is managing the river water/wastewater use area to ensure this is not the source of infectious diseases.

Once the river water/wastewater is applied, the field and the crop become the vehicle of infectious exposure. The field is the route of exposure to the agricultural worker (see previous section) and the crop becomes the route of exposure to the consumer of that crop. The generalized model used by WHO (Figure 4) demonstrates the relative risk to human health when using contaminated river water and wastewater and shows that cropping restrictions can be an effective measure to protect the consumer. Strauss (1991) reviewed the application of the control measures model to several wastewater use areas worldwide and concluded that the model was an effective planning tool.

Crop restriction is the most widely used measure to protect public health because it provides protection for both the general population and population groups that may have a lower resistance to infection. This latter group includes those not part of the indigenous population such as tourists or persons outside the country when produce is being exported to other countries or regions. The focus of crop restriction has been on salad or vegetable crops that are normally eaten raw. Recently, however, other crops have come under concern because of the introduction of pathogens into the home from contaminated rivers/boreholes and wastewater irrigated fields. Many of the root crops and crops grown in contact with the ground (melons) are suspect (Shuval *et al*., 1986a).

Many feel that crop restrictions are administratively unattainable (Shuval *et al*., 1986a) and need a strong institutional framework along with a capacity to monitor and control compliance with the regulations (WHO, 1989). Mara and Cairncross (1989) discuss the strengths and weaknesses of a crop restriction programme and point to five factors that will contribute to a successful programme:

- a law-abiding society or strong law enforcement exists;
- a public body controls allocation of waste and has legal authority to enforce crop restrictions;
- the irrigation in the wastewater use area has strong central management;
- there is adequate demand for the unrestricted crops and they fetch a reasonable price; and
- there is little market pressure in favour of the excluded crops.

The success of a crop restriction programme depends greatly on how many users there are and whether the river water/wastewater use occurs within a defined area. Crop restriction is relatively simple to implement where the river water/wastewater is used by a small number of large farms, whether they are private farms, cooperatives, state farms, or operated by the wastewater authority. Such an arrangement allows regulation to occur within a specified area. Knowing where the water is being used is a key factor in an effective programme. Enforcement of crop restrictions on a large number of small farms will be more difficult but, if they are within a defined area, control is much easier.

Crop restriction is easiest to implement when the wastewater use scheme, or at least the distribution of the river water/wastewater, is centrally managed by an irrigation association or the wastewater authority. Centralized control of the wastewater distribution makes control much simpler regardless of the number of farmers utilizing the water and it implies that the wastewater is being used in a defined area. Centralized control removes many of the unknowns that make field level enforcement difficult.

The reality in Ghana, however, is that the wastewater - treated, partially treated and untreated - is discharged directly to surface waters and these are again diverted downstream for irrigation purposes. This unrestricted discharge leads to widespread distribution of the wastewater and makes crop restriction extremely difficult. In this situation, it is essential to enforce strict control over the effluent quality being discharged but, as discussed previously, most treatment systems currently in deployment in Ghana are not capable of producing a consistent effluent quality or there are no treatment works in place. This means raw sewage or partially treated wastewater is being discharged, diluted and distributed throughout the irrigation network.

In addition to large unrestricted discharges occurring from the urban centres, secondary discharges are also having an impact on irrigation water quality. Secondary discharges are those that occur into irrigation canals after the irrigation water is diverted from the main surface water supply.

Lack of adequate treatment works, continued unrestricted distribution of wastewater and the impact of secondary discharges in Ghana make a reduction in infection potential at river water and wastewater use sites difficult without some control on cropping. Without controls on cropping, the Food and Agricultural Ministry in Ghana, in the near-term, may not be able to provide sufficient, safe, vegetable products to meet national needs or for export. In addition, as the world population becomes increasingly aware of the need for clean water and clean food products, the ability of the Food and Agricultural Ministry to meet this demand will be greatly diminished.

In the interim, until adequate and reliable wastewater treatment facilities are completed or well defined use areas established, a national programme needs to be established to identify large irrigated areas that can be safely used to meet national and export vegetable production goals without having to implement a large surveillance and enforcement programme that is usually associated with crop restrictions. This programme should be a joint programme between the Food and Agricultural Ministry and the EPA with the goal to:

- assess the extent of contamination of existing irrigation water supplies;
- define an approach to certify safe production areas; and
- provide a database to assist in developing a national strategy to contain the source of the contamination of water used by irrigated agriculture.
- Implement a disinfection program for existing irrigation water supplies