

INTERNATIONAL PERSPECTIVE ON WATER RESOURCES MANAGEMENT AND WASTEWATER REUSE APPROPRIATE TECHNOLOGIES

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ABSTRACT

The unabated urbanization and industrialization process in many arid and semi-arid countries leads to increasing demand for municipal and industrial water supply, often in direct competition with irrigation demand. In such cases wastewater reclamation and reuse should be an integral component of water resources management strategies. National reuse policies should be developed and implemented taking into account local conditions and based on affordable approaches that ensure safe reuse practice. This paper describes research and development carried out in several developing countries on appropriate technologies for implementing reuse, as well as coordinated international efforts to provide recommended guidelines and policies for safe wastewater reuse in agriculture and aquaculture.

KEYWORDS

Wastewater reuse; appropriate technology; policy and planning; public health guidelines; wastewater treatment; waste stabilization ponds; irrigation; aquaculture; water resources management.

INTRODUCTION

Reuse of Wastewater in Agriculture

The large-scale reuse of urban sewage for irrigation is commonplace in many arid and semi-arid regions of the world as a result of increasing population pressures, water shortages, and agricultural demand for both water and nutrients. More than 1.3 million ha in China benefit from the application of municipal wastewater or nightsoil (Wang, 1984). Extensive agricultural areas surrounding major metropolitan areas are irrigated with wastewater: 10,000 ha around Melbourne, Australia, 16,000 ha around Santiago, Chile, 90,000 ha around Mexico City, Mexico (Bartone and Arlosoroff, 1987). The relative importance of wastewater as a source of irrigation water in arid regions is illustrated by Israel where wastewater represents 11 percent of total irrigation water, and by Santiago and Mexico City where 70 and 80 percent respectively of dry season irrigation is with wastewater (Kalbermatten *et al.*, 1989).

In the industrialized countries, reuse is planned, strict water quality and treatment standards are observed, and restrictions are made on the types of crops permitted to be grown. In the developing countries, with a few notable exceptions, reuse occurs without effective controls and safeguards. Part of the problem is that commonly adopted standards are overly stringent and unachievable given existing economic conditions. International research efforts described below have focused on the public health aspects of reuse and the minimum sanitary control measures required for public health protection, including appropriate treatment technologies for achieving

effluent quality guidelines. The relationships between water quality, on the one hand, and treatment and irrigation technologies, on the other, has also been studied.

Reuse of Wastewater in Aquaculture

The use of wastewater to fertilize fish ponds was developed in Germany at the end of the 19th century (Prein, 1988) and independently in Calcutta in 1930, which now has the largest wastewater-fed aquaculture system in the world (Edwards, 1985). Today, wastewater is used for fishculture in India, Germany, Hungary (Olah, 1988), and a number of other countries. Treatment pond systems incorporating aquaculture (for fish, algae or macrophyte production) are the subject of much recent research. Most existing reuse systems use raw or partially treated wastewater, although at very low hydraulic loading rates to avoid oxygen depletion problems. It is unclear at present to what extent the use of raw wastewater promotes the transmission of enteric pathogens, and this question is the subject of current research (WHO, 1989).

International Cooperation

In view of the many questions raised by observed reuse practice, particularly in the developing countries, an international research effort was launched in the early-1980's to address public health issues, assess appropriate technologies, and recommend minimum safe reuse guidelines and policies. This became one of the priority areas for the International Water Supply and Sanitation Decade. This paper will summarize the results of this collaborative effort and describe current research and dissemination efforts.

PUBLIC HEALTH GUIDELINES

One of the first initiatives was begun in 1982 with the start up of the joint UNDP/World Bank Integrated Resource Recovery Project, which commissioned a study of the epidemiological evidence linking health risks with the use of wastewater in agriculture. Similar research on wastewater and nightsoil reuse in agriculture and aquaculture was sponsored by WHO and UNEP. Considerable bilateral grant funding was mobilized to support field research on appropriate treatment technologies.

Effluent Irrigation Guidelines

The seminal UNDP/World Bank study by Shuval *et al* (1986) reviewed available epidemiological data and formulated a risk model to evaluate sanitary control options for effluent irrigation. The study concluded that wastewater treatment processes which effectively remove all or most of the pathogens in wastewater provide a major or total reduction in the negative health effects caused by raw sewage reuse. Furthermore, the study found the recommended criteria for effective wastewater treatment for irrigation reuse in developing countries to be, in order of priority: (1) maximum removal of helminths; (2) effective reduction of bacterial and viral pathogens; and (3) freedom from odor and appearance nuisances (i.e. effective reduction of BOD, but not necessarily nutrients). Although health risks are clearly associated with the use of raw wastewater in agriculture, the epidemiological evidence compiled in the study suggests that the bacterial standards commonly used today are excessively restrictive for most situations (and for many developing countries unaffordable and unachievable) while, at the same time, they disregard the risk of parasitic infections prevalent in tropical areas.

The study suggests a guideline for unrestricted wastewater irrigation based on an effluent with less than one nematode egg (*Ascaris*, *Trichuris* or hookworm) per liter and a geometric mean fecal coliform concentration of 1,000 per 100 ml. For restricted irrigation, such as for forest trees, industrial crops, fodder crops, fruit trees and pasture, less than one nematode egg per liter is recommended as a guideline. These recommended guidelines were closely studied by WHO, UNEP, and FAO, in addition to UNDP and the World Bank, and were initially endorsed by a group of experts at a meeting convened in Engelberg, Switzerland (IRCWD, 1985). They were again examined by successive expert group meetings in Adelboden and Geneva in 1987, and formally published by WHO (1989) as recognized international guidelines. If these guidelines were routinely applied, no undue health risk of infectious disease transmission in effluent irrigation projects should arise. Governments currently without effective standards are urged to adopt standards based on these guidelines.

A number of technical and policy options for reducing and controlling the health risks associated with wastewater reuse in agriculture were also evaluated by the UNDP/World Bank study (Shuval *et al*, 1986). The following remedial measures were found to be the most effective for reducing possible risks: (1) wastewater treatment and/or storage practices aimed at effectively reducing

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Aquaculture Gu

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the concentration of the priority pathogens to low levels (e.g. the WHO guidelines); (2) restrictions on the type of crops irrigated so as to prevent consumers from being exposed directly to vegetable or salad crops eaten raw; (3) modifications of irrigation techniques and procedures so as to prevent or minimize direct contact between wastewater and crops; and (4) human exposure control for farm workers, crop handlers, consumers and those living near reuse sites. An integrated set of such measures should be adopted for any reuse project to provide maximum security (WHO, 1989).

Aquaculture Guidelines

Public health issues associated with aquaculture reuse were also investigated by WHO and the International Centre for Waste Disposal (IRCWD). A number of infections caused by excreted pathogens are of concern in connection with waste-fed aquaculture, including several caused by helminth parasites (*Schistosoma*, *Clonorchis*, and *Fasciolopsis*). For the control of helminth infections, the appropriate water quality guideline for aquaculture reuse is the absence of viable trematode eggs (WHO, 1989). This is readily achieved by stabilization pond treatment prior to reuse in fish ponds.

Fish grown in sewage-fertilized ponds may also become contaminated with bacteria and viruses. If fish are eaten raw or undercooked, infectious transmission may occur. Some evidence suggests that there is little accumulation of enteric organisms and pathogens on, or penetration into, edible fish tissue when the fecal coliform concentration in the fish-pond water is less than 1,000 per 100 ml. This value has been adopted as a tentative bacterial guideline given that there are only limited experimental and field data on the related health effects (WHO, 1989). Precautions are still necessary, however, to prevent the cross-contamination of fish flesh by pathogens that may be in the intestinal tract during fish handling and gutting. Cooking of fish, which is a common practice in many areas where waste-fed aquaculture exists, is an important health safeguard. Where concerns persist, fish grown in wastewater ponds can be withheld from human consumption and used instead as feed for other carnivorous fish species or animals.

Much additional research is needed on the potential for transmission of enteric pathogens through the use of raw wastewater for aquaculture, and appropriate means of control. An expert group meeting on sewage-fed aquaculture, which was convened in Calcutta, India in 1988 by UNDP, the World Bank and ESCAP, recommended that priority be given to collecting and interpreting information on public health parameters from existing aquaculture reuse sites.

Chemical Quality Guidelines

The level of most chemicals in raw or treated municipal wastewater is generally below toxic levels for humans. Industrial waste discharges, however, can add heavy metals and organic pollutants up to concentrations that become toxic. This contamination could present risks to human health if uncontrolled irrigation is being practiced. Raw industrial wastewater with significant amounts of hazardous compounds should not be discharged into municipal sewer systems but treated at the source if reuse is practiced.

Another potential toxicity problem is the accumulation of heavy metals in plant parts that enter the human food chain. Cadmium, for example, could be present in wastewaters at levels that are not toxic to plants; however, it could build up inside plants to levels that are harmful to humans or animals. Similar build-up can occur in animals or fish. For example, heavy metals contained in forage have been shown to accumulate in cow milk. Standard land application design methods have been developed to prevent this build-up, taking into account both concentration and total load of chemicals applied with wastewater (and other related sources such as sludge or compost derived from urban wastes).

Because of the seriousness and complexity of these problems, the UNDP/World Bank Program and WHO have agreed that the next priority for international collaboration will be to formulate a set of international guidelines for control of chemical quality in reuse projects, including wastewater as well as land application of sludge and compost.

WASTE STABILIZATION PONDS AND EFFLUENT REUSE

Conventional wastewater treatment processes, with the exception of disinfection, are not effective for the removal of pathogens from sewage, rarely achieving more than 90-95 percent of pathogen reduction. Furthermore, most conventional treatment plants are designed for maximum reduction of BOD and nutrients, while for reuse purposes it is desirable to retain biomass BOD and nutrients in the irrigation water. Disinfection of wastewater by chlorination is rarely done

in developing countries because of its cost and the technology involved. On the other hand, research has shown that waste stabilization ponds can be designed to remove virtually all helminths and large numbers of bacteria and viruses. These ponds also produce a nuisance-free effluent rich in nutrients which is very suitable for irrigation. For developing countries; particularly where vegetables are eaten raw, stabilization ponds are a preferred means of dealing with unwanted health effects of uncontrolled wastewater irrigation. The highest level of overall protection is provided by multicell pond systems that can meet the WHO effluent quality guidelines recommended for unrestricted irrigation. Research supported by the UNDP/World Bank Program at the San Juan ponds in Lima, Peru confirmed that fecal coliform removal efficiencies greater than 99.99 percent can be obtained in a five-cell pond system, and that similar removal rates apply for Salmonella (Bartone et al, 1985). Furthermore, virtually all helminths are removed in a two-pond system. These results are confirmed by other investigations as shown in Table 1 which summarizes data from several countries and climates.

TABLE 1 Reported Bacterial Removal Efficiencies of Multicell Waste Stabilization Ponds with Detention Times > 25 Days.

Pond System	No. of Cells in Series	Effluent Quality (f.c./100ml)*
Melbourne, Australia	8-11	100
EXTRABES, Brazil	5	30
Cogolin, France	3	100
Amman, Jordan	9	30
Lima, Peru	5	100
Tunis, Tunisia	4	200

* f.c. = fecal coliforms.

(Source: Bartone and Arlosoroff, 1987)

Waste stabilization ponds are particularly suitable for developing countries since ponds provide a robust, flexible, almost fail-safe treatment system having low construction costs and minimal operational requirements. In general, for hot climates a minimum 25-day, 5-cell stabilization pond system should afford an adequate level of protection for unrestricted irrigation. For restricted irrigation, a 2-pond system with 10-day detention time is adequate for helminth removal. These general design indications should, of course, always be verified for specific local conditions. To aid in the design of waste stabilization ponds in warm climates, several planning and design manuals are available from international agencies (Arthur, 1983; WHO/EMRO, 1987; Mara and Pearson, 1987).

OTHER NON-CONVENTIONAL TREATMENT OPTIONS

There are several other non-conventional treatment technologies that may also be appropriate in given circumstances. Where oversession storage of effluents is needed, anaerobic treatment ponds followed by a deep reservoir system with long detention time (greater than 60-90 days) is a practical system affording good protection, as has been demonstrated in Israel (Shuval et al, 1986; Streit, 1986). Where subsoil and groundwater conditions are favorable, soil-aquifer treatment systems may be appropriate. Such a system would comprise wastewater treatment followed by ground water recharge and storage for subsequent recovery for irrigation. A major system of this type is the Dan Region Reclamation Project in Israel (Diab and Shilo, 1988). To reduce land requirements associated with stabilization ponds, aerated ponds can be used. Finally, anaerobic treatment processes offer promise for reducing treatment costs and land requirements, particularly anaerobic upflow sludge-blanket reactors that have been tested extensively in South America (Aisse, 1985). However, research is still needed to determine the pathogen removal characteristics of such processes.

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EFFLUENT QUALITY AND IRRIGATION PRACTICE

Wastewater irrigation can supply almost all of the nitrogen and most of the phosphorus and potassium required by many crops, as well as important micronutrients. Pond effluents, because of their algal biomass content, have high fertilizer value and the algae act as slow-release fertilizer. These nutrients are important to the agricultural economy of developing countries where fertilizer costs are a major burden in cash outlay for farmers, and if imported use up foreign exchange. The fertilizer value of wastewater has been estimated at 5 US cents per cubic meter (Streit, 1986). Organic matter in the wastewater can also contribute to soil tilth and overall long-term fertility. Because of the amount of nitrogen in wastewater, however, problems may occur later in the growing season with certain crops such as cotton owing to excessive vegetative growth.

Toxic chemicals, including trace metals and salts, may be present in municipal wastewaters mixed with industrial discharges. In addition to potential toxic effects on plants, there is concern that toxics might accumulate in food crops and move up the food chain to humans. Industrial wastewaters should be isolated from the domestic sewage or receive appropriate pretreatment prior to being discharged to sewers wherever sewage farming is practiced. Other chemicals in wastewater can lead to salinization problems or can affect soil structure. FAO has published detailed information on the above irrigation water quality problems and corresponding water quality guidelines (Ayers and Wescott, 1985).

In arid and semi-arid areas, the low-rate application of effluent is recommended for irrigating crops. With efficient irrigation, the application rate could be about 2,500-5,000 m³/ha-yr depending on local climate and crops grown (Shuval et al, 1986). That is, the effluent of 100 persons each consuming 120 litres per day could irrigate about one hectare. A range of 10,000-20,000 m³/ha-yr is probably more typical of water use at the source in developing countries where flood or ridge-and-furrow irrigation is more common. If greater irrigation efficiencies are to be achieved, then closed-conduit systems, such as sprinkler, micro-sprinkler or drip irrigation, are needed that can deliver water to crops on demand (Hillel, 1987). However, such pressurized systems are susceptible to clogging by suspended solids in wastewater. Algae present in stabilization pond effluents may contribute to clogging in cases where this irrigation technology is used. The clogging problem in pressurized systems can be resolved by appropriate orifice size selection, by the use of gravel filters to remove suspended solids from the effluents, or by screen filters inserted before manifolds or individual laterals (Shuval et al, 1986). New bubbler irrigation technology, a variant of drip irrigation without emitters, avoids clogging problems and can be used for effluent irrigation (Hillel, 1987).

In addition to improved irrigation efficiency, closed-conduit systems are also preferable from a public health point of view. Flood irrigation with poorly treated sewage may contaminate vegetable crops lying on the ground and root crops, and exposes farmers to wastewater more than any method of irrigation. Sprinkler irrigation may contaminate ground crops and fruit trees, and also exposes sewage farm workers. Wastewater aerosol may also be transported to nearby residential areas. Micro-sprinklers reduce these risks considerably. Drip, or trickle, irrigation is the most effective in minimizing contacts between wastewater, crops, and farmers. Comparative research on these irrigation options in reuse projects is being carried out by FAO, and the results will provide guidance for selecting appropriate irrigation technologies.

IRRIGATION REUSE EXAMPLES

Examples of international support for wastewater reclamation and reuse in agriculture are becoming more frequent. The Bank-supported Israel Sewerage Project in the early seventies was the first of its kind. An *ex post* evaluation concluded that it was a successful project incorporating appropriate least-cost technology, and that the provision of sewage disposal and reuse facilities constituted a major environmental improvement and a significant supplementary source of water for irrigation. As an example, the use of long detention storage reservoirs was pioneered through this project. Other important features of this project were the provisions for cost-sharing and division of responsibility between municipalities wanting to dispose of wastewater and farmers wanting to use it (Streit, 1986).

In the Jordan Valley, future expansion of agricultural production will depend on the recycling of sewage from Amman and nearby urban areas. About one-third of Valley irrigation water will have to be provided through reuse, or some 105 Mm³ in total. Currently, all of Amman's sewage is treated at the Al Samra waste stabilization pond system (over 1 m³/s treated in 200 ha of ponds — 3 trains of 10 cells each) and the effluent is conveyed to the King Talal reservoir for mixing, storage and reuse. A joint FAO and UNDP/World Bank evaluation has been undertaken to

evaluate the efficiency of the Al Samra ponds and make recommendations on their future expansion to meet with growing sewage flows (Yanex and Pascod, 1988). Pond performance is satisfactory, resulting in total removal of helminth eggs and four log-cycle removal of fecal coliforms. The study compares the effluents and costs at Al Samra with those of conventional activated sludge plants in Jordan and concludes that pond treatment is preferred for future reuse schemes.

In Tunisia, irrigation with treated wastewater has been implemented since the early 1960's. Reuse of all treated wastewater by the most feasible way is a matter of national policy. There are currently more than 1,000 ha of agricultural land receiving treated wastewater, and an ambitious plan is being executed to irrigate an additional 6,000 ha, thus using 95% of the treated municipal wastewater produced. Tunisia and other Arab countries (viz. Morocco, Libya, Egypt, Jordan, Saudi-Arabia, Kuwait, Bahrain) are engaged in the testing of agricultural reuse of municipal wastewater treated by diverse processes. In addition, non-agricultural reuse such as for industries and ground water recharge is also being tested. As such experiments have applications in all of the Middle-East, a UNDP/World Bank regional project is aimed at bringing together and disseminating the research results and promoting wastewater reuse as a disposal alternative in all urban sanitation projects. Immediate project activities include the survey of wastewater reuse experiences in various countries of the region and the identification of projects that can facilitate the transition of wastewater reuse from research to full-scale application. These activities are being coordinated with the efforts of policy and research institutions within countries of the Middle-East, as well as regional and international organizations (FAO, WHO, UNEP, IRCWD, and others). Increased large scale reuse in the region is expected over the next years. A regional strategy for wastewater reuse is currently being drafted to aid in the channeling of financial and technical resources where they can be utilized most efficiently.

Projects in several Latin American countries are also examining reuse issues. In Santiago, Chile uncontrolled raw sewage irrigation of vegetables has been implicated as a major cause of typhoid fever in that city (Shuval et al, 1986). A priority project is being prepared for Bank funding that will provide for treatment of wastewater destined for the main vegetable irrigation areas surrounding Santiago. In Mexico City, most sewage is reused for agricultural irrigation, but a UNDP/World Bank study found that some 10 percent of the wastewater is treated in multiple plants and distributed for landscape irrigation and filling of recreational lakes in the city, as well as for industrial applications (Dagh-Watson, 1987). An interesting institutional model of reuse has been observed in Monterrey, Mexico in which industrial associations pay to receive municipal sewage, operate treatment plants and distribute the treated effluent to member industries at cost. The Mexico City study proposes testing this model in the Valley of Mexico. Elsewhere, the Inter American Development Bank recently financed a feasibility study for the reclamation and reuse of Lima's wastewaters to irrigate some 3,000 ha of coastal desert land.

In Asia, there is abundant opportunity for reuse in agriculture, and in countries such as China and India increasing priority is being given to wastewater reclamation and reuse. For Karachi, Pakistan, in parallel with a World Bank-sponsored sewerage project that is being prepared, the UNDP is financing a feasibility study for the treatment of Karachi sewage by land application to create large farms on desert land. Green fodder from the farms would be used to feed the large urban dairy buffalo herds.

AQUACULTURE REUSE EXAMPLES

A major review of sewage-fed aquaculture experiences around the world has recently been completed for the UNDP/World Bank Program (Edwards, 1989). Furthermore, the international group of experts who met in Calcutta in 1988 reached a consensus on the current state of knowledge in this field and reached the following conclusions (Edwards and Pullin, in preparation) about sewage-fed aquaculture systems:

- o such schemes, properly designed and managed, may offer a viable low-cost wastewater disposal alternative to conventional mechanical treatment technologies;
- o net fish yields in the order of 5-7 tonnes/ha-yr are common in well managed fish ponds in tropical climates where year round growth is possible without the need for often scarce supplementary fish feed or aeration;
- o similar daily production rates (15-20 kg/ha-day) are attainable during the growing season in temperate latitudes;

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whereas tropical waste stabilization ponds are designed to achieve high loading rates (e.g. 200-300 kg-BOD/ha-day); fishponds require low loading rates (10-20 kg-BOD/ha-day) sufficient to stimulate natural food production for sustained fish growth while maintaining a healthy, aerobic environment for fish; thus the term "optimal loading rate" is understood differently by sanitary engineers and aquaculturists, differing by an order of magnitude.

in general, three types of batch-fed fish ponds are used: single fish ponds directly fertilized with raw sewage (e.g. Calcutta); fish pond systems preceded by some form of primary treatment (e.g. Hungary); and fish ponds receiving fully treated waste stabilization pond effluent (e.g. Lima).

In Calcutta, the wetlands immediately east of the city have been used for sewage-fed fisheries for over 60 years. Currently, the fisheries include some 3,200 ha of ponds receiving a wastewater flow of about 3 m³/s, and produce on the order of 2.4 tonnes/ha-yr of mainly carp polyculture. Production is relatively low because of the artisanal management practices, although well-managed ponds have recorded sustained yields of 5.5 tonnes/ha-yr. Some 4,000 families are employed in this activity. Fish from the ponds supply about 20 tonnes of fish daily to Calcutta markets and fetch prices of US\$2-3/kg (Edwards, 1985). In addition to "treating" about one-third the wastewater of central Calcutta, a major consequence of the fisheries system has been the preservation of an important ecological system that would otherwise have been urbanized by now.

A modern commercial sewage-fed fisheries system in Ponyod, Hungary has been reported by Olah (1988). Polyculture carp are raised in ponds sprayed with primary effluent for fertilization. In a 120 day growing season, net yields of up to 2.4 tonnes/ha-yr are obtained without additional feed. A Hungarian national standard for domestic sewage fishponds was elaborated and approved in 1984 based on the results of five years of intensive monitoring of the Ponyod fish farm.

The use of high quality waste stabilization pond effluent for fish culture has been demonstrated in Lima, Peru, as part of a national project supported by the German GTZ and the UNDP/World Bank Program, and executed by the Pan American Center for Environmental Engineering and Sciences of PAHO/WHO. Tilapia were grown in advanced maturation ponds fertilized with algae-rich treated effluents. Monitoring over two growing seasons established that fish growth and sanitary quality were satisfactory, and that pond water quality could be routinely maintained helminth-free and with fecal coliform concentrations below 1,000 per 100 ml (Bartone *et al.*, 1985). Based on these results a full experimental facility was built, with twelve 400 m² and two 3,000 m² fish ponds to permit replicate experiments. Net yields of over 7 tonnes/ha-yr have been obtained (Moscoso, personal communication). Current research aims at producing tilapia of marketable size under optimal health, growth and economic conditions (Moscoso and Nava, 1988).

PLANNING AND MANAGEMENT ISSUES

While wastewater reclamation and reuse is becoming increasingly important in arid and semi-arid developing countries, it is necessary to consider it within an overall water resource development and management framework if reuse projects are to succeed and provide maximum benefits. Some key issues requiring attention during project formulation are:

- o development of an integrated, multisectoral policy framework for water resources management with a clear definition of reuse priorities and strategies;
- o establishment of environmental and public health standards and control policies based on local risk-benefit considerations;
- o selection of affordable and sustainable treatment and irrigation and/or aquaculture technologies to meet national standards;
- o application of cost recovery policies with equitable allocation of costs among beneficiaries, namely cities disposing of wastewater and farmers and fishermen using it; and
- o strengthening of institutional capacity to operate and maintain treatment, irrigation and aquaculture systems, and to monitor and enforce standards.

In order to assist government officials and national and Bank project officers in the preparation and appraisal of wastewater reclamation and reuse projects, a set of specific guidelines has been developed to deal with the above issues (Kalbermatten et al., 1989). The guidelines are based on an evaluation of international experience to date, as well as the lessons learned through the joint UNDP/world Bank studies and collaborative efforts with WHO, FAO and others. Incorporation of public health measures in reuse projects has been dealt with in detailed guidelines for planning and management prepared for WHO (Mara and Cairncross, 1989). Further guidance on the planning and implementation of irrigation and fertilization schemes based on the use of human wastes will be included in planned FAO publications.

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