Reuse of Wastewater in Agriculture: A Guide for Planners

by Nadim Khouri
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Water and
Sanitation
Report

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UNDP-World Bank
Water and Sanitation
Program

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UNDP-World Bank Water and Sanitation Program
The World Bank
Washington, DC

The International Bank for Reconstruction
and Development/The World Bank
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Much of the information in this report was developed as part of UNDP-World Bank project GLO/84/007 on Integrated Resource Recovery (Waste Management and Recycling) within the UNDP-World Bank Water and Sanitation Decade Program.

The authors are grateful to Saul Arlosoroff, the former UNDP-World Bank program manager, who supervised the project, and to Frederick Wright, economist, who contributed significantly to the economic discussions in the report. Appreciation goes to the following World Bank staff who reviewed and commented on the original proposal and earlier drafts of this report: A. Al-Khafaji, S. Barghouti, J. Briscoe, J. C. Collins, H. Garn, D. Howarth, E. Idelovitch, G. Le Moigne, D. MacEwen, M. Pommier, and A. Velderman. In addition, the comments of external reviewers were invaluable and are greatly appreciated, including those of T. Asano, D. A. Julius, K. Kawata, R. Schertenleib, H. Shuval, M. Strauss, and M. Suleiman. D. Murphy, J. Hopper, R. Pini, and J. Green of the UNDP-World Bank Program Publications Unit provided invaluable editing assistance.

This document has been prepared and published by the UNDP-World Bank Water and Sanitation Program, Transportation, Water, and Urban Development Department, The World Bank. Copies may be obtained from the UNDP-World Bank Water and Sanitation Program, 1818 H Street, NW, Washington, DC 20433.

ABSTRACT

These UNDP-World Bank guidelines summarize information on the reuse of wastewater for irrigation. They integrate the WHO health guidelines for the reuse of wastewater with the FAO water quality guidelines for irrigation. The report also summarizes relevant agronomic information including potential benefits of wastewater reuse and its environmental implications.

Properly designed, adequately implemented wastewater reuse is an environmental protection measure that is superior to discharging treated wastewater into surface waters. Wastewater reuse could also free large amounts of fresh water currently used for irrigation and make this resource available to meet the growing needs for fresh water of cities and towns in developing countries. The guidelines suggest consideration of land application as a disposal option even where no urgent need for additional sources of irrigation water exists. Close collaboration between the sectors involved--agriculture, water and wastes, environmental protection, and health--is essential, and this collaboration raises a number of institutional issues reviewed in these guidelines.

Finally, the report provides guidance for choosing among technical and policy options, and it proposes a framework for inclusion of economic and financial considerations. The guidelines will help task managers and development agency staff to prepare wastewater reuse projects.

Water quality and quantity problems at the urban-rural interface are increasing throughout the developing world. It is the authors' hope that this report will facilitate the consideration of reuse as an integral part of water management strategies in development projects.

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ACRONYMS AND ABBREVIATIONS

BOD	Biochemical oxygen demand
COD	Chemical oxygen demand
EPA	Environmental Protection Agency (U.S.A.)
FAO	Food and Agriculture Organization of the United Nations
ha	Hectare = 10,000 m^2 = 2.5 acres
IRCWD	International Reference Centre for Waste Disposal, Dübendorf, Switzerland
LLC	Land limiting constituent analysis
$\mathbf{Log_{10}}$	Removal efficiency expressed in $\log_{10}$ units removal (for example, 4 is equivalent to 10^{-4} = 99.99 percent removal)
$\mathbf{Mm^3}$	Million cubic meters
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
WHO	World Health Organization

EXECUTIVE SUMMARY

Reclaiming municipal wastewater for agricultural reuse is increasingly recognized as an essential management strategy in areas of the world where water is in short supply. Wastewater reuse has two major objectives: it improves the environment because it reduces the amount of waste (treated or untreated) discharged into water courses, and it conserves water resources by lowering the demand for freshwater abstraction. In the process, reuse has the potential to reduce the cost of both wastewater disposal and the provision of irrigation water, mainly around cities and towns with sewers.

Although treated municipal wastewater can be reused for domestic, municipal, industrial, and agricultural purposes, this report considers only the latter. The reason is that most reuse (whether controlled or uncontrolled) presently taking place in developing countries is through the irrigation of crops. Also, irrigation offers the highest level of consumptive use of water and plays a unique role in any scheme of sequential use of water, to dispose of final effluent.

This report is aimed at project planners who are involved in water-related projects including: (a) urban sanitation, (b) integrated water resources management, (c) irrigation in periurban areas, and (d) environmental improvement. The report does not provide detailed, sectoral information on the planning of sanitation systems, wastewater treatment plants, or irrigation projects. This report is concerned only with planning and design aspects that are multidisciplinary in nature, to facilitate the interaction of various technical, economic, and sociological areas of expertise in the success of reuse projects.

Wastewater reuse is, by definition, a multidisciplinary endeavor. The quality of wastewater effluent is the most important technical aspect in designing and implementing a coherent system of reuse that is accepted and supported by people affected (as producers or consumers) by the reuse scheme. This report integrates the WHO (1989) quality guidelines for safe reuse, as far as *public health* concerns, with the agronomic concerns for sound management of plants, soil, and water.

The first part of the report focuses on the principal multisectoral implications of reuse, especially with respect to ensuring the economical production of wastewater quality that is acceptable for its intended agricultural use with respect to health, agriculture production, and public acceptance.

The second part of the report presents the major elements of a wastewater reuse project planning framework and briefly discusses a number of "without-project" situations.

1. Introduction

Wastewater reuse in agriculture is the economically feasible, environmentally sound use of municipal wastewater for irrigation and aquaculture. Reuse generally will (a) provide additional sources of water, nutrients, and organic matter for soil conditioning; (b) improve the environment by eliminating or reducing discharge to surface waters; (c) conserve freshwater sources; and (d) improve the economic efficiency of investments in wastewater disposal and irrigation, mainly near cities and towns where sewerage systems exist.

Wastewater, as a resource, is often not used--or even considered--for five principal reasons: lack of information about its benefits, fear of possible health risks, cultural bias, lack of a method to analyze the economics of reuse projects comprehensively, and negative experiences with wastewater reuse in areas where it is practiced under uncontrolled or poorly designed conditions.

The project guidelines detailed in Chapter III provide the planner with state-of-the-art knowledge on the advantages of reusing wastewater for irrigation and for environmentally sound disposal to assist decision making on investments in reuse projects. Therefore, this report:

1. discusses the issues related to wastewater reuse in agriculture;
2. informs those responsible for planning wastewater disposal projects and those responsible for planning irrigation projects of the need to consult each other about reuse projects for the dual purpose of irrigation and wastewater disposal;
3. provides the necessary information to proponents of agriculture projects so they can evaluate the impact of wastewater reuse on health and productivity; and
4. aids in the preparation and appraisal of these projects.

Although most of the issues discussed relate to both irrigation and aquaculture (waste-fed production of fish, or feed, or both), only irrigation will be considered in detail here. Fundamental research on the health effects of aquaculture is still under way, and the results cannot yet be translated into definite guidelines. A global review of waste-fed aquaculture experience can be found elsewhere (Edwards 1991).

This report does not provide information on designing wastewater treatment plants or irrigation schemes, or on conducting epidemiological investigations. Guidelines for these procedures already exist, and specialists in the respective disciplines are aware of them. The guidelines in this report provide the additional multidisciplinary information necessary to evaluate the reuse of wastewater for irrigation. They familiarize the specialist with the facts required for the successful and adequate application of wastewater for irrigation.

History

The use of human waste in agriculture has been common practice for thousands of years. Semidry night soil (human feces and urine) was used to fertilize fields in China and other Asian countries in ancient times, and the practice continues to this day. Sewage farms were used to treat municipal wastewater and to grow crops in Germany as early as the sixteenth century, and in England during the seventeenth century. With the rapid rise of sewerage systems in the second half of the 1800s, sewage farms became a common method of wastewater treatment and disposal in Europe, North America, and Australia. Most have been discontinued, but those in Mexico City and Melbourne continue to perform adequately today.

Sewage farms were popular until early in the twentieth century, when expanding cities required more land. This encroachment by itself probably would not have resulted in abandonment of the sewage farms, which declined principally because of their poor construction and operation and the limited knowledge of their health effects. Concurrently, as modern farming methods and the use of chemical fertilizers increased and mechanical/biological wastewater treatment methods gained acceptance, interest in reclamation and nutrient recovery waned.

The 1950s saw a renewed interest in wastewater irrigation. One reason was rapid urbanization and the consequent rise in surface water pollution by wastewater discharges. Another reason was that in most cities, especially in arid areas, there was a scarcity of freshwater for irrigation and receiving water for sewage treatment plant effluent. These factors and a better understanding of health risks have resulted in increased reclamation of wastewater, primarily from treatment plant effluent.

The benefits today are similar to those in the past: environmental protection of the receiving waters, nutrient enrichment of the soil, and overall conservation of water resources. Reuse potential can be limited, however, when unrestricted industrial waste is discharged into sewers, making wastewater unsuitable for irrigation. Problems can also arise from inadequate water resource legislation and the inability to control: (a) effluent quality, (b) the site chosen for reuse, and (c) the method of effluent application. Other limitations are imposed by climate and geography. Nevertheless, an increasing number of countries are recognizing the value of wastewater reclamation and a few have already established national policies and programs for irrigation with wastewater.

Recent Developments in Water Quality Standards

The effect of wastewater irrigation on public health is the primary concern of regulatory agencies. In 1985, a multiagency collaboration began to review the epidemiological aspects of wastewater reuse. Participating organizations included WHO, UNDP, UNEP, IRCWD, and the World Bank. Based on their assessment of prevailing health conditions in developing countries, they proposed revised standards, the "Engelberg Standards" (IRCWD 1985), which take into account four major developments. These were later finalized as the WHO (1989) "Health

Guidelines for the Use of Wastewater in Agriculture and Aquaculture." The significance of these water-quality guidelines is that they are achievable with simple, inexpensive treatment methods. As a consequence, it is much more likely that the standards will be adhered to and enforced. They provide a starting point for those countries that are interested in regulating wastewater reuse and could lead to a significant increase in the adoption of reuse as a feasible wastewater disposal option.

A WHO scientific group meeting in Geneva adopted the Engelberg recommendations and formulated new guidelines to replace the 1973 edition. Published in 1989 (WHO 1989), these guidelines form the basis for the proposed increase in the use of wastewater for irrigation. Other important documents that reflect the WHO 1989 public health and microbial guidelines have been published (Mara and Cairncross, 1989; Shuval, 1990). For detailed case studies, the reader may refer to a thorough examination of reuse practices in various countries reported by Strauss and Blumenthal (1990). Wastewater reuse is a topic that has inspired many excellent documents and it would be practically impossible to cite them all here. The documents mentioned above in addition to the present report represent different perspectives of reuse but are all based on the collaborative efforts that culminated in the WHO 1989 guidelines. The present document differs from the others in that it does not try to justify the rationale for the new quality guidelines. It takes the microbiological guidelines for granted and broadens its application to include practical problems that are generally encountered at the project level. The objective of this report is to offer a project approach to wastewater reuse and enlarge the scope of the discussion to include agronomic and general environmental guidelines for reuse.

2. The Main Areas of Concern in Wastewater Reuse Planning

Wastewater reuse in agriculture requires consideration of the health impact, agricultural productivity, economic feasibility, and sociocultural aspects. As a consequence, at least two, and quite possibly four or five, professionals must cooperate to design a socially acceptable project that can optimize benefits, minimize costs, and protect public health. These professionals might represent the disciplines of public health, sanitary engineering, agronomy, irrigation engineering, finance and economics, and the behavioral sciences. Although the issues discussed in this chapter can be applied to any domestic/municipal wastewater reuse scheme, it is important to note that the multidisciplinary solution to these issues must be site-specific, adapted to local socioeconomic conditions, and sustainable.

Water Resources

Quantity

Seasonal variations in rainfall may be significant in any area, even though annual precipitation remains reasonably constant over the long term. Managing the available water resources (including precipitation and water from other sources) must include allocation programs to accommodate varying seasonal demands. Agriculture is usually the principal water user (about 75 percent of total water use in developing countries), followed by industry, commerce, and the home.

In arid and semiarid areas, water allocation is critical. Efficient use in agriculture (through more effective irrigation) and in industry is essential. Even at the household level, water-saving appliances can reduce demand. Realistic volumetric pricing can encourage water conservation in agriculture, industry, and households. Recycling of wastewater for lower-priority, in-house uses (industrial or domestic), or within a community, can conserve freshwater. For these measures to be effective, specific strategies and policies governing the allocation of fresh and used water resources are required. The use of reclaimed wastewater to irrigate agricultural lands near cities can be economically significant because of the available markets for high-value crops. In some arid zones, wastewater may contribute 15-80 percent of the available irrigation water. Table 2.1 shows examples of the extent of wastewater reuse and its effect on wastewater disposal and irrigation.

Quality

Allocation of water resources must be based on considerations of quality as well as quantity. The highest quality is usually required for human consumption and certain industrial processes.

Therefore, national policies (in the form of water resource master plans, river basin plans, and legislation) should make the allocation of freshwater for human use a priority, and they should set standards for wastewater quality that encourage its reuse for agricultural, domestic, or industrial purposes. This is especially important in arid or semiarid countries or regions. Prescribed standards of wastewater quality can be achieved by treatment or by mixing with freshwater (dilution), or with a combination of the two. The impetus for such a sequential use of water would not be limited to the need for "stretching" the available amount of water. It would also (and perhaps mainly) be linked to the need to preserve the quality of water resources. Wastewater that is used in a consumptive way before it reaches good quality water-supply sources is prevented from degrading this water source. In this respect, and because agriculture is often the only significant *consumptive* user of water (as compared to nonconsumptive domestic and industrial users), agriculture use can be conveniently located at the end of any combination of sequential users of water.[1]

Water Pricing and Allocation

The allocation of water resources affects various, and sometimes conflicting, interests. Farmers may not be aware of the benefits of irrigating with wastewater. Industries may resist investing in wastewater treatment and reuse. Resistance is often caused by a lack of information or by faulty policies in allocating or charging for water resources.

Adequate, but realistic, water pricing is important for cost recovery and to encourage conservation. In many instances, freshwater for irrigation is provided to farmers at no cost. This not only reduces the incentive to conserve water, but it also jeopardizes any attempt to satisfy part of the irrigation requirement with treated effluent at cost. Another potential obstacle to charging farmers for treated effluent is that often they are already using raw wastewater for irrigation and thus have recognized the agronomic benefits (but not the health risks) of reuse. In those cases, farmers might resist the imposition of water charges that are meant to offset part of the cost of the treatment system. Chapter III presents a more thorough discussion of different scenarios of project implementation. In each case, formulating an adequate policy for water pricing can determine the feasibility of the wastewater reuse scheme.

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[1] Here, and generally throughout this report, no attempt is made at distinguishing between agriculture reuse as a "land application system" for wastewater disposal and reuse as a source of additional water resources. Generally, reuse projects would combine optimum solutions to both problems, keeping in mind that the primary concern is with the safe and economical disposal of wastewater in the environment.

TABLE 2.1
Examples of Effluent Irrigation in Several Countries

	------ Extent of effluent reuse -------		
	Volume reused (Mm³/yr)	Total sewage (%)	Total irrigation (%)
National/regional level			
Australia	149	11	--
Germany	100	3	10
Jordan (Jordan Valley)	97[a]	100[a]	32[a]
India	730	55	--
Israel	140	65	11
South Africa	70	16	--
U.S.A. (Arizona)	790[a]	--	>14[a]
Urban areas			
Santiago (Chile)[b]	280	100	70[c]
Mexico DF (Mexico)[b]	1,500	100	80[c]
Tunis (Tunisia)	68[a]	75[a]	--

Source: Bartone and Arlosoroff 1987, Idelovitch 1988, and World Bank 1988.

a Planned expansion of existing reuse.
b Raw sewage irrigation.
c Dry season conditions.

It can be argued that each user should be required to pay for the actual cost of abstracting, treating, and transporting water to the point of use, and for its subsequent treatment and discharge after use. Within this broad principle, rules should provide for an equitable sharing of costs and benefits resulting from the multiple use of the water. If wastewater reuse saves money for the producer and the user, the benefits should be shared. Likewise, if the result is an extra cost to one or the other, then the burden also should be shared. One method of reconciling these different and conflicting demands is to create a river basin authority responsible for water resource allocation and management. Such an agency can plan the most efficient sequential use of water resources for all purposes, providing users with the quality and quantity of water they need in a manner that is cost effective and protective of the environment.

Costs and Benefits

In studying the feasibility of irrigation with wastewater, only the costs and benefits directly attributable to the use of wastewater should be considered. Thus, wastewater irrigation probably will not be financially or economically attractive where sufficient rainfall makes irrigation itself unattractive, because the marginal increase in productivity would have to offset the entire cost of an irrigation system. On the other hand, where an irrigation system already exists, or where the demand for irrigation water exceeds the supply, the marginal cost of adding the wastewater (including treatment) may be justified by increased productivity. Jordan (World Bank 1988), Israel (World Bank 1987), and the United States--California (Engineering-Science 1987) and Arizona (Ambrose and Lynn 1986)--are examples of countries where demand for irrigation water justified investments in a number of reuse projects.

As an alternative, irrigation with wastewater could be an attractive wastewater disposal option (called land application) in a situation where a high degree of treatment prior to discharge is required for environmental considerations or where expensive disposal works (for example, a marine outfall) might otherwise be required. The combined benefits of reduced treatment and disposal cost and increased agricultural production may well justify investment in an irrigation system.

Each case must be analyzed to determine whether wastewater irrigation is a viable solution from both the agricultural and the wastewater-disposal points of view. In some cases it may be more attractive as a wastewater-disposal option than as an irrigation solution. In other cases, it may be very attractive even if the cost of treatment must be borne by the irrigator. In situations where no other sources of water are readily available and large areas of arable land exist nearby, farmers have shown their willingness to invest in treatment and storage systems. Often, although benefits will not justify investments for disposal or irrigation alone, the combination of the two may make wastewater irrigation an attractive solution, especially when environmental benefits are considered (reduced contamination of receiving waters, secondary recharge of groundwater). As a consequence, the sanitary engineer should always evaluate the feasibility of wastewater irrigation as a disposal method, and the irrigation engineer should always consider the possibility of using wastewater as a source of irrigation water and nutrients in agricultural areas around urban settlements.

Microbial Health Risks

The most important constraint to wastewater reuse has most often been concern for public health. Wastewater does carry pathogenic organisms and, in general, modern treatment methods (for example, activated sludge) were not designed to eliminate them. Wastewater disinfection will eliminate them, but it is relatively costly and beyond the technological and financial capabilities of many regions in developing countries. Organisms that can survive wastewater treatment (without disinfection) include bacteria, protozoa, helminths, and viruses. Most of these pathogens affect the human body only through ingestion of waste-contaminated water and food.

The major factors that control the degree of microbial health risk include (a) the ability of pathogens to survive or multiply in the environment; (b) the dose required for infection; (c) the need for, and the presence or absence of, intermediate hosts; and (d) the susceptibility of the person at risk (constant exposure may have created immunity). These factors are summarized in Table 2.2. Figure 2.1 shows the persistence of various pathogens in the environment.

TABLE 2.2
Epidemiological Characteristics of Enteric Pathogens
in Terms of Their Effectiveness in Causing Infections
through Wastewater Irrigation

Pathogen	Persistence in environment	Minimum infective dose	Immunity	Concurrent routes of infection	Latency/soil development stage
Viruses	medium	low	long	mainly home contact and food and water	no
Bacteria	short to medium	medium to high	short to medium	mainly home contact and food and water	no
Protozoa	short	low to medium	none to little	mainly home contact and food and water	no
Helminths	long	low	none to little	mainly soil contact outside home and food	yes

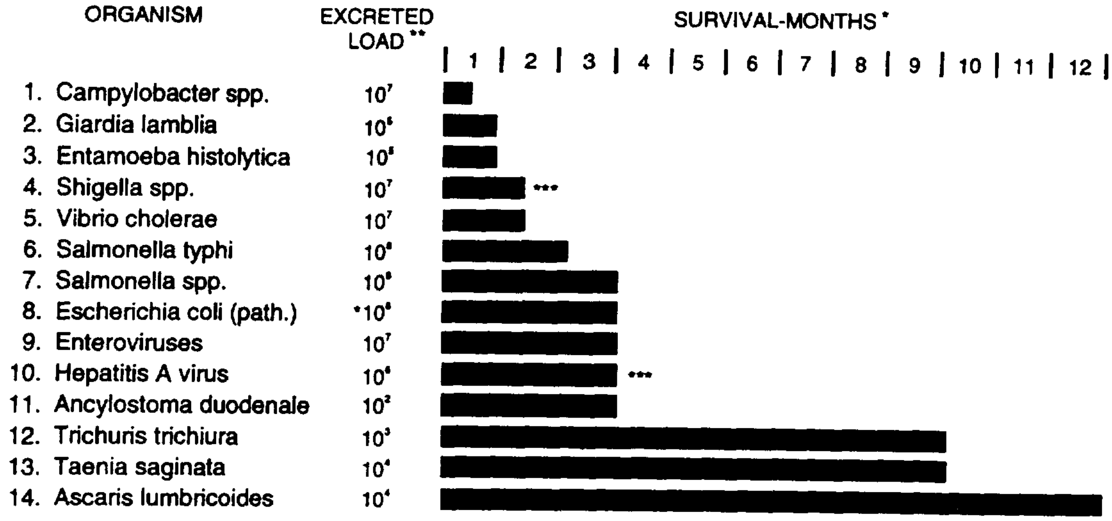
Source: Gerba et al. 1975.

Pathogens affect varied population groups differently. Consumers of raw vegetables are at greater risk than those who cook their vegetables. Workers in wastewater-irrigated fields are at greater risk than those working elsewhere. Some groups may not be affected at all. It is therefore important to aim health-protection measures at specific exposed groups.

Four groups of people who are at potential risk from the agricultural use of wastewater and excreta are:

1. agricultural field workers and their families,
2. crop handlers,
3. consumers (of crops, meat, and milk), and
4. persons living near the wastewater-irrigated fields.

Different methods to limit human exposure may be used for each of these population groups. The aim is (a) to prevent the people from coming into direct contact with the pathogens in the wastewater or (b) to prevent any contact with the pathogens from leading to the manifestation of disease. Figure 2.2 shows a generalized model illustrating the impact of the various measures on health risk.



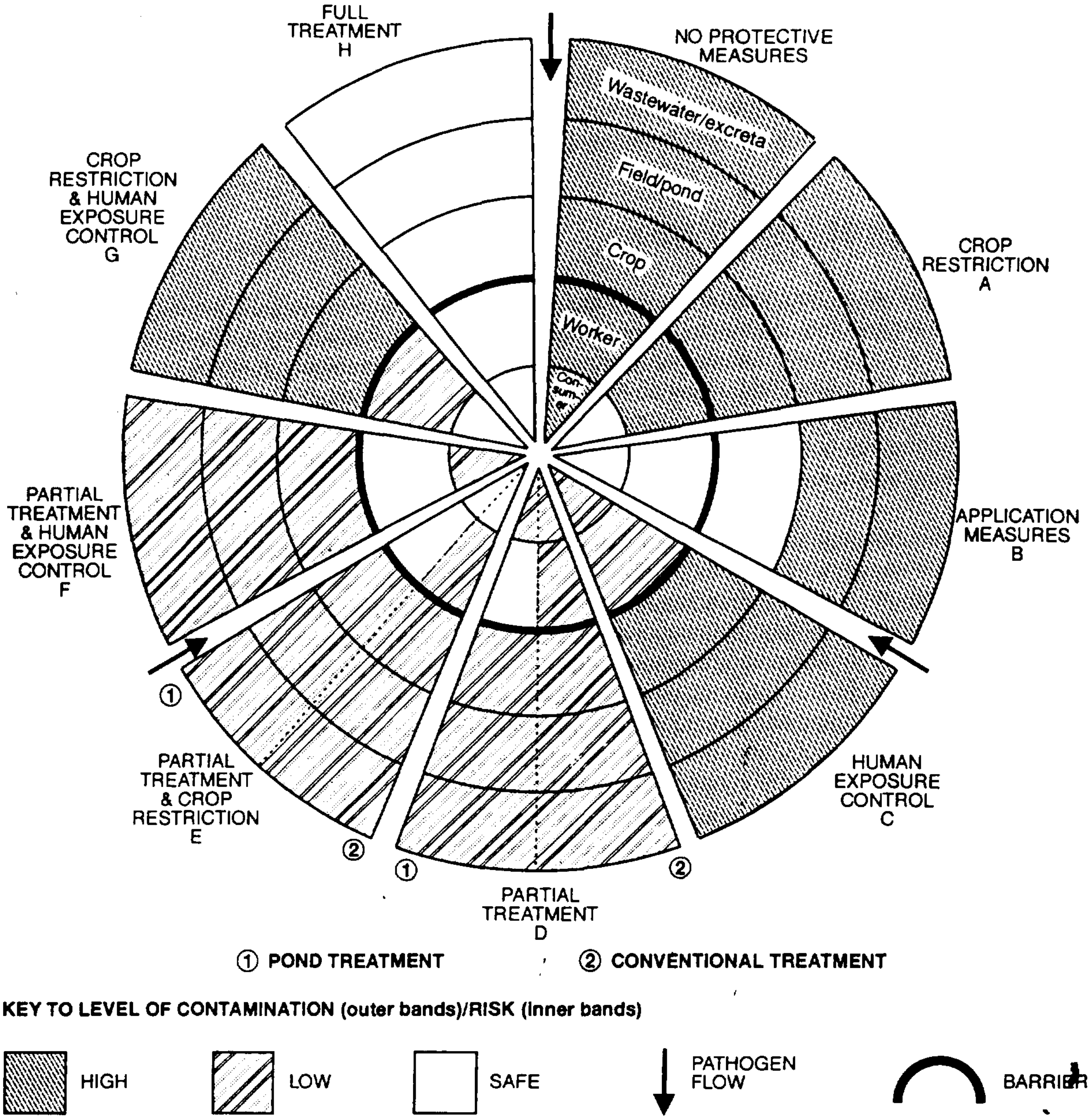
* Estimated average life of infective stage at 20°–30°C
** Typical average number of organism/gm feces
*** Figures approximate

Figure 2.1. Persistence of selected enteric pathogens in water, wastewater, and on crops.
Source: Based on Feachem et al. 1983.

Preventive measures to protect agricultural field workers and crop handlers include protective clothing, increased levels of hygiene, and possibly immunization. For example, the exposure of agricultural field workers to hookworm infection can be reduced if the workers use appropriate footwear. This may be more difficult to achieve than it seems, because in many areas traditional irrigation is carried out by scantily clad farmers. Immunization, another preventive measure, may be feasible against certain diseases (for example, typhoid and hepatitis A), but not against others (helminthic infections and diarrheal diseases). Curative health measures would require adequate medical facilities to treat diarrhea, amoebiasis, and severe nematode infections.

In agricultural and aquacultural reuse schemes, risks to consumers can be reduced if the food is cooked thoroughly before it is consumed and if high standards of hygiene are maintained. Food hygiene should be emphasized in health education campaigns. Vegetables usually eaten raw should not be irrigated with wastewater, even if treated. Where the irrigation of crops relies on wastewater, standards at least equal to the 1989 WHO guidelines should be applied (see table A1).

Local residents should be informed of the location of all fields where wastewater is used so they can avoid them and prevent their children from entering them. Warning notices (using symbols) should be posted along field borders and at water taps. There is evidence that population groups in contact with aerosols from sprinkler irrigation schemes could be at risk; therefore, sprinklers should not be used within 100 m of houses or roads.



Source: Blumenthal 1988.

Figure 2.2. Generalized model of the level of risk to human health associated with different combinations of control measures for the use of wastewater or excreta in agriculture or aquaculture. The concentric circles (bands) represent the various "media" on the path of human pathogens from the point of wastewater effluent disposal to the potential consumer of contaminated foods. The effect of different remedial techniques (interventions A to H) in protecting agriculture workers and consumers is shown and compared to the high contamination risk associated with the (nonrecommended) practice of reusing untreated wastewater for irrigation.
Source: Blumenthal 1988.

Special precautions should be taken to ensure that workers, residents, and visitors do not use wastewater for drinking or domestic purposes, either accidentally or for lack of an alternative. A fundamental exposure-control measure is to provide an adequate potable water supply. Moreover, all wastewater channels, pipes, and outlets should be clearly marked (preferably painted a characteristic color). Outlet fittings should be of a special type to prevent misuse.

Toxicological Health Risks

The amount of most chemicals in municipal wastewater (raw or treated) is generally below the toxic level for humans. Industrial waste discharges, however, can add toxic levels of certain compounds such as heavy metals and organic pollutants. This contamination could (a) endanger human health if uncontrolled irrigation is being practiced, or (b) affect the irrigation system design by forcing the addition of freshwater to dilute the toxic compounds. Raw industrial wastewater with significant amounts of hazardous compounds should be treated at the source, not discharged into the municipal sewer system.

Another potential toxicity problem is the accumulation of heavy metals in plant parts that enter the human food chain. Cadmium (Cd), for example, could be present in municipal wastewater at levels that are not toxic to plants but that could build up inside the plants to levels harmful to humans or animals. Similar buildups can occur in animals. For example, heavy metals contained in forage have been shown to accumulate in cow's milk, which could lead to a hazardous buildup in the consumer's body. Standard land application design methods to prevent this buildup take into account both the concentration and the total load of chemicals applied with wastewater. The land limiting constituent (LLC) analysis is an all-inclusive design method to control the accumulation of toxicants during waste reuse on land (Loehr and Overcash 1985). Figure 2.3 summarizes the steps involved in LLC analysis. Recommended limit values for heavy metal concentrations in soils and yearly loading rates are being developed in many regions (for example, the Council of the European Communities [1986] adopted the limits listed in Annex C).

Regulatory Aspects

Most countries where wastewater irrigation is practiced have public health regulations to protect both the agricultural worker and the irrigated crops consumer. The regulations may prohibit such irrigation within specified periods before harvesting, require appropriate clothing (such as boots), and provide for preventive health care of workers. The standards prescribed for irrigation water quality are often stringent, reflecting the California guidelines (Pettygrove and Asano 1985) or the 1973 WHO guidelines. In most industrialized countries, these standards can usually be met without major difficulties because of water pollution control requirements for treatment. Not only is the technology and the operational capacity available to achieve the standards, but regulatory agencies monitor effluent quality and enforce appropriate regulations. Regulations in the industrialized countries reflect their own sanitary conditions. Because helminths, for example, are no longer a concern in these countries, they were not a factor in the development of reuse standards.

In developing countries, the technological equipment necessary to produce effluent of a mandated quality is often unavailable or, if available, not maintained; and regulatory agencies, if

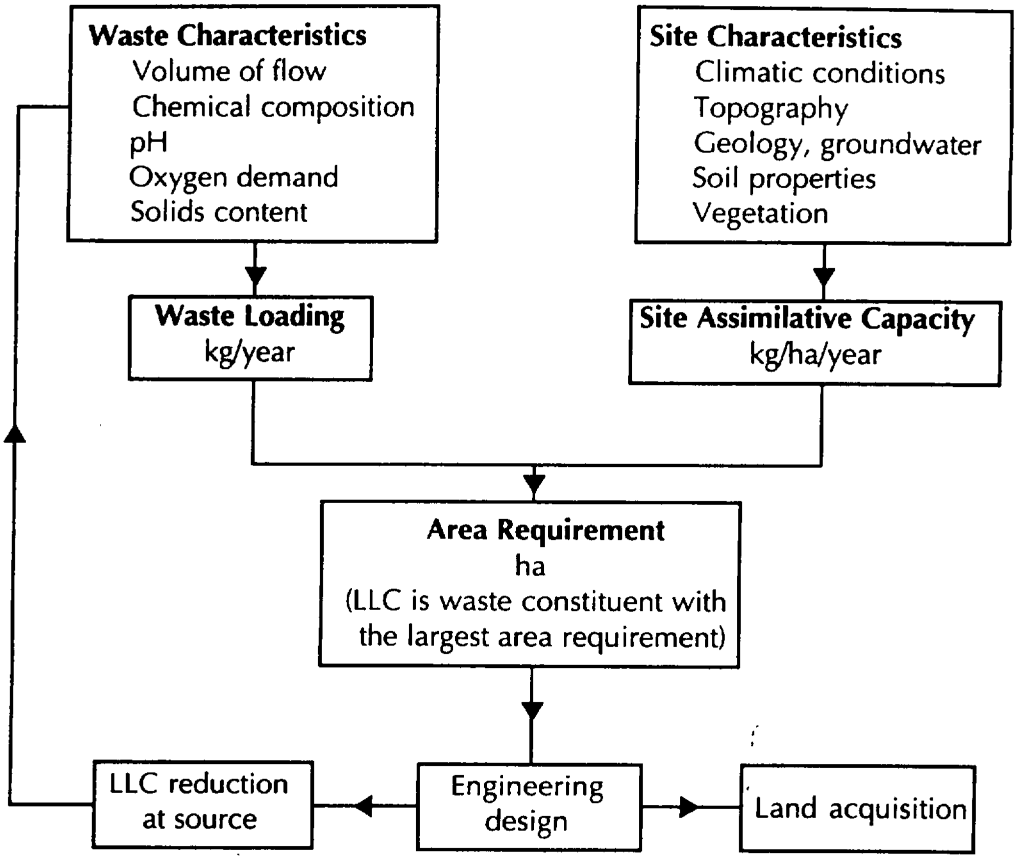


Figure 2.3. Land-limiting constituent (LLC) concept in land treatment design. This approach can be used to design safe land application systems (including crop irrigation) with respect to chemical (i.e., nonmicrobiological) wastewater pollutants *Source:* Adapted from Loehr and Overcash 1985. The site characteristics determine the site's general capacity to store wastewater constituents, naturally "treat" and "recycle" wastewater effluent (through evapo-transpiration). The wastewater (or sludge) characteristics determine the expected loading rate of various wastewater constituents. Combining loading rates with site assimilative capacity for every wastewater constituent leads to the definition of minimum land requirements for the safe disposal of these constituents. The LLC (equivalent to the "most polluting" wastewater constituent) determines the total area that would be required to dispose of the wastewater effluent safely on land ("Land Acquisition"). As an alternative, once the LLC has been identified, remedial interventions (e.g., additional treatment) can change the waste characteristics and reduce land requirements.

they exist, can seldom enforce the standards. Irrigation with wastewater is therefore often uncontrolled in these countries, and both the agricultural worker and the consumer are at risk. To resolve the legal problem of unenforceable standards, the first step is to set realistic criteria reflecting prevalent disease risks. This would result in fewer risks to health and enforceable standards that encourage the safe use of wastewater for irrigation.

Public Health Standards

As mentioned previously, in July 1985 a group of experts reviewed the existing practices and standards for wastewater irrigation in developing countries. The meeting in Engelberg, Switzerland, was sponsored by WHO, UNDP, UNEP, the World Bank, and IRCWD. FAO joined later (IRCWD 1985). After reviewing recent epidemiological studies of untreated wastewater reuse, the group concluded that the danger of infection was:

1. high with intestinal nematodes;
2. moderate with bacterial infections and diarrheas;
3. minimal with viral infections and diarrheas, and hepatitis A; and
4. high to nonexistent with trematode and cestode infections, schistosomiasis, clonorchiasis, and taeniasis, depending on local practices and circumstances.

As a consequence, the group developed new quality guidelines for irrigation water (the "Engelberg Standards") and recommended their adoption by WHO. These guidelines were then modified at a WHO scientific group meeting in Geneva on November 18-23, 1987 (table 2.3), which recommended their adoption as the new WHO Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture (WHO 1989). The guidelines evolving from the Engelberg Standards, with their more realistic assessments of health risks, are expected to lead to more widespread use of safe wastewater for irrigation.

Sociocultural Aspects

On an operational level, the sociocultural, or "software," component particular to a wastewater reuse project will evaluate two factors vital to project planning and implementation: (a) the perceived need for wastewater effluent as a substitute or supplemental source of water, and (b) the degree of acceptability of reuse by the people who will be affected by the project. A physical, natural resources-oriented survey complemented by a socioeconomic study of the communities affected by the reuse project (principally the farmers in the case of reuse in agriculture) will reveal the *need* for reuse. The *acceptance* of wastewater reuse and the adoption of practices for its safe implementation will be influenced by the sociocultural makeup of the people involved (that is, the values, beliefs, and customs that are concerned with water supply, sanitation, hygiene, and other activities related to water use). Although methods for including sociocultural data in water supply and sanitation projects have been developed and tested successfully during the past ten years (Simpson-Hebert 1983), there are few, if any, in-depth studies of the sociocultural aspects of reuse projects in developing countries. There are, however, a few reconnaissance-type studies that describe sociocultural aspects of reuse (for example, Strauss and Blumenthal 1990) that point to a number of useful conclusions briefly summarized below.

TABLE 2.3

Recommended Microbiological Quality Guidelines for Wastewater Use in Agriculture

Category	Reuse conditions	Group exposed	Intestinal nematodes[a] (arithmetic mean no. of eggs per liter[b])	Fecal coliforms (geometric mean no. per 100 ml[b])	Wastewater treatment expected to achieve required microbiological quality
A	Irrigation of crops likely to be eaten uncooked; sports fields, public parks[c]	Workers, consumers, public	≤ 1	≤ 1,000[c]	Series of stabilization ponds designed to achieve the microbiological quality indicated, or equivalent treatment
B	Irrigation of cereal, industrial and fodder crops; and pasture and trees[c]	Workers	≤ 1	No standard recommended	Retention in stabilization ponds for 8-10 days for equivalent helminth and fecal coliform removal
C	Localized irrigation category B crops if worker and public exposure does not occur	None	N/A	N/A	Pretreatment as required by irrigation technology, but not less than primary sedimentation

Source: WHO (1989).

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

a. *Ascaris* and *Trichuris* species, and hookworms.

b. During the irrigation period.

c. A more stringent guideline (≤ 200 fecal coliforms per 100 ml) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact.

d. 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.

The idea of irrigating with wastewater, particularly treated wastewater, does not appear to arouse appreciable repugnance where it is being implemented or proposed. Although in certain areas some farmers have refused to substitute treated wastewater for available freshwater, other farmers of similar background in the same area have readily accepted wastewater irrigation. Thus this attitude seems to reflect a personal, rather than a cultural, bias. Irrigation with wastewater is practiced in one form or another worldwide, regardless of the cultural background of the practitioners. There is, of course, a social and political cost associated with not reusing wastewater where it presents the only (or a significant) source of irrigation water. Farmers, recognizing the value of wastewater, have in some cases broken into sewer lines to take water even when reuse was not officially sanctioned. In all cases, special emphasis should be given to community information and education programs when any reuse project begins.

It is important, however, to recognize the limits of such an effort and expect only modest behavioral changes to accompany a wastewater reuse project. For example, one cannot expect to change the eating habits of an entire city to justify introducing a crop irrigated with treated wastewater. On the other hand, a well-directed and timely effort aimed at the population can overcome one of the greatest obstacles to wastewater treatment--public resistance to siting the facility--by highlighting the potential benefits of using the treated effluent.

Public opinion on water reuse will vary with the type of reuse envisaged. Research performed in the United States (Bruvold 1988) suggests that people generally prefer wastewater-effluent disposal options offering the least possible human contact such as stream discharge or reuse through irrigation of landscaped areas. When people are confronted with conservation options concerning their own communities, however, there is a significant shift toward the acceptability of reuse options having a more "useful" end, even if this means increased human contact with reclaimed wastewater. One can expect that the populations in developing countries, when made aware of imminent water-shortage problems, will be willing to consider reuse options that include increasing levels of human contact with treated wastewater, especially if reuse is one component of an integrated water conservation effort.

The effect of religion on the feasibility of reuse in Islamic countries is frequently cited as an example of sociocultural factors that can limit the application of wastewater reuse in these countries. The evidence, however, shows that in most Islamic countries of the Middle East, water is scarce and wastewater is reused, principally for irrigation (Ali 1987, Biswas and Arar 1988, Haddadin and Suleiman 1988). But religious authorities there reportedly have rejected attempts to institute other forms of reuse, such as for toilet flushing, because of the risk of contamination with nonpure water.

Agronomic Aspects

Benefits

The benefits of using wastewater in agriculture are related to the available water's quantity and nutrients. In arid and semiarid areas, wastewater irrigation may significantly increase farm production. At a flow of 140 liters per capita per day (lcd), 100,000 people would generate about 5 million cubic meters (Mm^3) of wastewater per year, enough to irrigate 1,000 ha (hectares) at a rate of 5,000 m^3/ha/year, using efficient irrigation methods. With inefficient methods, this amount of water could still irrigate 250-500 ha in arid regions. Even in temperate zones, the proximity of this water source may make it an attractive alternative to using costly potable water for urban park and green-space irrigation. The estimates presented here are meant as rough approximations of potential agronomic benefits for 100 percent reuse of treated effluents. The percentage of effluent that can be reused economically would generally be expected to be less than 100 percent.

Wastewater contains nutrients and trace elements necessary for plant growth. Five Mm^3 of wastewater contains about 250,000 kg of nitrogen, 50,000 kg of phosphorous, and 150,000 kg of potassium. Whether additional fertilizer is required depends on the crop being irrigated. Soil deficiencies usually can be corrected by the trace elements in wastewater. Their presence may be particularly significant in situations where fertilizers are not used or where subsistence farmers cannot afford chemical fertilizers. Marked yield increases result from wastewater irrigation under various climatic and agricultural conditions. Table 2.4 shows the results of test-plot productivity experiments in Thailand and India, where wastewater irrigation with no other fertilization produced greater yields than did freshwater irrigation with inorganic fertilization.

Clearly, nutrients in wastewater are beneficial. Whether the benefits justify the cost depends not only on agricultural productivity, but also on the costs that would be incurred for wastewater disposal without irrigation. These nutrients could, however, reach levels that are toxic to plants, as discussed previously in the section on toxicological health risks.

Costs

The costs of wastewater reuse specifically associated with irrigation result from (a) the special treatment or irrigation technologies required, (b) the possible use of lower-valued crops associated with specific wastewater applications, and (c) the measures required to protect public health. For example, wastewater used for tree crops needs little or no treatment, but the financial returns from tree crops are lower than those from vegetables. Wastewater used for vegetables, however, requires substantial investments in treatment and/or irrigation facilities and in health protection of farm workers. Table 2.5 is a generalized list of application methods and the advantages and disadvantages of each.

The nutrients, trace elements, and other salts contained in wastewater effluent may occasionally reach levels that are detrimental to crops or soils. In such cases, alternative crops must be selected or dilution water added, and these measures may decrease the economic benefits. The major chemical elements and compounds of concern are discussed briefly below; more detailed discussions can be found in the literature (for example, Bouwer and Idelovitch 1987).

Nitrogen: The water and nitrogen requirements of a plant vary independently during the growing season. Thus, if wastewater containing high levels of nitrogen is applied according to the crop's water requirements, then the amount of nitrogen applied may exceed the crop's nitrogen requirements. This excess nitrogen may have the following detrimental effects: (a) excessive leaf growth leading to plant lodging (bending due to weakening of plant cellulose tissue) and a decrease in the economic value of certain crops (such as cotton, tomatoes, and fruit trees); (b) accumulation of high levels of nitrogen in the plants, where nitrate could transform into nitrite--a form of nitrogen toxic to animals; and (c) groundwater contamination with percolating nitrogen in the form of nitrates.

TABLE 2.4

Productivity of Test Plots in Thailand and India
Using Different Qualities of Irrigation Water

Irrigation water	Crop yields (tons/ha/year) Wheat (8)[a]	Mung beans (5)	Rice (7)	Potatoes (4)	Cotton (3)
Raw wastewater	3.34	0.90	2.97	23.11	2.56
Settled wastewater	3.45	0.87	2.94	20.78	2.30
Stabilization pond effluent	3.45	0.78	2.98	22.31	2.41
Fresh water and commercial fertilizer	2.70	0.72	2.03	17.16	1.70

Source: Shende 1985.

a. The numbers in parentheses indicate years of harvest used to calculate the average yield.

Trace elements: Heavy metals in wastewater could be present at levels that affect the agricultural output of the farm. In this respect, two elements, boron and molybdenum, are often of particular concern in wastewater irrigation schemes (Bouwer and Idelovitch 1987). Boron in wastewater can be toxic to plants and molybdenum can accumulate in forage crops to levels that are toxic to cattle that feed on these crops. Other elements could also present a risk if industrial wastes are discharged into the municipal sewers. This is often the case in developing countries, where even small-sized factories or craft shops could significantly contaminate the wastewater flow. In that case, the wastewater should be tested for chemicals that are used by the industries, as well as for boron and molybdenum.

Salinity: Soil or irrigation-water salinity can reduce crop yields. Expressed in milligrams per liter (mg/l) of total dissolved solids (TDS), the salinity of wastewater is generally 200-400 mg/l higher than the salinity of freshwater supplied to a city. Industrial use of water-softening processes can significantly increase these values if the raw effluent is discharged into the municipal sewer. In general, however, the use of municipal wastewater has not been shown to cause more salinity hazards than freshwater irrigation because of a combination of the following factors: (a) in relative terms, the salinity of wastewater is not much higher than that of freshwater; (b) salts are generally

TABLE 2.5

Advantages and Disadvantages of Different Methods of Wastewater Irrigation in Terms of Disease Transmission Risks, Water Use Efficiency, and Cost

Method of application	Advantages	Disadvantages
Surface irrigation	Low cost; low level of wastewater treatment required	High potential health risks to field workers, crop handlers, and consumers; crop restrictions necessary; low water-use efficiency
Sprinkler and microsprayer	Medium water-use efficiency	High cost of treatment; potential health risks to field workers, local residents, and crop handlers, and to consumers, if irrigated crops consumed raw.
Localized irrigation (drip, bubbler)	Low health risks, high water-use efficiency	High cost of treatment for drip, somewhat less for bubbler irrigation; high cost of distribution

Source: Adapted from Mara and Cairncross 1989.

leached from the root zone by the excess water that is applied in these typically "inefficient" irrigation systems; and (c) organics present in the wastewater are thought to counteract the negative effects of salts. One notable exception to the generally optimistic consideration of salinity of treated effluent is where coastal wastewater collection systems (sewers) are leaking and allowing wastewater to mix with intruding salty sea water.

Agronomic Standards

In contrast to the quality standards designed to minimize public health risks, guidelines reflecting the effect of wastewater quality on plant growth arouse little controversy. Whether irrigation water is derived from wastewater, surface water, or groundwater, it will contain varying amounts of beneficial or detrimental substances. The nature and level of these substances will determine its suitability to irrigate specific crops. Crop selection depends not only on the characteristics of the irrigation water, but also on soil conditions and climate. Therefore, although the basic production management process is not changed, its complexity may be increased by wastewater reuse.

Unless it contains toxic substances (usually from industrial effluent) or a very high salt content, wastewater can be quite beneficial to plants. Annex C lists typical values for the nutrients and other trace elements contained in raw and treated wastewater. The annex also contains plant tolerance guidelines and recommendations for these constituents and salinity in general. For information on specific ions that are of concern, also refer to Pettygrove and Asano (1985), Maas (1984), and Ayers and Westcot (1985).

The decision on which irrigation methods to use and which crops to grow must be *site-specific* (considering wastewater quality, soil conditions, and local know-how), and no universally applicable recommendation can be made beyond the general guidelines indicated in Annex C. Recent technological developments (such as the microsprayer and bubbler irrigation systems) can provide the same benefits as the drip irrigation system, without the associated emitter-clogging problems. These developments have increased the choices for the adoption of wastewater irrigation.

Disposal Technologies and Reuse Benefits

Conventional wastewater treatment and disposal methods involve the least costly treatment required to limit the organic pollution of receiving waters to locally acceptable levels. Use of wastewater for irrigation has not generally been considered a disposal option (except in a few areas where water is scarce and virtually any source of water is accepted to supplement irrigation water). As a consequence, the primary objective of "conventional" wastewater treatment methods has been to reduce biodegradable material rather than to eliminate pathogenic organisms. These methods include primary sedimentation followed either by activated sludge treatment, biofiltration, oxidation ditches, or aerated lagoons. Occasionally, this is followed by tertiary treatment and disinfection. All these treatment processes require a relatively short detention time (one to four hours)--sufficient to remove suspended and dissolved organic matter, but not sufficient to inactivate pathogens without disinfection (table 2.6). Use of effluent from such treatment processes requires restrictions on the type of crop to be irrigated (for example, no irrigation of food crops that are usually consumed raw) unless (a) disinfection is practiced, (b) effluent storage is of sufficient duration to ensure die-off or inactivation of pathogens, or (c) irrigation methods (drip or underground) are used that limit exposure of crops and farm workers to the effluent.

Sludge produced by sewage treatment plants can be used as a soil conditioner-fertilizer after treatment. Sludge handling is one of the most expensive operational costs in wastewater treatment. Composting the sludge will control most pathogens and, if properly marketed, can contribute to the economic feasibility of the treatment plant. Relevant design and planning details can be found elsewhere (for example, *BioCycle* 1984). The land application of raw or digested sludge is widely practiced in the United States and Europe. However, the application rate of raw or composted sludge should be carefully calculated to avoid the buildup of toxic metals in the soil. The LLC concept discussed previously in this report and presented in figure 2.3 is a suitable framework for sludge application design; limit values for specific metals are given in Annex C.

TABLE 2.6

Expected Removal Rate of Excreted Bacteria and Helminths in Various Wastewater Treatment Processes

Treatment	Type of pathogen removed ($\log_{10}$ units)	
	Bacteria	Helminths
Primary sedimentation		
Plain	0 - 1	0 - 2
Chemically assisted[a]	1 - 2	1 - 3[W]
Activated sludge[b]	0 - 2	0 - 2
Biofiltration[b]	0 - 2	0 - 2
Aerated lagoon[c]	1 - 2	1 - 3[W]
Oxidation ditch[b]	1 - 2	0 - 2
Disinfection[d]	2 - 6	0 - 1
Waste stabilization pond[e]	1 - 6	1 - 3[W]
Effluent storage reservoir[f]	3 - 6[W]	2 - 3[W]
Constructed wetland[g]	2 - 3[W]	N/A
Soil-aquifer (groundwater recharge)[h]	3 - 4	N/A

Source: Adapted from Feachem et al. 1983, except where indicated.

W With good design and proper operation, the WHO 1991 guidelines are achievable.

a Further research is needed to confirm performance.
b Including secondary sedimentation.
c Including settling pond.
d Chlorination, ozonation.
e Performance depends on number of ponds in series.
f Performance depends on retention time, which varies with demand.
g *Source:* Reed et al. 1988.
h *Source:* Idelovitch and Michail 1984.

Low-Cost Treatment Technology

The preferred treatment technology for producing safe irrigation water from wastewater in developing countries is the use of waste stabilization ponds (figure 2.4). They require minimal operational and maintenance skills and energy. Another advantage is that, when operated in series, the ponds produce a high-quality effluent with few settleable solids, a safe level of pathogenic bacteria, no helminths, and a high level of nutrients. A series of ponds (at least two) with a total detention time of eight to ten days can be designed to remove helminths adequately. At least twice that detention time is usually required to reach prescribed bacterial standards in hot climates; this

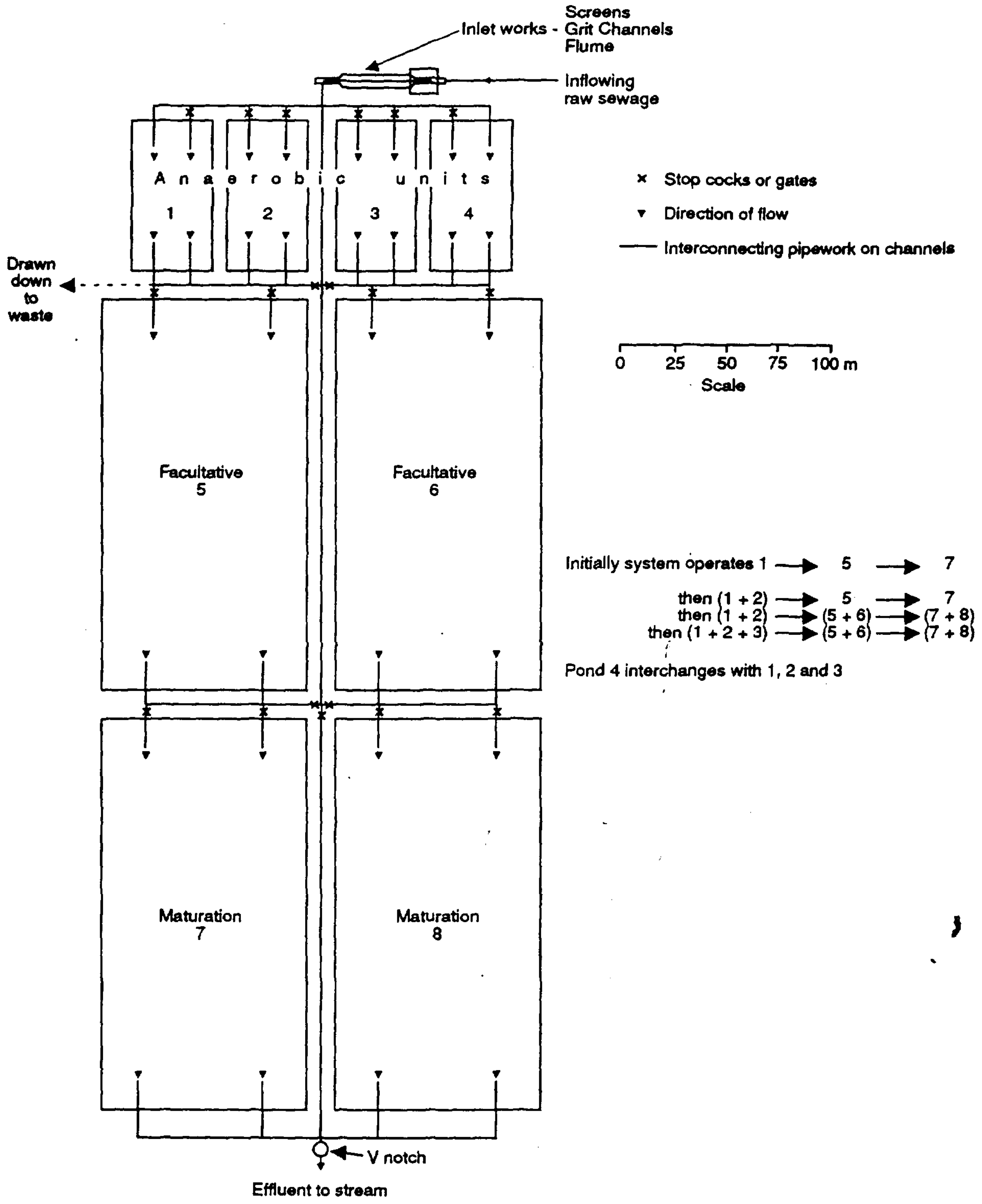


Figure 2.4. Example layout of waste-stabilization ponds. Adapted from Arthur 1983.

can be achieved with four or five ponds in series. Particular care must be taken in design to prevent short-circuiting, which would reduce the effective detention time.

Table 2.7 presents the effluent characteristics of a Brazilian pond system. In this case, a multicell stabilization pond system in a hot climate with a total detention time of twenty to twenty-five days provided a quality of effluent acceptable for unrestricted irrigation. It also showed clearly that the major reduction in organic load (BOD_5) and helminth (nematodes) concentration occurred in the first anaerobic cell, with bacterial die-off in subsequent cells proportional to detention time. Similar results have been achieved elsewhere under various climatic conditions (table 2.8). Arthur (1983) provides appropriate design criteria.

TABLE 2.7

Performance of a Series of Five Waste Stabilization Ponds in Northeast Brazil
(mean pond temperature 26° C)

Eggs Sample	Detention time (days)	BOD_5 (mg/l)	Suspended solids (mg/l)	Fecal coliforms (per 100 ml)	Intestinal Nematode (per liter)
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 1	5.5	25	61	2.4×10^4	0
Maturation pond 2	5.5	19	43	450	0
Maturation pond 3	5.8	17	45	30	0

Source: Mara et al. 1983.

Demand for irrigation water is often seasonal, but wastewater is produced at a relatively constant rate. Under these circumstances, storage capacity can be provided by designing a treatment system with an anaerobic pond or Imhoff tank followed by storage reservoirs. The anaerobic stage could be replaced by facultative or aerated lagoons. All these simple systems can be designed to produce an effluent suitable for unrestricted irrigation. Selection of the specific technology depends on local conditions.

One potential problem with waste stabilization pond systems is the large amount of land they require. Land costs can easily become the controlling factor when evaluating alternative treatment costs in urban areas and in countries with limited arable land. However, the recovery value of land used for ponds will generally appreciate if urban growth requires the treatment facility to be moved farther from the city.

TABLE 2.8

Reported Bacterial Removal Efficiencies of Multicell Waste Stabilization Ponds with Detention Times > 25 Days

Pond system location	Number of cells in series	Effluent quality (f.c./100 ml)[a]
Melbourne, Australia	8-11	100
Campina Grande, Brazil[b]	5	30
Cogolin, France	3	100
Amman, Jordan	9	30
Lima, Peru	5	100
Tunis, Tunisia	4	600[c]

Source: Bartone and Arlosoroff 1987.

a f.c. = fecal coliforms.

b Experimental Centre for Biological Treatment of Wastewater (Extrabes)

c *Source:* Trad Rais 1989.

Environmental Aspects

Irrigation with wastewater should be considered not only for agricultural purposes; it may also be the preferred disposal alternative because it provides public health and environmental benefits that are not achievable by modern treatment and disinfection alone. The principal environmental risks that may be associated with wastewater are (a) the spread of pathogens, (b) oxygen depletion by organic contaminants, and (c) the introduction of chemicals into susceptible ecosystems (mainly water sources). Most modern treatment processes used in industrialized countries are designed to reduce the chemical and biodegradable wastewater constituents, but they do not significantly affect pathogens (table 2.6). Adequate pathogen removal can be achieved, however, with a low-cost, nonconventional multicell waste-stabilization pond system with about twenty days of detention.

Disinfection of wastewater by chlorination is uncommon in many countries because of its high cost and the technology involved (in many developing countries, even potable water is not disinfected). A negative aspect is that the chlorine reacts with the humic compounds in wastewater to produce trihalomethanes. Chloroform, the most abundant of these trihalomethanes, is reported to be carcinogenic. Thus, wastewater treatment followed by irrigation provides public health and environmental benefits that cannot be achieved by treatment (including modern methods) and disinfection alone.

Controlled land application also reduces, through two natural processes, the amount of organic and chemical contaminants entering surface water and groundwater. First, the crops absorb the substances as nutrients and prevent them from entering the runoff or groundwater. Second, the soil filters out pathogenic organisms and trace elements as the water percolates downward. This occurs with a minimum of technical input and without potentially harmful side effects (as in chlorination).

The environmental aspects of reuse are not confined to the effect of treatment and reuse on pollution. They also include, for example, the irrigation of nonagronomic crops such as grasslands and forests. Irrigation with appropriately treated wastewater can be used to reduce desertification, create greenbelts, reforest barren areas, and control soil erosion. The growing scarcity and increasing cost of timber in developing countries, used mainly for cooking and heating by low-income groups, calls for renewed timber production, especially in the vicinity of urban centers.

Monitoring and Evaluation

Regular monitoring and evaluation are required to ensure that health protection measures are implemented effectively. Institutional capacity and enforcement capabilities must be increased in most developing countries if wastewater reuse projects are to succeed. Some of the elements of these projects that require regular monitoring and evaluation include implementation of the measures themselves, wastewater quality, crop quality, and disease surveillance (Mara and Cairncross 1989).

One important factor introduced by the WHO guidelines is the need to develop the capacity of local monitoring institutions to achieve the specific water quality parameters of the guidelines (WHO 1989). In particular, the methodology to achieve the recommended helminth egg count is not within the reach of most developing countries. Current research (Ayres et al. 1989) is aimed at finding simple and reliable techniques that can be easily introduced and maintained in developing countries. Local research centers should be encouraged to test those methodologies and perhaps play a role in training monitors. The actual monitoring, however, should not be executed by research centers. Until helminth monitoring can be considered a useful operational tool, fecal coliform bacteria should be used as the key indicator, and treatment facilities should be inspected routinely to ensure that wastewater treatment is adequate.

Conclusions

Irrigation with wastewater is an attractive solution to the problems of both wastewater disposal and the scarcity of irrigation water. Epidemiological evidence, on which the WHO guidelines (WHO 1989) are based, shows that previous standards and practices were, in general, unduly restrictive. Worse, they could not be enforced in many instances. The adoption of more realistic guidelines must be accompanied by rigorous public health measures. Issues that are raised by wastewater reuse are by no means restricted to health. The major questions to be addressed in setting the stage for a wastewater reuse project include:

1. People: Do they need and accept reuse?

2. Resources: Is water scarce?
   Is land available?

3.	Institutions:	How can the interests of municipalities and farmers be joined? Who should plan for, oversee, and operate reuse projects?
4.	Infrastructure:	Can pollution control and reuse regulations be implemented? Are public health interventions adequate? Can water quality or health protection measures be monitored? Are there mechanisms for emergency intervention?
5.	Wastewater disposal:	Does the least-cost alternative include land application? Is there potential for nonagricultural reuse?
6.	Agriculture:	Are there crops that can be grown economically with treated wastes? Is wastewater quality acceptable for irrigation?

The project planning guidelines that follow present a systematic framework for addressing these questions--as well as other issues raised in Chapter II--during project development.

3. Elements of Reuse Project Development

Although crop irrigation is the most common form of wastewater reuse in developing countries today, the reuse planner must give full consideration to other potential uses (such as industrial, domestic, or aquifer recharge) when beginning to identify the need for wastewater reuse in a given area. The five tables of planning guidelines in Annex D apply to other reuse schemes, as well as to those for agriculture. For more detailed guidance, the planner should refer to the papers by Asano and Mills (1988 and 1991) on the subject.

Agricultural reuse projects combine the techniques of two disciplines--wastewater disposal and irrigation. Projects in both disciplines are routinely developed and implemented through valid, established methods and guidelines. But guidelines for wastewater irrigation projects cannot merely mimic those for either one of the two disciplines. Certain aspects of reuse projects require special attention at various stages. The previous sections dealt with these issues--institutions, technology and policies, and financial and economic considerations--mainly in a technical context. The following paragraphs contain suggestions for the operational inclusion of these concerns in development project cycles.

Institutions

The proper identification of the stakeholders and institutions involved in reuse is particularly delicate because of the multisectoral nature of reuse projects. Safe wastewater disposal is a major concern of public and semipublic collection and disposal authorities; national, state, and municipal water and sanitation agencies; organizations charged with safeguarding public health and the environment, such as national ministries of health and of the environment; and state or local health authorities responsible for monitoring effluent contaminant levels.

Irrigation is the responsibility of still other organizations, such as authorities, cooperatives, and communes operating under the jurisdiction of agriculture or water resource ministries. These organizations are interested in the use of water and its timely provision and quality.

Finally, there may be an organization such as a national or regional planning body or river-basin authority concerned with water resource allocation and the enforcement of water laws specifying water use rights or water quality standards.

These varying interests and responsibilities must be considered and reconciled if a project is to succeed. As an ideal, policies of wastewater reuse and strategies for its implementation should be part of national water resource planning. At the local level, individual reuse projects should be part of the overall river-basin planning effort. To tackle the range of institutional levels involved, a project proponent must:

1. Identify all agencies and user organizations that would have an interest in the project, and list their responsibilities.

2. Identify, after appropriate consultation, the lead agency for project planning and implementation.

3. Develop and install consultative mechanisms giving all interested parties an opportunity to participate in the planning process and define their roles/responsibilities in project implementation.

4. Ensure opportunities for irrigation water users to participate in project development so they are aware of the benefits and requirements of wastewater irrigation.

5. Evaluate the organization and management of implementing agencies and propose changes as necessary.

6. Identify and develop monitoring programs and legal measures for their implementation to ensure adherence to public health regulations.

Technical and Policy Options

Irrigation and wastewater disposal projects provide planners with an array of options that will vary with local conditions, available resources, and project objectives. In general, preliminary project formulations based on individual least-cost solutions should be prepared for each type of project (both irrigation and wastewater disposal) and then reconciled to arrive at the least-cost common solution. The least-cost common solution may not be simply the total of the two individual least-cost solutions. For example, irrigation using treated effluent may require conveyance facilities that would exceed the cost of groundwater extraction. The reduction in wastewater disposal cost, however, could be significant. In such a case, the agency responsible for wastewater disposal should pay the extra cost of the conveyance system, in an amount up to the disposal cost savings. If the irrigators gained extra benefits from the combined scheme, these benefits could be shared or the extra cost to the effluent producer could be reduced.

Usually, the planning process begins with a market study to determine what kind of irrigation, if any, is feasible. This is followed by preliminary designs and cost estimates of alternatives, selection of preferred project components, and a detailed financial and economic evaluation. Consequently, agricultural sector studies always should assess the potential reuse of wastewater in terms of quantity, quality (existing or required treatment), and seasonal fluctuations in demand. Similarly, water supply and sewerage sector studies always should assess the potential of land application/irrigation as a wastewater disposal option.

When considering the available options in developing either type of project, the planner should:

1. Determine the market for irrigation water, its location, and quality requirements--legally mandated or as a condition of the proposed use. Potential users of irrigation water include not only farmers who produce crops with varying water quality requirements, but also reforestation projects, urban parks, greenbelts, and recreational areas such as football fields.

2. Determine the wastewater treatment requirements to meet irrigation-water quality standards or, as an alternative, the effluent quality required for discharge to surface waters.

3. Prepare preliminary designs and estimates for treatment facilities (considering, among other factors, placement of treatment facilities where the wastewater is generated or where it will be used for irrigation) for direct discharge and for wastewater irrigation.

4. Prepare preliminary designs and estimates of irrigation systems and farm budgets, listing separately those components required exclusively for wastewater irrigation (such as reservoirs needed to store wastewater until it is needed for irrigation, fertilizer supplements required if wastewater nutrients are insufficient for proposed crops or yields, worker protection, and health care programs).

5. Estimate the water and fertilizer requirements for the irrigation project if freshwater were used, so that the costs and benefits of substituting wastewater for freshwater can be determined, if necessary, and if alternative sources of water are available.

6. Estimate the financial and economic benefits of conserving potable water being used for crops. For example, further investments for drinking water supplies might be postponed or eliminated by substituting wastewater for irrigation use.

7. Ask additional questions to identify current users of wastewater. If wastewater is currently used, the planner should define who will *gain* and who will *lose* if the proposed project were implemented. (This might affect compliance with the new project and its ultimate success.)

This last point is critical for the early success of the reuse project. If, for example, previous users upstream from a new treatment facility lose their access to the wastewater, they may sabotage the new scheme. The planner may have to provide compensation or alternative sources of water to these upstream users of wastewater to increase the chances of success of the overall reuse scheme. Wastewater reuse schemes have failed in a number of places (for example, Peru) where this problem was not fully appreciated.

Economic and Financial Considerations

The economic evaluation and justification procedures for irrigation projects are widely used and usually are simpler than those for wastewater disposal projects. The latter require that economic values be assigned to a more complex stream of benefits. Justification of treated wastewater use in irrigation should be based on the incremental costs and benefits of such use. Besides increased agricultural productivity, benefits to be considered include environmental enhancements from the elimination of wastewater discharges (they may not always be quantifiable), public health protection by halting uncontrolled irrigation, and reduced financial investments for new sources of drinking water by substituting wastewater for high-quality irrigation water. Where local authorities have decreed a minimum purity standard for urban effluent discharged into the environment, the cost to attain this minimum treatment should be considered in determining net incremental benefits. This cost must be estimated as a baseline for the without-project situation.

The evaluation can be based on the following scenarios:

1. **No existing irrigation:** Where there is no existing agriculture or the only irrigation is from rainfall, benefits would be the introduction of agricultural production or more production from existing farms. Costs would include those for (a) setting up the irrigation

system, and (b) transporting and treating the wastewater (but only the cost *in excess* of that required to discharge it into receiving waters). Where sound environmental disposal is enforced, the cost of treatment for reuse may be less than that for direct discharge, in which case the value for (b) would be negative--a benefit.

2. **Existing irrigation:** Where wastewater can provide *supplemental* irrigation, it might permit a shift to more profitable crops (for example, from grains to vegetables) or longer growing seasons. The additional revenues of this expansion minus its cost would be the benefit. Wastewater-associated costs would be the same as those in (1).

3. **Existing irrigation:** Where wastewater can *substitute* for scarce freshwater sources, a no-action scenario would imply (in the medium or long term) reducing or abandoning irrigated areas to increase the drinking water supply for domestic consumers; the crop production saved would be the benefit. Wastewater-associated costs would be the same as those in (1).

4. **Existing, uncontrolled wastewater irrigation:** This is a situation quite often encountered in developing countries. Shifting to a controlled operation using treated wastewater would result in public health and environmental improvements. These improvements should have a major weight in project development, even if they are difficult to quantify. Two situations might further increase the overall feasibility of the controlled-reuse option. First, land application of treated effluent might be part of the least-cost wastewater treatment alternative. Second, irrigating with treated wastewater might lead to the production of more profitable crops.

5. **Existing or new freshwater irrigation of public parks or greenbelts:** Where this is the case, shifting to wastewater irrigation would be justified if it cost less than wastewater discharge to surface water and/or if it provided environmental benefits equal to the cost of reclamation and irrigation investments. These could be quantified or at least described qualitatively. Another benefit would be the value of the potable water saved, which could be substantial in cities where water is scarce.

6. **No existing irrigation, wastewater application as land treatment:** In this situation, there is no existing need or demand for irrigation water. The least-cost wastewater treatment alternative, however, would include the disposal of treated wastewater on land. The cost of the entire system, including irrigation, should be included in wastewater-associated costs. Benefits from irrigation could enhance the feasibility of wastewater treatment.

Economic justification does not automatically ensure that the project will be financially viable. Estimates of the quantifiable or unquantifiable environmental benefits that result from preventing wastewater discharge to surface water might make wastewater irrigation economically attractive, but it still might be too expensive for the farmer or the municipality. In all cases, the wastewater generator should pay for the least-cost environmentally sound treatment and disposal option. The user of the irrigation water should pay only the extra treatment costs required to achieve irrigation water quality, in addition to added conveyance and distribution costs. Balancing the requirements and possibilities of the two parties (the wastewater producers and the wastewater users) might require the intervention of state organizations. Where the municipality and the farmers are unable to pay the financial cost of the treatment-irrigation scheme, the state may intervene to achieve desired national environmental agricultural benefits.

In general, the user's cost of irrigation water should not exceed the least-cost alternative, unless water rationing exists. In many developing countries, however, the farmer uses heavily subsidized irrigation water or groundwater that does not adequately reflect the economic costs of depleting the aquifer. Until charges for irrigation water reflect actual costs, projects should be selected on the basis of an economic evaluation of alternatives, and subsidies should be used only as a last resort to support the selected solution. Preferably, the water pricing structure should be adjusted to reflect the marginal cost of water.

ANNEX A: Public Health Guidelines for Wastewater Reuse

TABLE A.1

Wastewater Treatment and Quality Criteria for Irrigation
(State of California 1978)

Treatment level	Coliform limits	Type of use
Primary		Surface irrigation of orchards and vineyards, fodder, fiber, and seed crops
Oxidation and disinfection	≤23/100 ml	Pasture for milking animals; landscape impoundments; landscape irrigation (golf courses, cemeteries, etc.)
	≤2.2/100 ml	Surface irrigation of food crops (no contact between water and edible portion of crop)
Oxidation, coagulation, clarification, filtration,[a] and disinfection	≤2.2/100 ml max. = 23/100 ml	Spray irrigation of food crops Landscape irrigation (parks, playgrounds, etc.)

Source: Pettygrove and Asano 1985.

[a] The turbidity of filtered effluent cannot exceed an average of two turbidity units during any 24-hour period.

ANNEX B. Irrigation Water Quality Guidelines

TABLE B.1

Guidelines for Interpreting Water Quality for Irrigation

		Degree of Restriction on Use		
Potential Irrigation Problem	Units	None	Slight to Moderate	Severe
Salinity (affects crop water availability)[a]				
EC_w	dS/m	<0.7	0.7 - 3.0	>3.0
or TDS	mg/l	<450	450 - 2,000	>2,000
Infiltration (affects infiltration rate of water into the soil; evaluate using EC_w and SAR together)[b]				
SAR = 0 - 3. and EC_w =	dS/m	>0.7	0.7 - 0.2	<0.2
= 3 - 6 =	dS/m	>1.2	1.2 - 0.3	<0.3
= 6 - 12 =	dS/m	>1.9	1.9 - 0.5	<0.5
= 12 - 20 =	dS/m	>2.9	2.9 - 1.3	<1.3
= 20 - 40 =	dS/m	>5.0	5.0 - 2.9	<2.9
Specific ion toxicity (affects sensitive crops)				
Sodium (Na)				
Surface irrigation	SAR	<3	3 - 9	>9
Sprinkler irrigation	me/l[c]	<3	>3	
Chloride (Cl)				
Surface irrigation	me/l	<4	4 - 10	>10
Sprinkler irrigation	me/l	<3	>3	
Boron (B)	mg/l	<0.7	0.7 - 3.0	>3.0
Trace elements (see Table B.2)				
Miscellaneous effects (affects susceptible crops)				
Nitrogen (NO_3 - N)	mg/l	<5	5 - 30	>30
Bicarbonate (HCO_3) (overhead sprinkling only)	me/l	<1.5	1.5 - 8.5	>8.5
pH			Normal range 6.5 - 8.4	

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a. EC_w means electrical conductivity, a measure of water salinity reported in deciSiemens per meter at 25° C (dS/m) or in millimhos per centimeter (mmho/cm). Both are equivalent. TDS means total dissolved solids, reported in milligrams per liter (mg/l).

b. SAR means sodium adsorption ratio.

c. 1 me/l = 1 milliequivalent per liter, where 1 me Na = 11 mg; 1 me Cl = 17 mg; 1 me HCO_3 = 31 mg.

Source: Adapted from Ayers and Westcot 1985, to which the reader may refer for detailed assumptions in and justification of the guidelines presented above.

TABLE B.2

Recommended Maximum Concentrations of Trace Elements in Irrigation Water

Element[a]	Recommended maximum concentration[b] (mg/l)	Remarks
Al	5.0	Can cause nonproductivity in acid soils (pH < 5.5), but more alkaline soils at pH > 7.0 will precipitate the ion and eliminate any toxicity.
As	0.10	Toxicity to plants varies widely, ranging from 12.0 mg/l for Sudan grass to < 0.05 mg/l for rice.
B	0.5 - 15	Toxicity to plants varies widely: for example, < 0.5 mg/l for lemon, 1.0 mg/l for wheat, 6.0 mg/l for tomato, and 15 mg/l for cotton.
Be	0.10	Toxicity to plants varies widely, ranging from 5.0 mg/l for kale to 0.5 mg/l for bush beans.
Cd	0.01	Toxic to beans, beets, and turnips at concentrations as low as 0.1 mg/l in nutrient solutions. Conservative limits recommended because of its potential to accumulate in plants and soils to concentrations that may harm humans.
Co	0.05	Toxic to tomatoes at 0.1 mg/l in nutrient solution. Tends to be inactivated by neutral and alkaline soils.
Cr	0.10	Not generally recognized as an essential growth element. Conservative limits recommended because of lack of knowledge about its toxicity to plants.
Cu	0.20	Toxic to a number of plants at 0.1 to 1.0 mg/l in nutrient solutions.
F	1.0	Inactivated by neutral and alkaline soils.
Fe	5.0	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of availability of essential phosphorus and molybdenum. Overhead sprinkling may result in unsightly deposits on plants, equipment, and buildings.
Li	2.5	Tolerated by most crops up to 5.0 mg/l; mobile in soil. Toxic to citrus at low concentrations (< 0.075 mg/l). Acts similarly to boron.
Mn	0.20	Toxic to a number of crops at a few tenths to a few mg/l, but usually only in acid soils.
Mo	0.01	Not toxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high concentrations of available molybdenum.
Ni	0.20	Toxic to a number of plants at 0.5 mg/l to 1.0 mg/l; reduced toxicity at neutral or alkaline pH.
Pb	5.0	Can inhibit plant cell growth at very high concentrations.
Se	0.02	Toxic to plants at concentrations as low as 0.025 mg/l and toxic to livestock if forage is grown in soils with relatively high levels of added selenium. An essential element to animals but in very low concentrations.
V	0.10	Toxic to many plants at relatively low concentrations.
Zn	2.0	Toxic to many plants at widely varying concentrations; reduced toxicity at pH > 6.0 and in fine-textured or organic soils.

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[a] This is not an exhaustive list of the effects of all trace elements found in wastewater, especially if industrial wastes are discharged directly into it. If industrial wastes are found in the wastewater, the trace elements contributed need to be identified and information obtained about their effects on a site-specific basis.

[b] The maximum concentration is based on a water application rate consistent with good irrigation practices (10,000 m^3/ha/yr). If the rate greatly exceeds this, the maximum concentrations should be adjusted downward accordingly. No adjustment should be made for application rates less than 10,000 m^3/ha/yr. The values given are for water used on a continuous basis at one site.

Source: Ayers and Westcot 1985.

TABLE C.1

Relative Salt Tolerance of Crops

Tolerant:

Fibers, seeds & sugar crops
- Barley
- Cotton
- Jojoba
- Sugarbeet

Vegetables
- Asparagus

Fruits & nuts
- Date palm

Moderately tolerant:

Fibers, seeds, & sugar crops
- Cowpea
- Oats
- Rye
- Safflower
- Sorghum
- Soybean
- Triticale
- Wheat
- Wheat, Durum

Vegetables
- Artichoke
- Beet, red
- Squash, zucchini

Fruits & nuts
- Fig
- Jujube
- Olive
- Papaya
- Pineapple
- Pomegranate

Moderately sensitive:

Fibers, seeds & sugar crops
- Broadbean
- Castorbean
- Maize
- Flax
- Millet, Foxtail
- Groundnut/peanut
- Rice, paddy
- Sugarcane
- Sunflower

Vegetables
- Broccoli
- Brussels sprouts
- Cabbage
- Cauliflower
- Celery
- Corn, sweet
- Cucumber
- Eggplant
- Kale
- Kohlrabi
- Lettuce
- Muskmelon
- Radish
- Pepper
- Potato
- Pumpkin
- Spinach
- Squash, scallop
- Sweet potato
- Tomato
- Turnip
- Watermelon

Fruits & nuts
- Grape

Sensitive:

Fibers, seeds & sugar crops
- Bean
- Guayule
- Sesame

Vegetables
- Bean
- Carrot
- Okra
- Onion
- Parsnip

Fruits & nuts
- Almond
- Apple
- Apricot
- Avocado
- Blackberry
- Boysenberry
- Cherimoya
- Cherry, sweet
- Cherry, sand
- Currant
- Gooseberry
- Loquat
- Grapefruit
- Lemon
- Lime
- Mango
- Orange
- Passion fruit
- Peach
- Pear
- Persimmon
- Plum
- Pummelo
- Raspberry
- Rose apple
- Sapote, white
- Strawberry
- Tangerine

The relative salt tolerance ratings are shown in Figure C.1 below.
Source: Maas 1984.

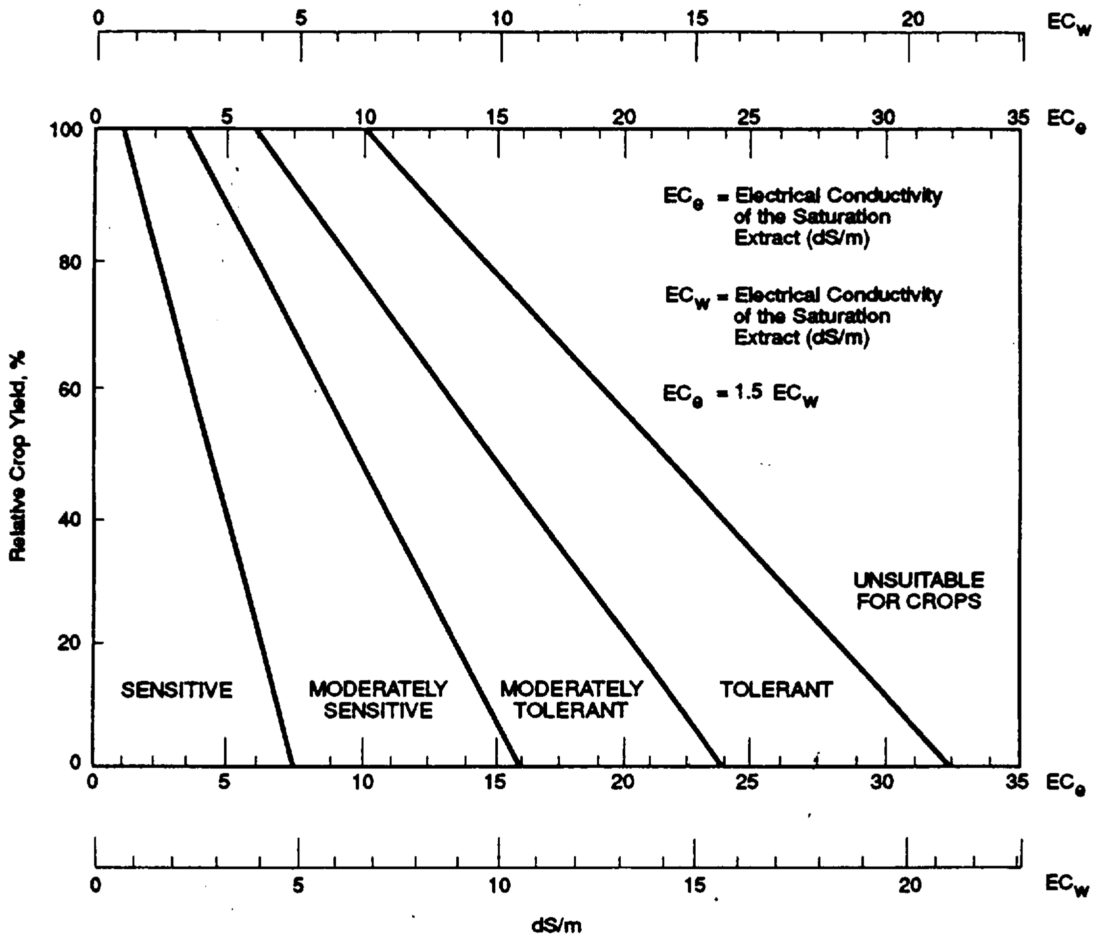

Figure C.1. Divisions for relative salt tolerance ratings of agricultural crops.
Source: Maas 1984.

TABLE C.2

Influence of Water Quality on the Potential for Clogging Problems in Drip Irrigation Systems

Potential problem	Units	None	Slight to moderate	Severe
		------ Degree of restriction on use ------		
Physical				
Suspended solids	mg/l	<50	50 - 100	>100
Chemical				
pH		<7.0	7.0 - 8.0	>8.0
Dissolved solids	mg/l	<500	500 - 2,000	>2,000
Manganese	mg/l	<0.1	0.1 - 1.5	>1.5
Iron	mg/l	<0.1	0.1 - 1.5	>1.5
Hydrogen sulfide	mg/l	<0.5	0.5 - 2.0	>2.0
Biological				
Bacterial populations	maximum number/ml	<10,000	10,000 - 50,000	>50,000

Source: Ayers and Westcot 1985.

TABLE C.3

Constituents of Concern in Wastewater Treatment and Irrigation Using Reclaimed Municipal Wastewater

Constituents	Measured Parameters	Reason for Concern
Suspended solids	Suspended solids, including volatile and fixed solids	Suspended solids can lead to the development of sludge deposits and anaerobic conditions when untreated wastewater is discharged into the aquatic environment. Excessive amounts of suspended solids cause plugging in irrigation systems.
Biodegradable organics	BOD, COD	Composed principally of proteins, carbohydrates, and fats. If discharged into the\ environment, their biological decomposition can lead to the depletion of dissolved oxygen oxygen in receiving waters and to the development of septic conditions.
Pathogens	Indicator organisms, total and fecal coliform bacteria	Communicable diseases can be transmitted by the pathogens in wastewater: bacteria, viruses, parasites.
Nutrients	Nitrogen, phosphorus, potassium	Nitrogen, phosphorus, and potassium are essential nutrients for plant growth, and their presence normally enhances the value of the water for irrigation. When discharged into the aquatic environment, nitrogen and phosphorus can lead to the growth of undesirable aquatic life. When discharged in excessive amounts on land, nitrogen can also lead to groundwater pollution.
Stable (refractory) organics	Specific compounds (e.g., phenols, pesticides, chlorinated hydrocarbons)	These organics tend to resist conventional methods of wastewater treatment. Some organic compounds are toxic in the environment, and their presence may limit the suitability of the wastewater for irrigation.

Table C.3 (cont.)

Constituent	Measured parameters	Reason for concern
Hydrogen ion activity	pH	The pH of wastewater affects metal solubility as well as alkalinity of soils. Normal range in municipal wastewater is 6.5-8.5, but industrial waste can alter pH significantly.
Heavy metals	Specific elements (e.g., Cd, Zn, Ni, Hg)	Some heavy metals accumulate in the environment and are toxic to plants and animals. Their presence may limit the suitability of the wastewater for irrigation.
Dissolved inorganics	Total dissolved solids, electrical conductivity, specific elements (e.g., Na, Ca, Mg, Cl, B)	Excessive salinity may damage some crops. Specific ions such as chloride, sodium, and boron are toxic to some crops. Sodium may pose soil permeability problems.
Residual chlorine	Free and combined chlorine	Excessive amounts of free available chlorine (>0.05 mg/l Cl_2) may cause leaf-tip burn and damage some sensitive crops. However, most chlorine in reclaimed wastewater is in a combined form that does not cause crop damage. Some concerns are expressed about the toxic effects of chlorinated organics in regard to groundwater contamination.

Source: Pettygrove and Asano 1985.

TABLE C.4

Limit Values for Concentration of Heavy Metals in Soil

Parameters	Limit values
Cadmium	1 - 3
Copper	50 - 140
Nickel	30 - 75
Lead	50 - 300
Zinc	150 - 300
Mercury	1 - 1.5
Chromium[a]	--- ---

TABLE C.5

Limit Values for Heavy Metal Concentrations in Sludge for Use in Agriculture

Parameters	Limit values
Cadmium	20 - 40
Copper	1,000 - 1,750
Nickel	300 - 400
Lead	750 - 1,200
Zinc	2,500 - 4,000
Mercury	16 - 25
Chromium[a]	--- ---

Note: Values are expressed in mg/kg of dry matter of soil with pH 6-7.

a. It is not currently possible to fix limit values for chromium.

Source: Council of the European Communities (CEC) 1986.

TABLE C.6

Limit Values for Amounts of Heavy Metals that May Be Added Annually to Agricultural Land, Based on a Ten-year Average

Parameter	Limit values
Cadmium	0.15
Copper	12
Nickel	3
Lead	15
Zinc	30
Mercury	0.1
Chromium[a]	---

Note: Values are expressed in kg/ha/yr

a. It is not currently possible to fix limit values for chromium.

Source: Council of the European Communities (CEC) 1986.

TABLE D.1

The Market for Reclaimed Water: Survey Preparation and Information

1. Inventory potential users and uses of reclaimed water.

2. Determine health-related requirements regarding water quality and application requirements (e.g., treatment, backflow prevention, irrigation methods) for each type of reclaimed water application.

3. Determine regulatory requirements to prevent nuisance and water quality problems, such as restrictions to protect groundwater.

4. Develop assumptions regarding probable water quality that would be available in the future with various levels of treatment, and compare those with regulatory and user requirements.

5. Estimate future freshwater supply costs to potential users of reclaimed water.

6. Survey potential reclaimed water users to obtain the following information:

    a. Specific potential uses of reclaimed water
    b. Current and future quantity needs
    c. Timing and reliability of needs
    d. Quality needs
    e. Modifications to on-site facilities that are necessary to convert to reclaimed water, meet regulatory requirements, and dispose of used water; estimate associated costs
    f. Internal capital investment of user, changes in operational costs, desired pay-back period or rate of return, and desired water cost savings
    g. Plans for changing use of site in future
    h. Preliminary desire to use reclaimed water now or in the future

7. Inform potential users of applicable regulatory restrictions, probable water quality available with different levels of treatment, future costs, and quality of fresh water

Source: Asano and Mills 1988.

TABLE D.2

The Market for Reclaimed Water: Outline of Assessment/Feasibility Report

1. Study-area characteristics: groundwater basins, surface waters, land use, population growth
2. Water supply characteristics and facilities: agency jurisdictions, sources and quality of supply, description of major facilities, water-use trends, future facilities needs, groundwater management and problems, current and future costs, subsidies, customer prices
3. Wastewater characteristics and facilities: agency jurisdictions, description of major facilities, quantity and quality of effluent, future facilities needs, description of existing reuse (users, quantities, contractual and pricing agreements)
4. Treatment requirements for discharge and reuse and other restrictions: health and water quality related requirements, user-specific water quality requirements, use-area controls
5. Potential water reuse customers: inventory of potential reclaimed water users and results of user survey
6. Preliminary water reclamation and reuse alternatives: preliminary screening of alternatives (economics, financial attractiveness, marketability of reclaimed water, potential constraints), selection of one alternative for more detailed review and financial analysis
7. Preliminary feasibility analysis: comparison of water reclamation and reuse of freshwater, compliance with regulatory and user requirements
8. Recommendations for continued study: decision on whether to continue, recommendations on modifying plan of study, identification of issues for further study

Source: Asano and Mills 1988.

TABLE D.3

Outline of Plan for Wastewater Reclamation and Reuse Facilities

1. Study-area characteristics: cf. table D.2

2. Water supply characteristics and facilities: cf. table D.2

3. Wastewater characteristics and facilities: Seasonal and hourly flow and quality variations, need for source control of constituents affecting reuse; cf. table D.2

4. Treatment requirements for discharge and reuse and other restrictions: cf. table D.2

5. Potential water reuse customers: Description of market analysis procedures; cf. table D.2

6. Project alternative analysis: capital and operation and maintenance costs, engineering feasibility, economic analysis, financial analysis, energy analysis, water quality impacts, market acceptance, water rights impacts, environmental and social impacts, comparison of alternatives and selection

   a. Treatment alternatives
   b. Alternative markets: based on different levels of treatment and service areas
   c. Alternative pipeline routes
   d. Alternative locations and options for storage of reclaimed water
   e. Freshwater alternatives
   f. Water pollution control alternatives
   g. No project alternative

7. Recommended plan: Description of proposed facilities, preliminary design criteria, projected cost, list of potential users and commitments, quantity and variation of reclaimed water demand in relation to supply, reliability of supply and need for supplemental or backup water supply, implementation plan, operational plan

8. Construction financing plan and revenue program: Sources and timing of funds for design and construction; pricing policy of reclaimed water; cost allocation between water supply and pollution purposes; projection of future reclaimed water use, freshwater prices, reclamation project costs, unit costs, unit prices, total revenue, subsidies, sunk costs, and indebtedness; sensitivity analysis

Source: Asano and Mills 1988.

TABLE D.4

Potential Obstacles to Securing Commitments from Users of Reclaimed Water

1. Concern of users over effects of water on industrial process, landscaping, or crops
2. User has own water supply at lower cost than either municipal potable supply or offered price for reclaimed water
3. Disagreement over acceptable reclaimed water price
4. User unwilling or unable to pay for extra costs for pipelines or on-site water system modifications
5. User lies outside of project proponent's boundaries, requiring negotiations with other jurisdictions
6. Disapproval of local or state health department

Source: Asano and Mills 1988.

TABLE D.5

Desirable Provisions of Reclaimed Water User Contracts.

1. Contract duration: term, conditions for termination
2. Reclaimed water characteristics: source, quality, pressure
3. Quantity and flow variations
4. Reliability of supply: potential lapses in supply, backup supply provisions
5. Commencement of use: when user can or will begin use
6. Financial arrangement: pricing of reclaimed water, payment for facilities
7. Ownership of facilities, rights-of-way: responsibility for operation and maintenance
8. Miscellaneous: liability, restrictions on use, right of purveyor to inspect site

Source: Asano and Mills 1988.

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