Water Pollution Control - A Guide to the Use of Water Quality Management Principles
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Chapter 4* - Wastewater as a Resource

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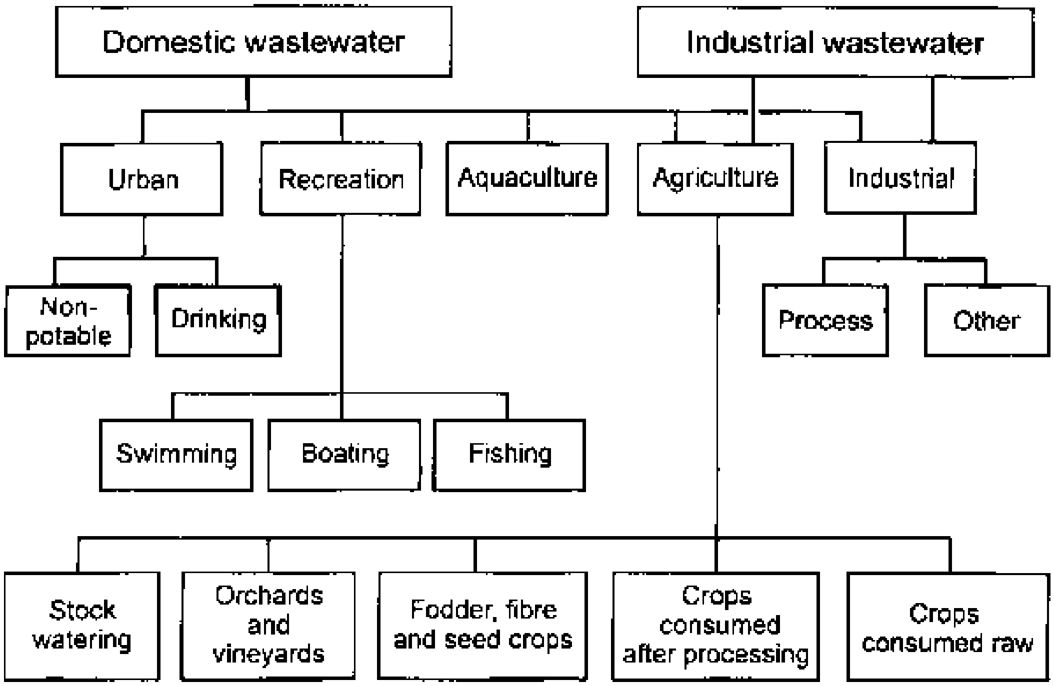
4.1 Introduction

In many arid and semi-arid regions of the world water has become a limiting factor, particularly for agricultural and industrial development. Water resources planners are continually looking for additional sources of water to supplement the limited resources available to their region. Several countries of the Eastern Mediterranean region, for example, where precipitation is in the range of 100-200 mm a^{-1}, rely on a few perennial rivers and small underground aquifers that are usually located in mountainous regions. Drinking water is usually supplied through expensive desalination systems, and more than 50 per cent of the food demand is satisfied by importation.

In such situations, source substitution appears to be the most suitable alternative to satisfy less restrictive uses, thus allowing high quality waters to be used for domestic supply. In 1958, the United Nations Economic and Social Council provided a management policy to support this approach by stating that "*no higher quality water, unless there is a surplus of it, should be used for a purpose that can tolerate a lower grade*" (United Nations, 1958). Low quality waters such as wastewater, drainage waters and brackish waters should, whenever possible, be considered as alternative sources for less restrictive uses.

Agricultural use of water resources is of great importance due to the high volumes that are necessary. Irrigated agriculture will play a dominant role in the sustainability of crop production in years to come. By the year 2000, further reduction in the extent of exploitable water resources, together with competing claims for water for municipal and industrial use, will significantly reduce the availability of water for agriculture. The use of appropriate technologies for the development of alternative sources of water is, probably, the single most adequate approach for solving the global problem of water shortage, together with improvements in the efficiency of water use and with adequate control to reduce water consumption.

Figure 4.1 Types of wastewater use (After WHO, 1989)



4.2 Types of reuse

Water is a renewable resource within the hydrological cycle. The water recycled by natural systems provides a clean and safe resource which is then deteriorated by different levels of pollution depending on how, and to what extent, it is used. Once used, however, water can be reclaimed and used again for different beneficial uses. The quality of the once-used water and the specific type of reuse (or reuse objective) define the levels of subsequent treatment needed, as well as the associated treatment costs. The basic types of reuse are indicated in Figure 4.1 and described in more detail below (WHO, 1989).

4.2.1 Agriculture and aquaculture

On a world-wide basis wastewater is the most widely used low-quality water, particularly for agriculture and aquaculture. This rest of this chapter concentrates on this type of reuse because of the large volumes used, the associated health risks and the environmental concerns. Other types of reuse are only discussed briefly in the following sub-sections.

4.2.2 Urban

In urban areas, reclaimed wastewater has been used mainly for non-potable applications (Crook *et al.,* 1992) such as:

• Irrigation of public parks, recreation centres, athletic fields, school yards and playing fields, and edges and central reservations of highways.

• Irrigation of landscaped areas surrounding public, residential, commercial and industrial buildings.

• Irrigation of golf courses.

• Ornamental landscapes and decorative water features, such as fountains, reflecting pools and waterfalls.

• Fire protection.

• Toilet and urinal flushing in commercial and industrial buildings.

The disadvantages of urban non-potable reuse are usually related to the high costs involved in the construction of dual water-distribution networks, operational difficulties and the potential risk of cross-connection. Costs, however, should be balanced with the benefits of conserving potable water and eventually of postponing, or eliminating, the need for the development of additional sources of water supply.

Potable urban reuse can be performed directly or indirectly. Indirect potable reuse involves allowing the reclaimed water (or, in many instances, raw wastewater) to be retained and diluted in surface or groundwaters before it is collected and treated for human consumption. In many developing countries unplanned, indirect potable reuse is performed on a large scale, when cities are supplied from sources receiving substantial volumes of wastewater. Often, only conventional treatment (coagulation-flocculation-clarification, filtration and disinfection) is provided and therefore significant long-term health effects may be expected from organic and inorganic trace contaminants which remain in the water supplied.

Direct potable reuse takes place when the effluent from a wastewater reclamation plant is connected to a drinking-water distribution network. Treatment costs are very high because the water has to meet very stringent regulations which tend to be increasingly restrictive, both in terms of the number of variables to be monitored as well as in terms of tolerable contaminant limits.

Presently, only the city of Windhoek, Namibia is performing direct potable reuse during dry periods. The Goreangab Reclamation Plant constructed in 1968 is currently being enlarged to treat about 14,000 m^3 d^{-1} by 1997 in order to further augment supplies to the city of Windhoek (Van Der Merwe *et al.,* 1994).

4.2.3 Industry

The most common uses of reclaimed water by industry are:

• Evaporative cooling water, particularly for power stations.
• Boiler-feed water.
• Process water.
• Irrigation of grounds surrounding the industrial plant.

The use of reclaimed wastewater by industry is a potentially large market in developed as well as in developing and rapidly industrialising countries. Industrial reuse is highly cost-effective for industries where the process does not require water of potable quality and where industries are located near urban centres where secondary effluent is readily available for reuse.

4.2.4 Recreation and landscape enhancement

The use of reclaimed wastewater for recreation and landscape enhancement ranges from small fountains and landscaped areas to full, water-based recreational sites for swimming, boating and fishing. As for other types of reuse, the quality of the reclaimed water for recreational uses should be determined by the degree of body contact estimated for each use. In large impoundments, however, where aesthetic appearance is considered important it may be necessary to control nutrients to avoid eutrophication.

4.3 Implementing or upgrading agricultural reuse systems

Land application of wastewater is an effective water pollution control measure and a feasible alternative for increasing resources in water-scarce areas. The major benefits of wastewater reuse schemes are economic, environmental and health-related. During the last two decades the use of wastewater for irrigation of crops has been substantially increased (Mara and Cairncross, 1989) due to:

- The increasing scarcity of alternative water resources for irrigation.

- The high costs of fertilisers.

- The assurances that health risks and soil damage are minimal, if the necessary precautions are taken.

- The high costs of advanced wastewater treatment plants needed for discharging effluents to water bodies.

- The socio-cultural acceptance of the practice.

- The recognition by water resource planners of the value of the practice.

Economic benefits can be gained by income generation and by an increase in productivity. Substantial increases in income will accrue in areas where cropping was previously limited to rainy seasons. A good example of economic recovery associated with the availability of wastewater for irrigation is the Mesquital Valley in Mexico (see Case Study VII) where agricultural income has increased from almost zero at the turn of the century when waste-water was made available to the region, to about 16 million Mexican Pesos per hectare in 1990 (CNA, 1993). The practice of excreta or wastewater fed aquaculture has also been a substantial source of income in many countries such as India, Bangladesh, Indonesia and Peru. The East Calcutta sewage fisheries in India, the largest wastewater use system involving aquaculture in the world (about 3,000 ha in 1987), produces 4-9 t ha^{-1} a^{-1} of fish, which is supplied to the local market (Edwards, 1992). Economic benefits of wastewater/excreta-fed aquaculture can also be found elsewhere (Bartone, 1985; Bartone *et al.,* 1990; Ikramullah, 1994).

Table 4.1 Increases in crop yields (tons ha^{-1} a^{-1}) arising from wastewater irrigation in Nagpur, India

	Wheat	Moong beans	Rice	Potato	Cotton
Irrigation water	8 yrs[1]	5 yrs[1]	7 yrs[1]	4 yrs[1]	3 yrs[1]
Raw wastewater	3.34	0.90	2.97	23.11	2.56
Settled wastewater	3.45	0.87	2.94	20.78	2.30
Stabilisation pond effluent	3.45	0.78	2.98	22.31	2.41
Freshwater + NPK	2.70	0.72	2.03	17.16	1.70

[1] Years of harvest used to calculate average yield

Source: Shende, 1985

Studies carried out in several countries have shown that crop yields can increase if wastewater irrigation is provided and properly managed. Table 4.1 shows the results of field experiments made in Nagpur, India, by the National Environmental Research Institute (NEERI), which investigated the effects of wastewater irrigation on crops (Shende, 1985).

Effluents from conventional wastewater treatment systems, with typical concentrations of 15 mg l^{-1} total N and 3 mg l^{-1} P, at the usual irrigation rate of about 2 m a^{-1}, provide application rates of N and P of 300 and 60 kg ha^{-1} a^{-1}, respectively. Such nutrient inputs can reduce, or even eliminate, the need for commercial fertilisers. The application of wastewater provides, in addition to nutrients, organic matter that acts as a soil conditioner, thereby increasing the capacity of the soil to store water. The increase in productivity is not the only benefit because more land can be irrigated, with the possibility of multiple planting seasons (Bartone and Arlosoroff, 1987).

Environmental benefits can also be gained from the use of wastewater. The factors that may lead to the improvement of the environment when wastewater is used rather than being disposed of in other ways are:

- Avoiding the discharge of wastewater into surface waters.
- Preserving groundwater resources in areas where over-use of these resources in agriculture are causing salt intrusion into the aquifers.
- The possibility of soil conservation by humus build-up and by the prevention of land erosion.
- The aesthetic improvement of urban conditions and recreational activities by means of irrigation and fertilisation of green spaces such as gardens, parks and sports facilities.

Despite these benefits, some potential negative environmental effects may arise in association with the use of wastewater. One negative impact is groundwater contamination. The main problem is associated with nitrate contamination of groundwaters that are used as a source of water supply. This may occur when a highly porous unsaturated layer above the aquifer allows the deeper percolation of nitrates in the wastewater. Provided there is a deep, homogeneous, unsaturated layer above the aquifer which is capable of retaining nitrate, there is little chance of contamination. The uptake of nitrogen by crops may reduce the possibility of nitrate contamination of groundwaters, but this depends on the rate of uptake by plants and the rate of wastewater application to the crops.

Build up of chemical contaminants in the soil is another potential negative effect. Depending on the characteristics of the wastewater, extended irrigation may lead to the build up of organic and inorganic toxic compounds and increases in salinity within the unsaturated layers. To avoid this possibility irrigation should only use wastewater of predominantly domestic origin. Adequate soil drainage is also of fundamental importance in minimising soil salinisation.

Extended irrigation may create habitats for the development of disease vectors, such as mosquitoes and snails. If this is likely, integrated vector control techniques should be applied to avoid the transmission of vector-borne diseases.

Indirect health-related benefits can occur because wastewater irrigation systems may contribute to increased food production and thus to improving health, quality of life and social conditions. However, potential negative health effects must be considered by public health authorities and by institutions managing wastewater reuse schemes because farm workers, the consumers of crops and, to some extent, nearby dwellers can be exposed to the risk of transmission of communicable diseases.

4.3.1 Policy and planning

The use of wastewater constitutes an important element of a water resources policy and strategy. Many nations, particularly those in the arid and semi-arid regions such as the Middle Eastern countries, have adopted (in principle) the use of treated wastewater as an important concept in their overall water resources policy and planning. A judicious wastewater use policy transforms wastewater from an environmental and health liability to an economic and environmentally sound resource (Kandiah, 1994a).

Governments must be prepared to establish and to control wastewater reuse within a broader framework of a national effluent use policy, which itself forms part of a national plan for water resources. Lines of responsibility and cost-allocation principles should be worked out between the various sectors involved, i.e. local authorities responsible for wastewater treatment and disposal, farmers who will benefit from effluent use schemes, and the state which is concerned with the provision of adequate water supplies, the protection of the environment and the promotion of public health. To ensure long-term sustainability, sufficient attention must be given to the social, institutional and organisational aspects of effluent use in agriculture and aquaculture.

The planning of wastewater-use programmes and projects requires a systematic approach. Box 4.1 gives a system framework to support the characterisation of basic conditions and the identification of possibilities and constraints to guide the planning phase of the project (Biswas, 1988).

Government policy on effluent use in agriculture has a deciding effect on the achievement of control measures through careful selection of the sites and the crops that may be irrigated with treated effluent. A decision to make treated effluent available to farmers for unrestricted irrigation removes the possibility of taking advantage of careful selection of sites, irrigation techniques and crops, and thereby of limiting the health risks and minimising the environmental impacts. However, if crop selection is not applied but a government allows unrestricted irrigation with effluent in specific controlled areas, public access to those areas can be prevented (and therefore some control is achieved). The greatest security against health risk and adverse environmental impact arises from limiting effluent use to restricted irrigation on controlled areas to which the public has no access.

It has been suggested that the procedures involved in preparing plans for effluent irrigation schemes are similar to those used in most forms of resource planning, i.e. in accordance with the main physical, social and economic dimensions summarised in Figure 4.2. The following key issues or tasks are likely to have a significant effect on the ultimate success of effluent irrigation schemes:

- The organisational and managerial provisions made to administer the resource, to select the effluent-use plan and to implement it.

- The importance attached to public health considerations and to the levels of risk taken.

- The choice of single-use or multiple-use strategies.

- The criteria adopted in evaluating alternative reuse proposals.

- The level of appreciation of the scope for establishing a forest resource.

Box 4.1 Framework for the analysis of wastewater irrigation projects

Nature of the problem

- How much wastewater will be produced and what will be the seasonal distribution?
- At what places will wastewater be produced?
- What will be the characteristics of wastewater that will be produced?
- What are feasible alternative disposal possibilities?

Legal feasibility

- What uses of wastewater are possible under national and/or state regulations if they exist?
- If no regulations exist, what uses seem feasible under WHO and FAO guidelines or irrigation?
- What are the prevailing water rights and how will these be affected by wastewater use?

Technical feasibility

- Is the quality of treated wastewater produced acceptable for restricted or unrestricted irrigation?
- How much land is available or required for wastewater irrigation?
- What are the soil characteristics of land to be irrigated?
- What are the present land use practices? Can these be changed?
- What types of crops can be grown?

- How do crop-water requirements match with seasonal availability of wastewater?
- What types of irrigation techniques can be used?
- If groundwater recharge is a consideration, are the hydrogeological characteristics of the study are suitable?
- What will be the impact of such recharge on groundwater quality?
- Are there additional health and environmental hazards that should be considered?

Political and social feasibility

- What have been the political reactions to past health and environmental hazards which may have been associated with wastewater reuse?
- What is the publics perception of wastewater reuse?
- What are the attitudes of influential people in areas where wastewater will be reused?
- What are the potential benefits of reuse to the community?
- What are the potential risks?

Economic feasibility

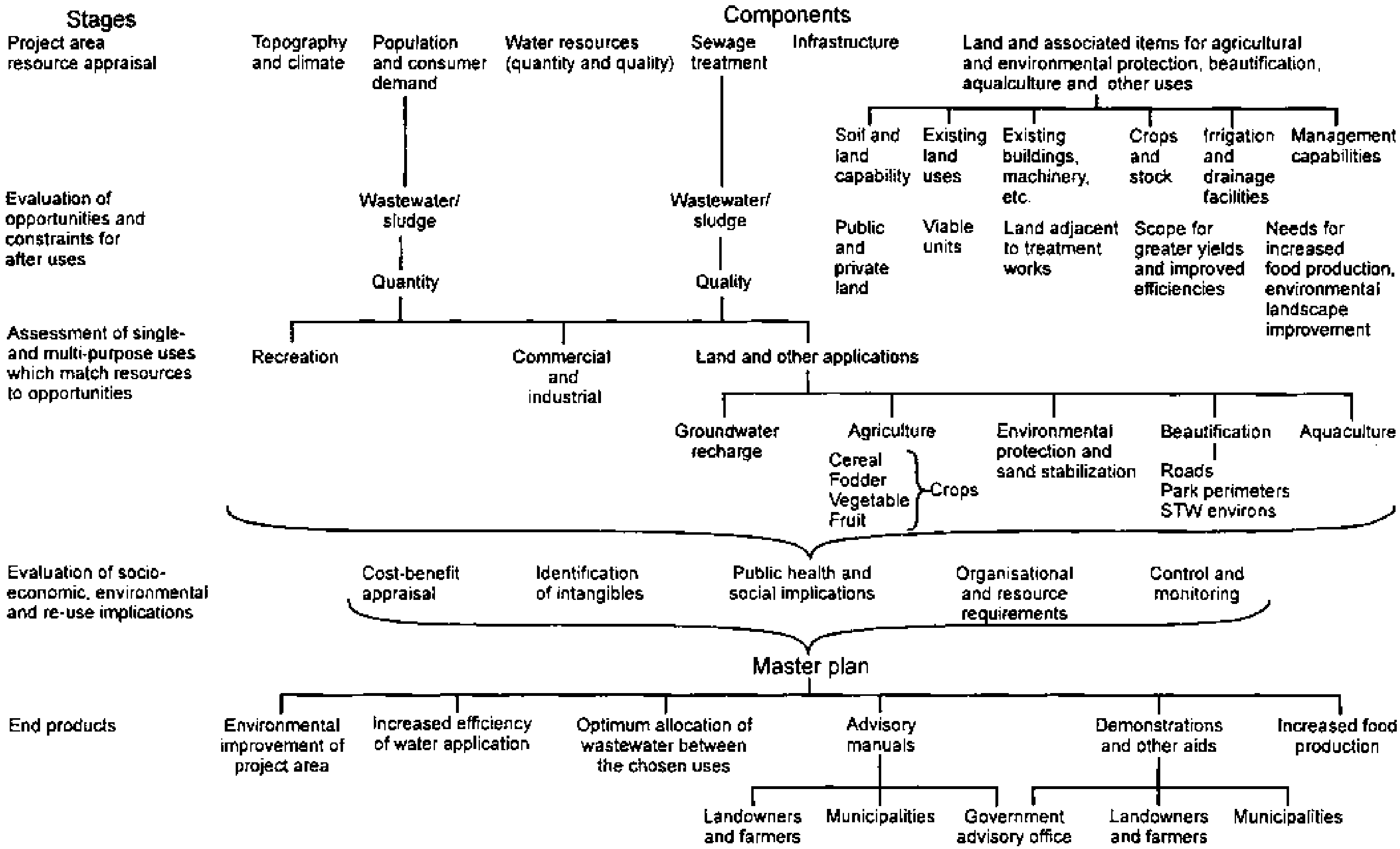
- What are the capital costs?
- What are the operation and maintenance costs?
- What is the economic rate of return?
- What are the cost of development of effluent-irrigated agriculture, e.g. cost of conveyance of wastewater to the irrigation site, and-levelling, installation or irrigation system, agricultural inputs, etc.?
- What are the benefits from the effluent-irrigated agricultural system?
- What is the benefit-cost ratio for the irrigation project?

Personnel feasibility

- Is adequate local labour and expertise available for adequate operation and maintenance of: wastewater treatment, irrigation and groundwater recharge works, agricultural facilities, and health and environmental control aspects?
- If not, what types of training programmes should be instituted?

Source: Biswas, 1988

Figure 4.2 Components of general planning for wastewater use (After Cobham and Johnson, 1988)



Adopting a mix of effluent use strategies normally has the advantages of allowing greater flexibility, increased financial security and more efficient use of wastewater throughout the year, whereas a single-use strategy gives rise to seasonal surpluses of effluent for unproductive disposal.

4.3.2 Legal and regulatory issues

The use of wastewater, particularly for irrigation of crops, is associated with two main types of legal issues:

• Establishment of a legal status of wastewater and the delineation of a legal regime for its use. This may include the development of new, or the amendment of existing, legislation; creation of new institutions or the allocation of new powers to existing institutions; attributing roles of, and relationships between, national and local government in the sector; and public health, environmental and agricultural legislation such as standards and codes of practice for reuse.

• Securing tenure for the users, particularly in relation to rights of access to and ownership of waste, and including public regulation of its use. Legislation should also include land tenure, without which security of access to wastewater is worthless.

The delineation of a legal regime for wastewater management should address the following aspects (WHO, 1990):

• A definition of what is meant by wastewater.

• The ownership of wastewater.

• A system of licensing of wastewater use.

• Protection of other users of the water resources that may be adversely affected by the loss of return flows into the system arising from the use of wastewater.

• Restrictions for the protection of public and environmental health with respect to intended use of the wastewater, treatment conditions and final quality of wastewater, and conditions for the siting of wastewater treatment facilities.

• Cost allocation and pricing.

• Enforcement mechanisms.

• Disposal of the sludges which result from wastewater treatment processes.

• Institutional arrangements for the administration of relevant legislation.

• The interface of this legal regime with the general legal regime for the management of water resources, particularly the legislation for water and environmental pollution control and the legislation governing the provision of water supply and sewerage services to the public, including the relevant responsible institutions.

At the operational level, regulatory actions are applied and enforced through guidelines, standards and codes of practice (see Chapters 2 and 5).

Guidelines

One of the many functions of the World Health Organization (WHO) is to propose regulations and to make recommendations with respect to international health matters. Guidelines for the safe use of wastewater, produced as part of this function are intended to provide background and guidance to governments for risk management decisions related to the protection of public health and to the preservation of the environment.

It must be stressed that guidelines are not intended for absolute and direct application in every country. They are of advisory nature and are based on the state-of-the-art in scientific research and epidemiological findings. They are aimed at the establishment of a health basis and the health risks and, as such, they provide a common background against which national or regional standards can be derived (Hespanhol and Prost, 1994).

Agriculture. The Scientific Group on Health Guidelines for the Use of Waste-water in Agriculture and Aquaculture, held in Geneva in 1987 (WHO, 1989) established the basic criteria for health protection of the groups at risk from agricultural reuse systems and recommended the microbiological guidelines shown in Table 4.2. These criteria and guidelines were the result of a long preparatory process and the epidemiological evidence available at the time. They are related to the category of crops, the reuse conditions, the exposed groups and the appropriate wastewater treatment systems, in order to achieve microbiological quality.

Aquaculture. The use of wastewater or excreta to fertilise ponds for fish production has been associated with a number of infections caused by excreted pathogens, including invasion of fish muscle by bacteria and high pathogen concentrations in the digestive tract and the intra-peritoneal fluid of the fish. Limited experimental and field data on health effects of excreta or wastewater fertilised aquaculture are available and, therefore, the Scientific Group Meeting recommended the following tentative guidelines:

- A geometric mean of less than 10^3 faecal coliform per 100 ml for fish pond water, to ensure that bacterial invasion of fish muscle is prevented. The same guideline value should be maintained for pond water in which edible aquatic vegetables (macrophytes) are grown because in many areas they are eaten raw. This can be achieved by treating the wastewater supplied to the ponds to a concentration of 10^3-10^4 faecal coliforms per 100 ml (assuming that the pond will allow one order of magnitude dilution of the incoming wastewater).

- Total absence of trematode eggs, to prevent infection by helminths such as clonorchiasis, fascialopsiasis and schistosomiasis. This can be readily achieved by stabilisation pond treatment.

• High standards of hygiene during fish handling and gutting to prevent infection of fish muscle by the intra-peritoneal fluid of the fish.

Table 4.2 Recommended microbiological guidelines for wastewater use in agriculture

Category	Reuse conditions	Exposed group	Intestinal nematodes[1] (No. of eggs per litre)[2]	Faecal coliforms (No. per 100 ml)[3]	Wastewater treatment expected to achieve microbiological quality
A	Irrigation of crops likely to be eaten uncooked, sports fields, public parks[4]	Workers, consumers, public	≤1	≤1,000	A series of stabilisation ponds designed to achieve the microbiological quality indicated, or equivalent treatment
B	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees[5]	Workers	≤1	na	Retention in stabilisation ponds for 8-10 days or equivalent helminth and faecal coliform removal
C	Localised irrigation of crops in category B if exposure of workers and public does not occur	None	na	na	Pre-treatment as required by irrigation technology, but no less than primary sedimentation

In specific cases, local epidemiological, socio-cultural and environmental factors should be taken into account, and these guidelines modified accordingly.
na Not applicable

[1] *Ascaris, Trichuris* and hookworms
[2] During the irrigation period. Arithmetic mean
[3] During the irrigation period. Geometric mean
[4] A more stringent guideline (200 faecal coliforms per 100 ml) is appropriate for public lawns, such as hotel lawns, with which the public may have direct contact
[5] 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

The chemical quality of treated domestic effluents used for irrigation is also of particular importance. Several variables are relevant to agriculture in relation to the yield and quality of crops, the maintenance of soil productivity and the protection of the environment. These variables are total salt concentration, electrical conductivity, sodium adsorption ratio (SAR), toxic ions, trace elements and heavy metals. A thorough discussion of this subject is available in FAO (1985).

Standards and Codes of Practice. Standards are legal impositions enacted by means of laws, regulations or technical procedures. They are established by countries by adapting guidelines to their own national priorities and by taking into account their own technical, economical, social, cultural and political characteristics and constraints (see Chapter 5).

They are established by competent national authorities by adopting a risk-benefit approach. This infers that the standards produced will consider not only health-related concerns but also a wide range of economic and social consequences. At any time, national standards can be changed or modified whenever new scientific evidence or new technologies become available, or in response to changes in national priorities or tendencies.

Standards are, in many countries, complemented by codes of practice which provide guidance for the construction, operation and maintenance and surveillance of wastewater use schemes. Codes of practice should be prepared according to local conditions, but the following basic elements are frequently included:

- Crops allowed under crop restriction policies.
- Wastewater treatment and effluent quality.
- Wastewater distribution network.
- Irrigation methods.
- Operation and maintenance.
- Human exposure control.
- Monitoring and surveillance.
- Reporting.
- Charges and fines.

4.3.3 Institutional arrangements

Wastewater-use projects at national level touch on the responsibilities of several ministries and government agencies. For adequate operation and minimisation of administrative conflicts, the following ministries should be involved from the planning phase onwards:

- Ministry of Agriculture and Fisheries: overall project planning; management of state-owned land; installation and operation of an irrigation infrastructure; agricultural and aquacultural extension, including training; and control of marketing.

- Ministry of Health: surveillance of effluent quality according to local standards; health protection and disease surveillance; responsibility for human exposure control, such as vaccination, control of anaemia and diarrhoeal diseases (see section 4.4); and health education.

- Ministry of Water Resources: integration of wastewater use projects into overall water resources planning and management.

- Ministry of Public Works and Water Authorities: wastewater or excreta collection and treatment.

- Ministry of Finance/Economy/Planning: economic and financial appraisal of projects; and cost/benefit analysis, financing, criteria for subsidising, etc.

According to national arrangements, other ministries such as those concerned with environmental protection, land tenure, rural development, co-operatives and women's affairs may also be involved (Mara and Cairncross, 1989).

Countries starting activities involving wastewater use for the first time can benefit greatly from the establishment of an executive body, such as an inter-agency technical standing committee, which is under the aegis of a leading ministry (Agriculture or Water Resources) and which takes responsibility for sector development, planning and management. Alternatively, existing organisations may be given responsibility for the sector (or parts of it), for example a National Irrigation Board might be responsible for wastewater use in agriculture and a National Fisheries Board might be responsible for the aquacultural use of excreta and wastewater. Such organisations should then co-ordinate a committee of representatives from the different agencies having sectoral responsibilities. The basic responsibilities of inter-agency committees are:

- Developing a coherent national or regional policy for wastewater use and monitoring its implementation.

- Defining the division of responsibilities between the respective ministries and agencies involved and the arrangements for collaboration between them.

- Appraising proposed reuse schemes, particularly from the point of view of public health and environmental protection.

- Overseeing the promotion and enforcement of national legislation and codes of practice.

- Developing a rational staff development policy for the sector.

In countries with a regional or federal administration, such arrangements for inter-agency collaboration are even more important at regional or state level. Whereas the general framework of waste-use policy and standards may be defined at national level, the regional body will have to interpret and add to these, taking into account local conditions.

In Mexico, the National Water Commission (CNA), which is attached to the Ministry of Agriculture and Water Resources, administers the water resources of the country and, as such, is the institution in charge of the planning, administration and control of all wastewater use schemes at national level. Other governmental departments, such as the Ministry of Health, the Ministry of the Environment and the Ministry of Social Development, also participate according to specific interests within their own field of activity. At regional level, the State government is also integrated with the administration of local schemes. In the Mesquital Valley, for example, the State of Hidalgo collaborates with the local agency of CNA for the operation and maintenance of the irrigation districts as well as for monitoring, surveillance and enforcement actions. In the Mesquital Valley there is also a strong participation by the private sector, dealing with the administration of small irrigation units integrated into co-operative systems.

4.3.4 Economic and financial aspects

Economic appraisal of wastewater irrigation projects should be based on the incremental costs and benefits accrued from the practice. One procedure adopted in many projects is to adjust marginal benefits and costs to the current value at a real discount rate and to design the system carefully in order that the benefit/cost ratio is greater than 1. Another procedure consists of determining the internal rate of return of the project and confirming that it is competitive (Forero, 1993).

The financial evaluation can be done by comparison with one of the following hypothetical scenarios, each of which is configured with different benefits and costs:

- No agriculture at all.
- No irrigation at all (rain-fed agriculture).
- Irrigation with water from an alternative source without fertiliser application.
- Irrigation with water from an alternative source with fertiliser application.

Costs. The following costs must be considered in a wastewater irrigation project (Papadopoulos, 1990):

- Wastewater treatment costs, including land and site preparation, civil engineering works, system design, materials and equipment.

- Irrigation costs, including water handling, storage, conveyance and distribution.

- On-farm costs, associated with institutional build-up, including facilities and training, measures for public health protection, hygiene facilities for field workers, and use of lower value crops associated with specific waste-water application.

- Operation and maintenance costs, including additional energy consumption, labour, protective clothing for field workers, supplementary fertiliser if needed, management and overhead costs, and monitoring and testing.

It is of fundamental importance that only marginal costs are taken into account in the appraisal. For example, only the additional costs required to attain local effluent standards for reuse should be considered (if they are needed). Costs associated with treatment systems for environmental protection (which would be implemented anyway), should not be accounted in the economic evaluation of reuse systems. In the same way, irrigation and on-farm costs that should be considered are solely the supplementary costs accrued in association with the use of wastewater rather than any other conventional source of water.

Benefits. Direct benefits are relatively easy to evaluate. In agriculture or aquaculture systems they can be directly evaluated, for example in terms of the increase in crop production and yields, savings in fertiliser costs and saving in freshwater supply. By contrast, indirect benefits are complex and difficult to quantify properly. Among the many other benefits that attract decision-making officials who are able to foresee the health and environmental advantages of wastewater use in agriculture are:

- The improved nutritional status of poor populations through increased food availability.
- The increase in jobs and settlement opportunities.

- The development of new recreation areas.
- Reduced damage to the urban environment.
- Protection of groundwater resources from depletion.
- Protection of freshwater resources against pollution and their conservation.
- Erosion control, reduced desertification, etc.

The indirect benefits are "non-monetary issues" and, unfortunately, they are not taken into account when performing economical appraisals of projects involving wastewater use. However, the environmental enhancement provided by wastewater use, particularly in terms of preservation of water resources, improvement of the health status of poor populations in developing countries, the possibility of providing a substitute for freshwater in water-scarce areas, and the incentive provided for the construction of urban sewerage works, are extremely relevant. They are also sufficiently important to make the cost/benefit analysis purely subsidiary when taking a decision on the implementation of wastewater reuse systems, particularly in developing and rapidly industrialising countries.

Cost recovery. Adopting an adequate policy for the pricing of water is of fundamental importance in the sustainability of wastewater reuse systems. The incremental cost basis, which allocates only the marginal costs associated with reuse, seems to be a fair criteria for adoption in developing countries, where wastewater reuse is assumed to be a social benefit. A charge in the form of tariffs, or fees, based on the volumes of treated wastewater distributed, or in terms of hours of distribution, has been used in many countries. Where the volumes are very large and the distribution network covers a wide area, as in the Mesquital Valley in Mexico, the charges are made to farmers in relation to the individual areas being irrigated.

Subsidising reuse systems may be necessary in the early stages of system implementation, particularly when the associated costs are very large. This would avoid any discouragement to farmers arising from the permitted use of the treated wastewater. In order to determine the necessity of governmental support for the cost-recovery scheme it would be advisable to investigate the willingness and the ability of the farmers to pay for the services. The easiest way to collect fees is by imposing charges that are payable just after the harvest season.

4.3.5 Socio-cultural aspects

Public acceptance of the use of wastewater or excreta in agriculture and aquaculture is influenced by socio-cultural and religious factors. In the Americas, Africa and Europe, for example, there is a strong objection to the use of excreta as fertiliser, whereas in some areas of Asia, particularly in China, Japan and Java, the practice is performed regularly and regarded as economical and ecologically sound.

In most parts of the world, however, there is no cultural objection to the use of wastewater, particularly if it is treated. Wastewater use is well accepted where other sources of water are not readily available, or for economic reasons. Wastewater is used for the irrigation of crops in several Islamic countries provided that the impurities (*najassa*) are removed. This results, however, from economical need rather than cultural preference. According to Koranic edicts, the practice of reuse is accepted religiously provided impure water is transformed to pure water (*tahur*) by the following methods (Farooq and Ansari, 1983): self-purification, addition of pure water in sufficient quantity to dilute the impurities, or removal of the impurities by the passage of time or by physical effects.

Due to the wide variability in cultural beliefs, human behaviour and religious dogmas, acceptance or refusal of the practice of wastewater reuse within a specific culture is not always applicable everywhere. A complete assessment of local socio-cultural contexts and religious beliefs is always necessary as a preliminary step to implementing reuse projects (Cross, 1985).

4.3.6 Monitoring and evaluation

As mentioned before (see section 4.3.3), projects and programmes associated with the use of wastewater should be led and co-ordinated by inter-agency committees under the aegis of a leading ministry. This entity should also be in charge of monitoring and evaluation programmes and should have the legal powers to enforce compliance with local legislation.

Monitoring activities for wastewater use projects are of two different types. Process control monitoring is carried out to provide data to support the operation and optimisation of the system, in order to achieve successful project performance. It includes the monitoring of treatment plants, water distribution systems, water application equipment, environmental aspects (such as salinisation, drainage waters, water logging), agricultural aspects (such as productivity and yield) and health-related problems (such as the development of disease vectors and health problems associated with the use of wastewater). In addition to providing data for process control, this level of monitoring generates information for project revision and updating as well for further research and development. Responsibility for process control monitoring belongs to the operating agency (for example, a state agency or a municipal sewerage board) which is part of the inter-agency committee.

Compliance monitoring is required to meet regulatory requirements and should not be performed by the same agency in charge of process control monitoring. This responsibility should be extended to an enforcement agency that possesses legal powers to enforce compliance with quality standards, codes of practice and other pertinent legislation. The responsibility for compliance monitoring is usually granted to Ministries of Health because health problems are of prime importance for wastewater use systems (see section 4.4).

A successful monitoring programme should be cost effective (only essential data should be collected and analysed); it should provide adequate coverage (only representative sectors of the system should be covered); it must be reliable (representative sampling, accurate analysis with adequate analytical quality control, appropriate storing, handling and reporting of information); and it should be timely, in order to provide operators and decision-making officials with fresh and up-to-date information that allows the application of prompt remedial measures during critical situations.

4.3.7 Public awareness and participation

To achieve general acceptance of reuse schemes, it is of fundamental importance that active public involvement is obtained from the planning phase to the full implementation process. Public involvement starts with early contact with potential users, leading to the formation of an advisory committee and the holding of public workshops on potential reuse schemes. The continuous exchange of information between authorities and the public representatives ensures that the adoption of a specific water reuse programme will fulfil real user needs and generally-recognised community goals for health, safety, ecological concerns, programme cost, etc. (Crook *et al.,* 1992).

Acceptance of reuse systems depends on the degree to which the responsible agencies succeed in providing the concerned public with a clear understanding of the complete programme; the knowledge of the quality of the treated wastewater and how it is to be used; confidence in the local management of the public utilities and on the application of locally accepted technology; assurance that the reuse application being considered will involve minimal health risks and minimal detrimental effects to the environment; and assurance, particularly for agricultural uses, of the sustainability of supply and suitability of the reclaimed wastewater for the intended crops.

Figure 4.3 provides a flow chart for establishing programmes to involve the concerned community with all phases of wastewater use projects, from the planning phase to full implementation of the project, and Table 4.3 presents a series of tools to address, educate and inform the public at different levels of involvement.

4.4 Technical aspects of health protection

Health protection in wastewater use projects can be provided by the integrated application of four major measures: wastewater treatment, crop selection and restriction, wastewater irrigation techniques and human exposure control.

4.4.1 Wastewater treatment

Wastewater treatment systems were first developed in response to the adverse conditions caused by the discharge of raw effluents to water bodies. With this approach, treatment is aimed at the removal of biodegradable organic compounds, suspended and floatable material, nutrients and pathogens. However, the criteria for wastewater treatment intended for reuse in irrigation differ considerably. While it is intended that pathogens are removed to the maximum extent possible, some of the biodegradable organic matter and most of the nutrients available in the raw wastewater need to be maintained.

Figure 4.3 A flow chart illustrating a public participation programme (After Crook *et al*., 1992)

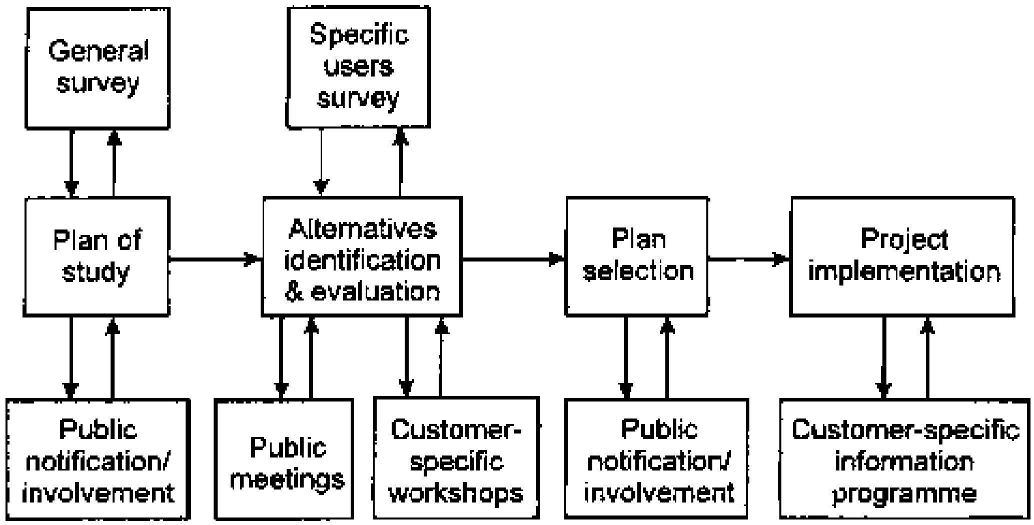


Table 4.3 Removal of excreted bacteria and helminths by various wastewater treatment systems

	Removal (log_{10} units) of			
Treatment process	Bacteria	Helminths	Viruses	Cysts
Primary sedimentation				
Plain	0-1	0-2	0-1	0-1
Chemically assisted[1]	1-2	1-3 (G)	0-1	0-1
Activated sludge[2]	0-2	0-2	0-1	0-1
Biofiltration[2]	0-2	0-2	0-1	0-1
Aerated lagoon[3]	1-2	1-3 (G)	1-2	0-1
Oxidation ditch[2]	1-2	0-2	1-2	0-1
Disinfection[4]	2-6	0-1	0-4	0-3
Waste stabilisation ponds[5]	1-6 (G)	1-3 (G)	1-4	1-4
Effluent storage reservoirs[6]	1-6 (G)	1-3 (G)	1-4	1-4

G With good design and proper operation the recommended guidelines are achievable
[1] Further research is needed to confirm performance
[2] Including secondary sedimentation
[3] Including settling pond
[4] Chlorination or ozonation
[5] Performance depends on number of ponds in series and other environmental factors
[6] Performance depends on retention time, which varies with demand

Source: Mara and Cairncross, 1989

Table 4.4 Reported effluent quality from stabilisation ponds with a retention time of 25 days

Location of ponds	No. of ponds in series	Effluent quality (fc/100 ml)[1]
Australia, Melbourne	8-11	100
Brazil, Extrabes	5	30
France, Cogolin	3	100
Jordan, Amman	9	30
Peru, Lima	5	100
Tunisia, Tunis	4	200

[1] Faecal coliforms per 100 ml

Source: Bartone and Arlosoroff, 1987

Table 4.4 summarises the efficiency of wastewater treatment systems for the removal of pathogens, indicating where the proposed WHO guidelines for Category A (unrestricted irrigation) can be met. The following general comments provide technical support to guide the choice of adequate treatment systems for the use of wastewater in irrigation (Hespanhol, 1990).

Conventional primary and secondary treatments

Raw domestic wastewater contains between 10^7 and 10^9 faecal coliform per 100 ml. Conventional treatment systems, such as plain sedimentation, bio-filtration, aerated lagoons and activated sludge, which are designed particularly for removal of organic matter, are not able to remove pathogens in order to produce an effluent that meets the WHO guideline for bacterial quality ($\leq$ 1,000 faecal coliform per 100 ml). In the same way, they are not generally effective in helminth removal. More research and adaptive work is required to improve the effectiveness of conventional systems in removing helminth eggs.

Waste stabilisation ponds

Ponding systems are the preferred technology to provide effluents for reuse in agriculture and aquaculture, particularly in warm climates and whenever land is available at reasonable cost (Mara, 1976; Arthur, 1983; Bartone, 1991). Ponding systems integrating anaerobic, facultative and maturation units, with an overall average retention time of 10-50 days (depending on temperature), can produce effluents that meet the WHO guidelines for both bacterial and helminth quality.

Table 4.5 Performance of five wastewater stabilisation ponds (mean temperature 26 °C) in Northeast Brazil

Sample	Retention time (days)	BOD_5 (mg 1^{-1})	Suspended solids (mg 1^{-1})	Faecal coliforms	Intestinal nematode eggs/litre
Raw wastewater		240	305	4.6×10^7	804
Effluent from					
Anaerobic pond	6.8	63	56	2.9×10^6	29
Facultative pond	5.5	45	74	3.2×10^5	1
Maturation pond No. 1	5.5	25	61	2.4×10^4	0
Maturation pond No. 2	5.5	19	43	450	0
Maturation pond No. 3	5.8	17	45	30	0

Sources: Mara *et al.,* 1983; Mara and Silva, 1986

Tables 4.5 and 4.6 illustrate the high confidence with which pond systems can meet the WHO guidelines and Table 4.6 also shows their excellent capacity for reducing BOD and suspended solids. The FAO Irrigation and Drainage Paper No. 47 *Wastewater Treatment in Agriculture* (FAO, 1985) also provides a good review of wastewater treatment systems which are recommended for wastewater use schemes. The following advantages are the reasons why stabilisation ponds are an adequate treatment system for the conditions prevailing in developing countries:

- Lower construction, operation and maintenance costs.
- No energy requirements.
- High ability to absorb organic and hydraulic loads.
- Ability to treat a wide variety of industrial and agricultural wastes.

Disinfection

Disinfection of wastewater through the application of chlorine has never been completely successful in practice, due to the high costs involved and the difficulty of maintaining an adequate, uniform and predictable level of disinfection efficiency. Effluents from well-operated conventional treatment systems, treated with 10-30 mg l^{-1} of chlorine and a contact time of 30-60 minutes, provide a good reduction of excreted bacteria, but have no capacity for removing helminth eggs and protozoa. As a well designed and operating stabilisation ponding system will provide an effluent with less than 1,000 faecal coliform per 100 ml and less than one egg of intestinal nematodes per litre, there is usually no need for disinfection of pond effluents intended for reuse.

Table 4.6 Evaluation of common irrigation methods in relation to the use of treated wastewater

Parameters of evaluation	Furrow irrigation	Border irrigation	Sprinkler irrigation	Drip irrigation
Foliar wetting and consequent leaf damage resulting in poor yield	No foliar injury as the crop is planted on the ridge	Some bottom leaves may be affected but the damage is not serious enough to reduce yield	Severe leaf damage can occur resulting in significant yield loss	No foliar injury occurs under this method of irrigation
Salt accumulation in the root zone with repeated application	Salts tend to accumulate in the ridge which could harm the crop	Salts move vertically downwards and are not likely to accumulate in the root zone	Salt movement is downwards and root zone is not likely to accumulate salts	Salt movement is radial along the direction of water movement. A salt wedge is formed between drip points
Ability to maintain high soil water potential	Plants may be subject to stress between irrigations	Plants may be subject to water stress between irrigations	Not possible to maintain high soil water potential throughout the growing season	Possible to maintain high soil water potential throughout the growing season and minimise the effect of salinity
Suitability to handle brackish wastewater without significant yield loss	Fair to medium. With good management and drainage acceptable yields are possible	Fair to medium. Good irrigation and drainage practices can produce acceptable levels of yield	Poor to fair. Most crops suffer from leaf damage and yield is low	Excellent to good. Almost all crops can be grown with very little reduction in yield

Source: Kandiah, 1994b

Storage reservoirs

Water demand for irrigation occurs mainly in the dry season or during particular periods of the year. Wastewater intended for irrigation can, therefore, be stored in large, natural or specially constructed reservoirs, which provide further natural treatment, particularly in terms of bacteria and helminth removal. Such reservoirs have been used in Mexico and Israel (Shuval, *et al.,* 1986).

There are insufficient field data available to formulate an adequate design criterion for storage reservoirs, but pathogen removal depends on retention time and on the possibility of having the reservoir divided into compartments. The greater the retention time and the larger the number of compartments in series, the higher the efficiency of pathogen removal. A design recommendation, based particularly on data available from natural storage reservoirs operating in the Mesquital Valley, Mexico, is to provide a minimum hydraulic average retention time of 10 days, and to assume two orders of magnitude reduction in both faecal coliform and helminth eggs. Thus, the stored waste-water should contain no more than 10^2 eggs per litre and not more than 10^5 faecal coliform per 100 ml, in order that the WHO guidelines for unrestricted irrigation are attained.

Tertiary treatment

Tertiary or advanced treatment systems are used to improve the physico-chemical quality of biological secondary effluents. Several unit operations and unit processes, such as coagulation-flocculation-settling-sand filtration, nitrification and denitrification, carbon adsorption, ion exchange and electro-dialysis, can be added to follow secondary treatment in order to obtain high quality effluents. None of these units are recommended for use in developing countries when treating wastewater for reuse, due to the high capital and operational costs involved and the need for highly skilled personnel for operation and maintenance.

If the objective is to improve effluents of biological plants (particularly in terms of bacteria and helminths), for the irrigation of crops or for aquaculture, a more appropriate option is to add one or two "polishing" ponds as a tertiary treatment. If land is not available for that purpose, horizontal or vertical-flow roughing filtration units (which have been used for pre-treatment of turbid waters prior to slow-sand filtration) may be considered. These units, which are low cost and occupy a relatively small area, have been shown to be very effective for the treatment of secondary effluents and remove a considerable proportion of intestinal nematodes. Detailed information on the design, operation and removal efficiencies of roughing filters can be found elsewhere (Wegelin, 1986; Wegelin *et al.,* 1991).

Sludge treatment

The excess sludge produced by biological treatment plants is valuable as a source of plant nutrient as well as a soil conditioner. It can also be used in agriculture or to fertilise aquaculture ponds. However, biological treatment processes concentrate organic and inorganic contaminants as well as pathogens in the excess sludge. Given the availability of nutrients and moisture, helminth eggs can survive and remain viable for periods close to one year. If adequate care is taken during the handling process, raw sludge can be applied to agricultural land in trenches and covered with a layer of earth. This should be done before the planting season starts and care should be taken that no tuberous plants, such as beets or potatoes, are planted along the trenches.

The following treatment methods can be applied to make sludges safe for use in agriculture or aquaculture:

- Storage, from 6-12 months, at ambient temperature in hot climates.

- Mesophyllic (around 35 °C) anaerobic digestion, which removes 90-95 per cent of total parasite eggs, but only 30-40 per cent of *Ascaris* eggs (Gunnerson and Stuckey, 1986).

- Thermophilic (around 55 °C) anaerobic digestion for about 13 days ensures total inactivation of all pathogens. Continuous reactors can allow pathogens to by-pass the removal process and therefore the digestion process should be performed under batch conditions (Strauss, 1985).

- Forced-aeration co-composting of sludge with domestic solid waste or some other organic bulking agent, such as wood chips, for 30 days at 55-60 °C followed by maturation for 2-4 months at ambient temperature, will produce a stable, pathogen-free compost (Obeng and Wright, 1987).

4.4.2 Crop selection

According to the WHO guidelines (see Table 4.2) wastewater of a high microbiological quality is needed for the irrigation of certain crops, particularly crops eaten uncooked. Nevertheless, a lower quality is acceptable for irrigation of certain types of crop and corresponding levels of exposure to the groups at risk, because lower quality waters will affect consumers and other exposed groups such as field workers and crop handlers. For example, crops which are normally cooked, such as potatoes, or industrial crops such as cotton and sisal, do not require a high quality wastewater for irrigation.

Crops can be grouped into two broad categories according to the group of persons likely to be exposed and the degree to which health protection measures are required:

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

Category B. Protection required for agricultural workers only, because there would be no microbiological health risks associated with the consumption of the crops if they were irrigated with wastewater (there is no risk to consumers because crops in this category are not eaten raw, or they are processed before they reach the consumer). This category includes cereal crops, industrial crops, food crops for canning, fodder crops, pastures and trees. Some vegetable crops may be included in this category if they are not eaten raw (potatoes and peas), or if they grow well above the ground (chillies, tomatoes and green beans). In such cases it is necessary to ensure that the crop is not contaminated by sprinkler irrigation or by falling to the ground, and that contamination of kitchen utensils by such crops, before cooking, does not give rise to health risks.

The practice of crop restriction infers that crops that are allowed to be irrigated with wastewater are restricted to those specified under category B. This category protects consumers but additional protective measures are necessary for farm workers (see below).

Although it appears simple and straightforward, in practice it is very difficult to implement and to enforce crop restriction policies. A crop restriction policy is effective for health protection only if it is fully implemented and enforced. It requires a strong institutional framework and the capacity to monitor and to control compliance with the established crop restriction regulations. Farmers should be advised of the importance and necessity of the restriction policy and be assisted in developing a balanced mix of crops which makes full use of the available partially-treated waste-water. The likelihood of succeeding is greater where:

- A law-abiding society exists or the restriction policy is strongly enforced.

- A public body controls the allocation of wastewater under a strong central management.

- There is adequate demand for the crops allowed under the policy and they fetch a reasonable price.

- There is little market pressure in favour of crops in category A.

Crop restriction does not provide health protection in aquaculture schemes, because fish and macrophytes grown in wastewater or excreta-fertilised ponds are, in many places, eaten uncooked. An alternative and promising approach, already practised in many parts of the world, is to grow duckweed (*Lemna* sp.) in wastewater-fed ponds. The duckweed is then collected and dried, and fed to high-value fish grown in freshwater ponds. The same approach can be used to produce fishmeal for animal feed (or for fish food) by growing the fish to be used for the production of fishmeal in wastewater ponds.

4.4.3 Irrigation techniques

The different methods used by farmers to irrigate crops can be grouped under five headings (Kandiah, 1994b):

- Flood irrigation: water is applied over the entire field to infiltrate into the soil (e.g. wild flooding, contour flooding, borders, basins).

- Furrow irrigation: water is applied between ridges (e.g. level and graded furrows, contour furrows, corrugations). Water reaches the ridge (where the plant roots are concentrated) by capillary action.

- Sprinkler irrigation: water is applied in the form of a spray and reaches the soil in much the same way as rain (e.g. portable and solid set sprinklers, travelling sprinklers, spray guns, centre-pivot systems).

- Sub-surface irrigation: water is applied beneath the root zone in such a manner that it wets the root zone by capillary rise (e.g. subsurface canals, buried pipes).

- Localised irrigation: water is applied around each plant or group of plants so that only the root zone gets wet (e.g. drip irrigation, bubblers, micro-sprinklers).

The type of irrigation method selected depends on water supply conditions, climate, soil, the crops to be grown, the cost of irrigation methods and the ability of the farmer to manage the system.

There is considerable scope for reducing the negative effects of wastewater use in irrigation through the selection of appropriate irrigation methods. The choice of method is governed by the following technical factors:

- Type of crops to be irrigated.
- The wetting of foliage, fruits and aerial parts.
- The distribution of water, salts and contaminants in the soil.
- The ease with which high soil-water potential can be maintained.
- The efficiency of application.
- The potential to contaminate farm workers and the environment.

Table 4.7 analyses these factors in relation to four widely practised irrigation methods, namely border, furrow, sprinkler and drip irrigation.

A border (as well as a basin or any flood irrigation) system involves complete coverage of the soil surface with treated wastewater which is not normally an efficient method of irrigation. This system contaminates root crops and vegetable crops growing near the ground and, more than any other method, exposes field workers to the pathogen content of wastewater. Thus, with respect to both health and water conservation, border irrigation with wastewater is not satisfactory.

Table 4.7 Different levels of tools for public participation in the decision to reuse wastewater

Purpose	Tools
Education and information	Newspaper articles, radio and TV programmes, speeches and presentations, field trips, exhibits, information depositories, school programmes, films, brochures and newsletters, reports, letters, conferences
Review and reaction	Briefings, public meetings, public hearings, surveys and questionnaires, question and answer columns, advertised "hotlines" for telephone inquiries
Interaction dialogue	Workshops, special task forces, interviews, advisory boards, informal contacts, study group discussions, seminars

Source: Crook *et al*., 1992

Furrow irrigation does not wet the entire soil surface, and can reduce crop contamination, because plants are grown on ridges. Complete health protection cannot be guaranteed and the risk of contamination of farm workers is potentially medium to high, depending on the degree of automation of the process. If the treated wastewater is transported through pipes and delivered into individual furrows by means of gated pipes, the risk to irrigation workers is minimum. To avoid surface ponding of stagnant wastewater, which may induce the development of disease vectors, levelling of the land should be carried out carefully and appropriate land gradients should be provided.

Sprinkler, or spray, irrigation methods are generally more efficient in water use because greater uniformity of application can be achieved. However, such overhead irrigation methods can contaminate ground crops, fruit trees and farm workers. In addition, pathogens contained in the wastewater aerosol can be transported downwind and create a health hazard to nearby residents. Generally, mechanised or automated systems have relatively high capital costs and low labour costs compared with manually-operated sprinkler systems. Rough levelling of the land is necessary for sprinkler systems in order to prevent excessive head loss and to achieve uniformity of wetting. Sprinkler systems are more affected by the quality of the water than surface irrigation systems, primarily as a result of clogging of the orifices in the sprinkler heads but also due to sediment accumulation in pipes, valves and distribution systems. There is also the potential for leaf burn and phytotoxicity if the wastewater is saline and contains excessive toxic elements. Secondary treatment systems that meet the WHO microbiological guidelines have generally been found to produce an effluent suitable for distribution through sprinklers, provided that the wastewater is not too saline. Further precautionary measures, such as treatment with sand filters or micro-strainers and enlargement of the nozzle orifice to diameters not less than 5 mm, are often adopted.

Localised irrigation, particularly when the soil surface is covered with plastic sheeting or other mulch, uses effluent more efficiently. It produces higher crop yields and certainly provides the greatest degree of health protection to farm workers and consumers. However, trickle and drip irrigation systems are expensive and require a high quality of treated wastewater in order to prevent clogging of the orifices through which water is released into the soil. A relatively new technique called "bubbler irrigation", that was developed for localised irrigation of tree crops, avoids the needs for small orifices. This system requires, therefore, less treatment of the wastewater but needs careful setting for successful application.

When compared with other systems, the main advantages of trickle irrigation are:

- Increased crop growth and yield achieved by optimising the water, nutrients and air regimes in the root zone.

- High irrigation efficiency because there is no canopy interception, wind drift or conveyance losses, and minimal drainage loss.

- Minimal contact between farm workers and wastewater.

- Low energy requirements because the trickle system requires a water pressure of only 100--300 kPa (1-3 bar).

- Low labour requirements because the trickle system can be easily automated, even to allow combined irrigation and fertilisation.

In addition to the high capital costs of trickle irrigation systems, another limiting factor in their use is that they are mostly suited to the irrigation of crops planted in rows. Relocation of subsurface systems can be prohibitively expensive.

Special field management practices that may be required when wastewater irrigation is performed, include pre-planting irrigation, blending of waste-water with other water supplies, and alternating treated wastewater with other sources of supply.

The amount of wastewater to be applied depends on the rate of evapo-transpiration from the plant surface, which is determined by climatic factors and can therefore be estimated with reasonable accuracy, using meteorological data. An extensive review of this subject is available in FAO (1984).

4.4.4 Human exposure control

The groups of people that are more susceptible to the potential risk from the use of wastewater in agriculture are agricultural field workers and their families, crop handlers, consumers of crops, meat and milk originating from wastewater irrigated fields, and those living near wastewater irrigated fields. The basic methods for eliminating or minimising exposure depend on the target groups. Agricultural field workers and crop handlers have higher potential risks mainly associated with parasitic infections. Protection can be achieved by:

• The use of appropriate footwear to reduce hookworm infection.
• The use of gloves (particularly crop handlers).
• Health education.
• Personal hygiene.
• Immunisation against typhoid fever and hepatitis A and B.
• Regular chemotherapy for intense nematode infections in children and the control of anaemia.
• Provision of adequate medical facilities to treat diarrhoeal diseases.
Protection of consumers can be achieved by:
• Cooking of vegetables and meat and boiling milk.

• High standards of personal and food hygiene.

• Health education campaigns.

• Meat inspection, where there is risk of tapeworm infections.

• Ceasing the application of wastes at least two weeks before cattle are allowed to graze (where there are risk of bovine cysticercosis).

• Ceasing the irrigation of fruit trees two weeks before the fruits are picked, and not allowing fruits to be picked up from the ground.

• Provision of information on the location of wastewater-irrigated fields together with the posting of warning notices along the edges of the fields.

There is no epidemiological evidence that aerosols from sprinklers cause significant risks of pathogen contamination to people living near wastewater irrigated fields. However, in order to allow a reasonable margin of safety and to minimise the nuisance caused by odours, a minimum distance of 100 m should be kept between sprinkler-irrigated fields and houses and roads.

4.4.5 Integrated measures for health protection

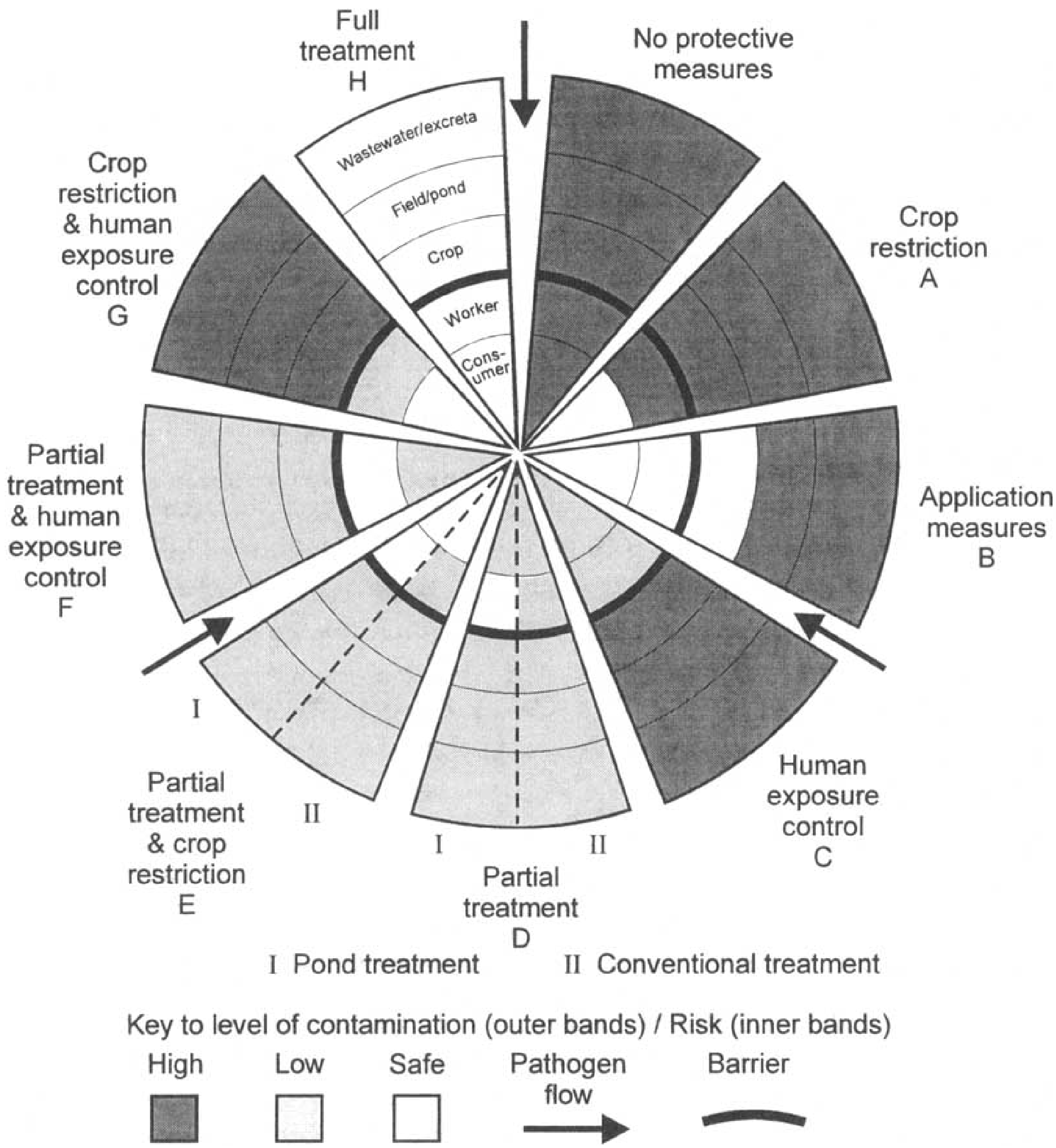
To planners and decision makers, wastewater treatment appears as a more straightforward and "visible" measure for health protection, second only to crop restriction. Both measures, however, are relatively difficult to implement fully. The first is limited by costs and operational problems and the second by lack of adequate markets for allowable crops or by legal and institutional constraints. The application of single, isolated measures will not, however, provide full protection to the groups at risk and may entail high costs of implementation and maintenance. Crop restriction, for example, if applied alone provides protection to consumers of crops but not to field workers.

To analyse the various measures in an integrated fashion aimed at the optimisation of a health protection scheme, a generalised model has been proposed (Mara and Cairncross, 1989; WHO, 1989). This model was conceived to help in decision making, by revealing the range of options for protecting agricultural workers and the crop-consuming public, and by allowing flexibility in responses to different situations. Each situation can be considered separately and the most appropriate option chosen after taking in account economic, cultural and technical factors.

The graphical conception of the model is shown in Figure 4.4. It was assumed that pathogens flow to the centre of the circle going through the five concentric rings representing wastewater or excreta, irrigated field or wastewater-fed fishpond, crops, field workers and consumers of crops. The thick black ring represents a barrier beyond which pathogens should not go if the health of the groups at risk is to be protected. The level of contamination of wastewater, field or crop, or the level of risk to consumers or workers, is indicated by the intensity of the shading. White areas in the three outer bands indicate zero or no significant level of contamination and, in the inner rings, they indicate a presumed absence of risk to human health, thereby indicating that the strategy will lead to the safe use of wastewater. If no protective measures are taken, both field workers and consumers will be at the highest risk of contamination. Assuming that a policy of crop restriction is enforced (regime A in Figure 4.4) consumers will be safe but workers will still be at high risk. Regime B assumes that application of wastewater is made through sub-urface or localised irrigation, thereby avoiding crop contamination and, consequently, maintaining both workers and consumers virtually free of contamination.

If human exposure control is the single protective measure taken, both consumers and field workers will still be submitted to the same level of risk because such measures are rarely fully effective in practice. Regime D assumes partial treatment of wastewater through ponding (D-I) or conventional systems (D-II). Stabilisation ponds with an average retention time of 8-10 days are able to remove a significant proportion of helminth eggs, thus providing protection to field workers. However, the reduction of bacteria present is not sufficient to meet WHO guidelines and hence the risk to consumers remains high. Since conventional treatment systems are not efficient at helminth removal there will be some remaining risk for both consumers and field workers.

Figure 4.4 A model illustrating the effect of control measures in reducing health risks from wastewater use (After Mara and Cairncross, 1989; WHO, 1989)



The regimes E, F and G are examples of the many possible associations of protective measures. Regime E integrates partial wastewater treatment with crop restriction, thus providing a large margin of protection to consumers of crops. However, full protection of field workers can be achieved only if the treatment is made through well-designed systems of stabilisation ponds. In regime F, human exposure control is integrated with partial treatment which may lead to complete protection of workers but some low level of risk remaining to consumers of the crops. The association of crop restriction with human exposure control (regime G) provides full protection to consumers but some risk remains to field workers. Finally, regime H provides full wastewater treatment allowing for complete protection to both field workers and consumers.

The feasibility and efficacy of any combination of protective measures will depend on several local factors which must be considered carefully before a final choice is made. Some factors to be considered are the availability of institutional, human and financial resources, the existing technological level (engineering and agronomic practices), socio-cultural aspects, and the prevalent pattern of excreta-related diseases.

4.5 Conclusions and recommendations

The incorporation of wastewater use planning into national water resource and agricultural planning is important, especially where water shortages exist. This is not only to protect sources of high quality waters but also to minimise wastewater treatment costs, safeguard public health and to obtain the maximum agricultural and aquacultural benefit from the nutrients that wastewater contains. Wastewater use may well help reduce costs, especially if it is envisaged before new treatment works are built, because the standards of effluents required for various types of use may result in costs lower than those for normal environmental protection. It also provides the possibility of recovering the resources invested in sewerage and represents a very efficient way of postponing investment of new resources in water supply (Laugeri, 1989).

The use of wastewater has been practised in many parts of the world for centuries. Whenever water of good quality is not available or is difficult to obtain, low quality waters such as brackish waters, wastewater or drainage waters are spontaneously used, particularly for agricultural or aquacultural purposes. Unfortunately, this form of unplanned and, in many instances unconscious, reuse is performed without any consideration of adequate health safeguards, environmentally sound practices or basic agronomic and on-farm principles.

Authorities, particularly the Ministries of Health and Agriculture, should investigate current wastewater reuse practices and take gradual steps for upgrading health and agronomic practices. This preliminary survey provides the basis for the clear definition of reuse priorities and the establishment of national strategies for reuse.

The implementation of an inter-sectoral institutional framework is the next step that should be taken. This entity should be able to deal with technological, health and environmental, economic and financial, and socio-cultural issues. It should also assign responsibilities and should create capacity for operation and maintenance of treatment, distribution and irrigation systems, as well as for monitoring, surveillance and the enforcement of effluent standards and codes of practice.

In countries with little or no experience on planned reuse, it is advisable to implement and to operate a pilot project. This experimental unit should include treatment, distribution and irrigation systems and provides the basis for the establishment of national standards and codes of practice which can then be fully adapted to local conditions and skills. Once the experimental phase has been completed, the system can be transformed into a demonstration and training project which could be able to disseminate the local experience to neighbouring countries.

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