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WELL Study

A Review of Policy and Standards for Wastewater Reuse in Agriculture: A Latin American Perspective

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Executive Summary

Wastewater is a valuable resource, however without a properly developed framework policy, safe and efficient management of this resource can not be achieved. Wastewater reuse standards for agriculture are reviewed in this document in the light of recent epidemiological and microbiological studies. There is a particularly emphasis on their impact on wastewater reuse policy and standards in Mexico.

Results of the studies presented indicate that a bacterial standard of 10^3 FC/100ml for unrestricted irrigation, as proposed within the Mexican wastewater reuse standards (NOM 1996) and by WHO (1989), would seem adequate for restricted irrigation. Epidemiological studies suggest that there is a small risk to the health of consumers of raw crops irrigated with water whose microbiological quality is one order of magnitude above the WHO guideline level. Consumption of certain raw crops is associated with slight risk of enteric infection, while other crops appear not to pose a threat. However in situations where there are insufficient resources to reach 10^3 FC/100ml, then a more relaxed guideline of 10^4 FC/100ml could be adopted, but should be supplemented by other health protection measures.

Recent studies indicate that the nematode egg guideline of ≤1 nematode egg/litre for unrestricted irrigation, while adequate to protect consumers of cultivated vegetables spray-irrigated with effluent of consistent quality and at high temperatures, does not necessarily protect consumers of vegetables surface-irrigated with such effluent at lower temperatures. A slight risk of Ascaris infection was detected where there was consumption of wild vegetables irrigated with effluent containing ≤1 nematode egg/litre. Microbiological studies of lettuces irrigated with water ≤1 nematode egg/litre found a few viable though not infective eggs at harvest suggesting a potential risk to consumers. The Mexican wastewater reuse standards (NOM 1996) and WHO guidelines (1989) propose a nematode egg guideline of ≤1 nematode egg/litre, therefore a stricter guideline of ≤0.1 nematode egg/litre is suggested to protect consumers and prevent transmission among farmworkers cultivating vegetables. Where crops have a short shelf life and where workers are not in direct contact with wastewater, a nematode egg standard of ≤1 nematode egg/litre would appear adequate. For populations living in less contaminated environments, i.e. middle-classes in the city, or those living in less endemic countries, the risk associated with consumption of such crops may be greater. For policy makers in Mexico, it will be important for them to consider the markets where produce will be sold (eg Mexico City or USA), since this may affect the actual risk. In such cases, a stricter standard may be justified.

There is now evidence of a need for a bacterial guideline of 10^3 FC/100ml in restricted irrigation, to protect adults and particularly children in direct contact with wastewater, as proposed within Mexican wastewater reuse standards. No bacterial guideline was proposed for restricted irrigation in the WHO guidelines (1989), due to the lack of evidence of risks of bacterial and viral infections to farmworkers and nearby residents. Recent evidence presented here demonstrates that contact with partially treated irrigation water (10^3 -10^4 FC/100ml) is associated with an increased risk of diarrhoeal disease among 5-14 year olds and of the human calicivirus, Mexico virus, among adults. However in situations where there are insufficient resources to reach 10^3 FC/100ml, then a more relaxed guideline of 10^4 FC/100ml could be adopted, but should be supplemented by other health protection measures for children. In situations where no children are involved in farm work, there is insufficient evidence to justify a faecal coliform guideline as there is only limited evidence of a risk to adults from enteric infections.

Studies presented here have also shown that farmworkers and their families, particularly children continued to be at risk when in contact with wastewater containing ≤1nematode egg/litre. Therefore the Mexican nematode egg guideline (≤5 nematode egg/litre) and the WHO (1989) guideline (≤1 nematode egg/litre) would appear inadequate to protect farmworkers and their families, especially children. A nematode egg guideline of 0.1 nematode egg/litre is proposed.

Where children are not in direct contact with wastewater, the nematode egg guideline could be relaxed to 1.0 nematode egg/litre.

The evidence reviewed did not support the need for a separate guideline to specifically protect against viral infection, but there were insufficient data to evaluate the need for a specific guideline for protozoa.

There are currently several alternative approaches to the setting of microbiological guidelines for wastewater reuse, which have different outcomes as their objective (a) no potential risk (b) no measurable excess cases of infection, and (c) a model-generated estimated risk below a defined acceptable risk. In making the recommendations for changes to the guidelines, approach (b) has mainly been adopted. Where epidemiological evidence was lacking microbiological evidence was used, and where risk assessment evidence was available, the results of approach (b) have been checked with the results of approach (c).

The revised microbiological guidelines for agriculture can be met through the use of waste stabilisation ponds (WSP), wastewater storage and treatment reservoirs (WSTR), or through conventional treatment processes. When using WSP, the revised guidelines usually require the use of 1 or more maturation ponds after the anaerobic and facultative ponds. Use of sequential batch-fed storage and treatment reservoirs can be designed to meet the guidelines for unrestricted and restricted irrigation. When conventional treatment processes are used secondary treatment, filtration and disinfection are often needed to meet the revised guidelines. The cost and difficulty in operating and maintaining conventional treatment plants to the level needed to meet the guidelines means that they are not recommended where WSP and WSTR can be used.

There has been wastewater irrigation in Mexico for over 80 years. Despite wastewater reuse guidelines having developed considerably over that period, currently only 25% of domestic wastewater receives treatment prior to discharge. In Mexico, as in many countries, there has been a conflict between the use of conventional treatment plants and the benefits from WSP and WSTR. After many years of wastewater treatment plant inefficiencies due to operational and maintenance problems, the Mexican National Water Commission (CNA) are now carrying out routine monitoring of wastewater treatment plant effluents. Inefficiencies were not confined to conventional treatment systems and the CNA is also organising a program of training, monitoring and evaluation of WSPs.

It is also important for policy makers to consider all available health protection measures, not just wastewater treatment, and so create a realistic wastewater reuse policy that ensures that those in contact with irrigation water are genuinely protected. Crop restriction, irrigation technique, human exposure control and chemo-therapeutic intervention should all be considered as health protection measures to be used in conjunction with partial wastewater treatment. In some cases, community interventions using health promotion programmes and/or regular chemotherapy programmes could be considered, in particular where no wastewater treatment is provided or where there is a time delay before treatment plants can be built.

The development of a policy framework for wastewater reuse in agriculture enables full advantage to be taken of this valuable resource. The problems experienced in Mexico, and described here, are not unique, but do give an excellent example of how lesser developed countries can proceed forward. Too many countries have omitted wastewater from legislation, or only consider issues of environmental degradation, water resource management and public health within their respective ministries. It is essential that coherent policy frameworks, covering all aspects of wastewater be developed.

1. Introduction

This document aims to address the policy issues that surround wastewater reuse in agriculture with particular emphasis on Mexico, a country with a long history of wastewater reuse. There is a brief explanation of the policy process in Mexico over the past 10 years. The results from recent epidemiological and microbiological studies are then described and their implications for wastewater reuse in agriculture discussed, with examples from Mexico. Particular emphasis is given to studies funded by DFID; these include epidemiological studies done by the London School of Hygiene and Tropical Medicine (LSHTM) in collaboration with colleagues in Mexico and microbiological studies done by Leeds University with colleagues in Portugal and Brazil [1].

Intended for policy makers in developing and newly industrialised countries, particularly in Latin America, this document aims to assist in the development of appropriate wastewater reuse policies, including the formation of guideline standards for effluent destined for agricultural irrigation and the implementation of health protection measures, including wastewater treatment, crop restriction, selection of irrigation technique and community intervention programmes. In a companion document, the implications of the studies for the setting of international guidelines for the use of wastewater in agriculture and aquaculture are considered, along with the wastewater treatment and other health protection measures needed to achieve these guidelines.

1.1 Wastewater Reuse

According to current World Bank estimates, the wastewater for more than 4,000 million people worldwide does not receive any form of treatment (Klas Ringskog 1999). In Latin America alone, it is estimated that by the year 2000, more than one hundred million cubic metres of domestic wastewater will be discharged daily into drains across Latin America, of which less than 10% will receive some form of treatment before discharge into rivers or reuse in agricultural irrigation (CEPIS 1995). Currently, in Latin America, around 400 m^3/s of untreated wastewater is discharged into rivers and lakes and over 500,000 hectares irrigated with wastewater (Mexico-350,000, Chile-16,000, Peru-5,500 and Argentina-3,700), the majority of which has received no treatment (CEPIS 1996). Though in many countries there are no official figures, it is known that there is direct or indirect wastewater reuse in most regions where cities have adjoining agricultural areas (CEPIS 1996). Throughout Mexico, as throughout Latin America, direct reuse is minor, when compared with the amount of agricultural land irrigated with contaminated surface waters, whose microbiological quality is comparable with that of untreated wastewater (CEPIS 1995).

1.2 Standards for Wastewater Reuse

Microbiological standards for the safe reuse of wastewater in agriculture in Latin America are varied (CEPIS 1998). Some countries have very little legislation, favouring indiscriminate reuse and its negative implications for health and the environment. For example, Brazil has no legislation. Argentina did not previously have legislation specifically regarding wastewater. It had a general water law that aimed to prevent surface water contamination, but wastewater was not specifically mentioned. It is however, currently considering the introduction of guidelines for sludge from treatment plants. Legislators have also been recommended to consider wastewater within the legislation. Chile, which similarly had general legislation to prevent surface water contamination, will next year be introducing a guideline for the control of domestic and industrial discharges into rivers, lakes and the sea, though crop irrigation does not appear to be included in the legislation.

[1] This document was originally presented as the background paper for the Technical meeting "Wastewater reuse in agriculture and its health impact: Is it time to review the guideline NOM-001-ECOL-1996 " . The meeting was organised by LSHTM and INNSZ, and was held on December 4th 1998 in the Mexican Health Foundation, Mexico City, Mexico. The document has since been expanded, and comments and suggestions from participants incorporated.

Other countries have established strict regulations that are difficult to enforce and can not hope to be achieved, including the banning of crop irrigation with untreated wastewater and crop restrictions. Legislation in Peru recommends primary (physical-sedimentation) and secondary (biological) treatment, but does not establish a bacterial nor nematode guideline maximum (CEPIS 1999). The guidelines currently prohibit wastewater irrigation of vegetables that are grown at ground level or with a short stem, and that are eaten uncooked, even when the wastewater is treated. Cereal crops, fodder crops and fruit trees require secondary treatment, industrial crops require primary treatment. Milking herds are prohibited access to wastewater irrigated fields. Their guidelines are currently under review. Some countries have put forward standards for wastewater reuse that do permit a more controlled reuse of wastewater for crop irrigation. Many of these are based on the WHO guidelines (Table 1-1), for example, Mexico (Table 6-1) and Andalucia Province, Spain (Annex G). The WHO Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture were published in 1989 and propose different water qualities depending on the endpoint of discharge eg. for restricted or unrestricted crop irrigation (WHO 1989). A summary of the evidence presented in support of the WHO (1989) guidelines is given in Annex B.

Table 1-1. The 1989 WHO guidelines for the use of treated wastewater in agriculture[a] (*1*)

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

the guidelines modified accordingly.
[b] *Ascaris* and *Trichuris* species and hookworms.
[c] During the irrigation period.
[d] A more stringent guideline (≤ 200 faecal coliforms per 100 ml) is appropriate for public lawns, such as hotel lawns, with which the public may cone into direct contact.
[e] In the case of fruit trees, irrigation should cease two weeks before fruit is picket, and no fruit should be picked off the ground. Sprinkler irrigation should be used.

2. Wastewater reuse in Mexico

2.1 Extent of Reuse in Mexico

In Mexico, there is a desperate need to increase land available for agriculture and to improve productivity. Wastewater reuse in agricultural irrigation apart from providing water, adds natural fertilizers to the soil and helps increase topsoil. Mexico has a population of over 91 million (Plan Hidraulico 1995-2000), 71% of which is concentrated in urban centres, making up just 2% of the national territory (e.g. in the Federal District population density is 5660 people / km^2). The remainder of the population lives in small rural communities (15 people / km^2). The varied topography and climate in Mexico, from arid desert regions void of vegetation to lush rain forests with 4000mm annual rainfall, result in around 80% of land being classified as unsuitable for agriculture (INEGI 1990). Mexico currently is reported to irrigate over 350,000 hectares directly with wastewater (CNA 1998).

There is evidence in Mexico of irrigation as far back as the pre-hispanic colonies. However it was not until 1917, that the Department of Irrigation, was created. Its aim was to promote and organise irrigation projects, establish quotas for the private use of national waters and obtain funds to finance further irrigation programs. The Department of Irrigation encouraged land reforms and, in January 1926, with the creation of the irrigation law and the National Irrigation Commission, crop irrigation began in Mexico. First, with most economic and social impact, were the engineering projects such as small storage reservoirs and irrigation channels, leading to the first irrigation systems which later were called irrigation districts.

Now, over 80 years later wastewater irrigation is widespread in Mexico; there are over 40 irrigation districts utilizing wastewater, and over 350,000 hectares of arable land under wastewater irrigation. Table 2-1 gives a breakdown of most of this area between various irrigation districts. However recent figures (CNA 1998) show that only about 11% of the wastewater used has been treated. All irrigation districts using untreated wastewater enforce restricted irrigation. In the remainder of the irrigation districts in Mexico, where wastewater is not utilized, it is thought that there are wastewater discharges into irrigation channels and drains, which are used in unrestricted crop irrigation, though the full extent has yet to be quantified (CNA 1998).

Table 2-1. Wastewater Irrigation Districts in Mexico

Irrigation district			Volume used ($m^3 \times 10^3$)			Area (hectares)
			Total	Treated	Untreated	
North-east	010	Culiacan, Sinaloa	4144	0	4144	800
	014	Rio Colorado, Baja California	340	0	340	69
	037	Alt.Pitiquito, Sonora	0	0	0	0
	043	Edo. De Nayarit, Sonora	0	0	0	0
	063	Guasave, Sinaloa	0	0	0	0
	066	Sto.Domingo, Baja Calif. Sur	140	0	140	22
	074	Mocorito, Sinaloa	0	0	0	0
	075	Rio Fuerte, Sinaloa	0	0	0	0
North-Central	001	Pabellon, Aguas Calientes	0	0	0	0
	005	Delicias, Chihuahua	695	0	695	589
	009	Cd.Juarez, Chihuahua	117521	0	117521	7503
	017	R.Lago, Coahuila-Durango	5600	0	5600	1600
	052	Estado de Durango	0	0	0	0
	090	B.Rio Conchos, Chihuahua	0	0	0	0
Northeast Central	004	Don Martin, Nuevo Leon	0	0	0	0
	029	Xicotencatl, Tampico	19504	0	19504	2300
	035	La Antigua, Veracruz	12300	0	12300	1000
	082	Rio Blanco, Veracruz	296790	2667	294123	13000
	025	B.Rio Bravo, Tampico	0	0	0	0
	026	B.Rio San Juan, Tampico	0	0	0	0
	060	El Higo, Veracruz	0	0	0	0
	092	R.Panuco, Tampico – S.L.P.	0	0	0	0
Mexico Valley	003	Tula, Hidalgo	1075979	0	1075979	57973
	016	Estado de Morelos	337180	34687	302493	23000
	033	Estado de Mexico	18973	0	18693	5498
	028	Tulancingo, Hidalgo	4500	0	4500	300
	044	Jilotepec, Mexico	0	0	0	0
	088	Chiconautla, Mexico	25202	0	25202	3123
	100	Alfajayucan, Hidalgo	373649	0	373649	24745
Lerma-Balsas	011	Alto Rio Lerma, Gto	0	0	0	0
	013	Estado de Jalisco	153702	0	153702	13077
	016	Estado de Morelos	0	0	0	0
	020	Morelia, Michoacan	22722	0	0	0
	023	San Juan del Rio, Gto	2300	2300	0	230
	024	C.de Chapala, Mich.	6269	0	6269	10469
	030	Valsequillo, Puebla	259766	227000	32766	20600
	045	Tuxpan, Michoacan	54997	5500	49497	4300
	053	Estado de Colima	0	0	0	0
	056	Atoyac-Zahuapan, Tlaxcala	25004	7500	17504	3800
	061	Zamora, Mich	21000	0	21000	2000
	068	Tepecuac y Quechul, Guerrero	2304	0	2304	100
	085	La Begoña, Mich.	0	0	0	0
	087	Rosario-Mezq, Mich.	303013	0	303013	33080
	094	Jalisico Sur	0	0	0	0
	097	Lazaro Cardenas, Mich.	286439	0	286439	21899
	099	Quitupan Magdalena, Mich.	5550	0	5550	5000
South-east	019	Tehuantepec, Oaxaca	0	0	0	0
	046	Cacahoatan, Chiapas	0	0	0	0
TOTAL			3435583	279654	3132927	256077

2.2 Wastewater treatment in Mexico

Mexico is estimated to produce 170m^3/s of domestic wastewater, of which 25% is currently treated prior to discharge. Industry is reported to produce 140m^3/s of wastewater, though only 15% is treated (Moeller G. et al. 1999). There are 808 domestic wastewater treatment plants in Mexico (including 416 waste stabilisation ponds), of which 76% are reported to be functional. For example, in Hidalgo, there are 5 treatment plants, however only 1 is operational (CNA, 1997). When treatment plants are operational, they often fail to achieve design flow rates and have low removal efficiencies as in the state of Guerrero (Table 2-2). Of the 416 waste stabilisation ponds (WSP), only 334 are operational and most have problems. Often the design models adopted for WSPs are not suitable for local conditions (Escalante V & Noriega H. 1999), there are few operation and maintenance routines, flow capacities are exceeded and there is no routine monitoring of effluent quality (Escalante V. et al 1999).

A detailed investigation of the main treatment processes employed in Mexico revealed that treatment plants, regardless of the system, were often inefficient due to operational and maintenance problems. However conventional treatment was generally more expensive (N$0.79/m3 compared with N$0.3/m3) and less efficient (<50% compared with 46-93%) than non-conventional treatments e.g. oxidation ditches and aerobic ponds (IMTA 1992). A large conventional wastewater treatment plant in the state of Guerrero provides a good example of the problems that can occur. Investigation of this advanced primary treatment plant in Acapulco revealed low efficiency removal rates for BOD (53%) and chlorine was below 0.2mg/l. As a result, only 65% of faecal coliforms were eliminated. The report concluded that the inefficiencies were due primarily to operational and maintenance problems which related to a lack of understanding of the system, security and hygiene issues, and to a poorly equipped laboratory with untrained personnel.

In response to the deficiencies that existed throughout the Mexican republic, the National Water Commission has setup a network of laboratories around the country to carry out routine monitoring of treatment plant effluents to ensure compliance with national microbiological standards. The Mexican Institute of Water Technology (IMTA) has instigated a program of training, monitoring and evaluation of WSP facilities in Mexico (Moeller G. et al. 1999). To date a total of 123 technicians in six states have been trained and five WSPs were monitored and evaluated. Upgrading plans were proposed to ensure effluent quality complied with microbiological standards for discharge or for its use in irrigation (Esclante V. et al 1999). IMTA has also begun to develop design models for WSP systems appropriate to the local conditions in Mexico (Escalante V. & Noriega H. 1999).

Table 2-2. Wastewater treatment plants in Guerrero State

Location	Process	No.	Flow (% of design)	Site of Discharge	Reported % efficiency
Municipal	Activated sludge	13	0.49 (45)	River / lake	96
	Advanced primary	1	0.75 (56)	Sea	64
Private	Activated sludge	6	0.04 (51)	River / lake / sea / green areas	82
	Advanced primary	0	-	-	-

The Mexico Valley is seen as a particular problem in its own right, producing 1660 million cubic metres of wastewater each year, and expected to produce 2000 million cubic metres each year by the year 2000. There are several problems that make it a unique situation. The wastewater and run-off are combined and, as a result, both the volume and quality of the wastewater produced varies greatly depending on the season. For example, the mean number of helminth ova/litre is 20.5 with a range from 7-93 ova/litre. The mean total suspended solids is 280mg/l, with a range from 52-3383mg/l, while most treatment processes quote a mean of 250mg/l, maximum 500mg/l for domestic wastewater (Jimenez-Cisneros B. & Chavez-Mejia A. 1998). The flow rate varies from 45m3/s to 300m3/s in the rainy season (Jimenez-Cisneros B & Chavez-Mejia A. 1997). There are currently 16 secondary wastewater treatment plants in the Mexico Valley, which treat just 6% of the wastewater produced. The effluent from these plants is used to irrigate green areas in Mexico city. A World Bank loan was approved in 1996 for a sanitation programme for the Mexico Valley. The programme is to be paid for by the Inter-American Development Bank (US$365 million), Mexican Government (US$260 million) and the Overseas Economic Cooperation Fund of Japan (US$410 million). Within the program, there is a plan to build 3 or 4 macro conventional wastewater treatment plants to treat all the wastewater from the Mexico city metropolitan area. There is much discussion about the appropriate treatment processes to be adopted in view of the temporal variations in flow and quality of the wastewater (Jimenez B & Chavez-Mejia A. 1997). There was also concern about safe disposal of the large volumes of sludge that would be produced. Studies by IMTA and the National University of Mexico are currently assessing the best approach to sludge treatment (Jimenez-Cisneros B & Chavez-Mejia A. 1997, Moeller G. personal communication). To date the Mexican government has not taken up the loan.

3. Current policies for wastewater reuse and treatment in Mexico

3.1 Wastewater reuse policy

Microbiological standards for wastewater reuse in agriculture have developed considerably in Mexico over the last ten years (Table 3-1). In 1991, standards establishing the maximum permissible limits for physical and chemical parameters in urban or municipal wastewater destined for use in agricultural irrigation were revised in guidelines NTE-CCA-033/91 (1991) and NTE-CCA-032/91 (1991). Particular attention was paid to (1) the cultivation of vegetables and other crops eaten raw, (2) the importance of wastewater reuse in agriculture as a form of wastewater treatment and disposal, and (3) the diversity of treatment processes available to achieve the guidelines.

Table 3-1. The Policy Process in Mexico 1971-1996

Year	Law or Guideline
1971	Law for the Prevention and Control of Contamination of Water (Reglamento para la Prevencion y Control de la Contamination de Aguas)
1991	NTE-CCA-032/91 (Diario Oficial de la Federacion 24/09/91)
1991	NTE-CCA-033/91 (Diario Oficial de la Federation 24/10/91)
1993	NOM-CCA-032-ECOL-1993 (Diario Oficial de la Federacion 18/10/93)
1993	NOM-CCA-033-ECOL-1993 (Diario Oficial de la Federation 18/10/93)
1996	NOM-001-ECOL-1996 (Diario Oficial de la Federation 06/01/97 with corrections published 30/04/97)

In 1992 the 032 and 033 standards were reviewed. Many of the chemical parameter limits were considerably relaxed in the revised standard, NOM-CCA-032-ECOL-1993. However the microbiological standard NOM-CCA-033-ECOL-1993 was not altered, except for the addition of gherkins and green beans to the list of restricted vegetables, while chillies continued to be omitted from the list of restricted crops, despite chillies being commonly eaten raw in Mexico.

The final revision of the microbiological standards occurred in 1996, resulting in the introduction of NOM-001-ECOL-1996 (Table 3-2) "that establishes the maximum permissible limits of contaminants in wastewater to be discharged into national waters and onto national soil". This was part of a major reorganisation of standards for industrial and domestic discharge into national waters and soils. Previously 44 separate standards existed, the majority of which governed discharges from municipal drains, hospitals, factories and food and drink manufacturers. The new standard, with a single set of parameter limits regardless of the discharge source, was designed to be achievable with the technology and resources available at present and in the near future in Mexico and to be more realistically policed, by reducing the amount of monitoring required. The limits imposed within the standard were designed to be sufficient to protect "at-risk" groups according to currently available literature. Revision of many of the possible treatment processes resulted in the proposed microbiological standards. A stricter helminth standard would have required conventional treatment plants to use filters and this would have carried significant financial implications (personal comm. Ing E.Mejia). The standard is aimed to be workable, understandable, compact and clear for the general public, its main objective being to reduce microbial and chemical contamination of rivers, lakes, aquifers and other water sources.

The standard was aimed at limits for wastewater discharged into rivers and other water sources. The limits are the same as for restricted irrigation i.e. a daily mean of no more than 2000 FC/100ml and a monthly mean of no more than 1000 FC/100ml. Municipalities and industry were given time limits for compliance with the standard (Annex A Table A3).

Table 3-2. Mexican Standard NOM-001-ECOL-1996 governing wastewater reuse in agriculture

Irrigation	FC/100ml (MPN[2])	Helminth ova/litre
Restricted	1000_m - 2000_d	≤5
Unrestricted	1000_m - 2000_d	≤1

(m=monthly mean, d=daily mean)

Note: Unrestricted irrigation is defined as permitting irrigation of all crops, whilst restricted irrigation excludes salad crops and vegetables that are eaten raw (individual crops are no longer specified in the standard).

3.2 Wastewater treatment policy

The aim of the Mexican government in 1996 (Plan Hidraulico 1995-2000) was to increase the volume of treated wastewater from 17 to 82m^3/s (0.54 to 2.6 km3/year), through improvements in the existing treatment infrastructure and the construction of new treatment systems. The program also pledged assistance to dischargers to ensure compliance with discharge standards was achieved. However, legally it is the responsibility of the discharger, whether a municipality or a factory, to treat the discharge within the allowed time frame (Annex A Table A3) and to ensure the discharge complies with current standards. The choice of treatment methodology adopted can depend on the source of funding for the treatment. When funding is federal or international, funders usually stipulate an engineering consultant to advise on the plant process to be adopted; this can be a private engineering consultant or alternatively the National Water Commission. Generally however, the discharger decides the treatment methodology to be adopted. They can request advice from the State Water and Drainage department, or from the state or federal offices of the National Water Commission, but are under no obligation to do so. Commercial companies tend to take advantage of this, promoting complex treatment technologies which will be difficult to maintain at optimum efficiency and expensive to repair. All too often treatment plants are operated at less than the designed flow capacity and do not comply with initially projected standards for the effluent. In Mexico City during 1996 - 1997, 50% of treatment plants were operating at less than the designed flow capacity (World Resources 1997). There is a loophole in the system, since the National Water Commission is required by law to monitor discharges and fine those failing to comply with current standards, while they are only required to assist where help is requested.

3.3 Current policy questions and dilemmas

In many areas in Mexico, wastewater treatment is not available so that untreated wastewater is used for crop irrigation. The current standard (NOM-001-ECOL-1996) is therefore exceeded and risks to public health exist. There is an issue as to how the standards are going to be met in the proposed time-scale, what wastewater treatment can practically be provided and what other health protection measures could be adopted.

The Ministry of Environment, Natural Resources and Fisheries (SEMARNAP) is concerned with protecting Mexico's scarce and rapidly diminishing national waters and aquifers from over-exploitation and contamination, providing sufficient water for the needs of farmers and ensuring that standards are technically achievable and not financially burdening to the economy. Health authorities need to consider the burden of disease among the "at-risk" population that is attributable to current wastewater reuse policies and whether its cost in terms of both morbidity and mortality justifies stricter standards, hygiene intervention programs or other measures to reduce these health risks. Local governments are generally more concerned about wastewater collection and rapid disposal; unfortunately this is often into rivers or the sea. While rural areas

[2] MPN - Most probable number. This technique is used to determine faecal coliform concentrations.

see the wastewater as a valuable resource for crop irrigation, without overly worrying about the accompanying health risks. It is essential that all interested parties, whether federal and state government, municipalities, private water companies, farmers or the general population, evaluate current health protection measures, including wastewater treatment, crop restriction or irrigation systems, their effectiveness and their enforcement.

Once standards and accompanying health protection measures are established, there are two very important issues; who is responsible for ensuring compliance and who pays the cost of such policies. The question of who pays has long been an issue for debate, however it has now been generally accepted that the discharger pays the cost of treatment. However until this is can be achieved, the discharger and the user must share the burden of treatment; the discharger to help prevent environmental contamination and the water user to ensure the sanitary quality of his crops.

The non-uniform population density in Mexico increases the difficulties for the water authority to provide adequate wastewater treatment systems throughout the country. Conventional treatment may seem appropriate for large urban conurbations faced with the problem of space to build WSPs, such as the Mexico Valley (Jimenez-Cisneros B & Chavez-Mejia A 1997). However, this immediate response, to opt for conventional treatment systems, requires a large initial investment and such projects have high running and maintenance costs, in terms of personnel, reagents and parts. In regions where such systems are the only realistic solution, the financial burden of operation and maintenance must be fully considered before cities opt for conventional treatment systems. However, where population densities are low, the best option is often WSPs (Moeller G. et al. 1999). WSPs require a low initial investment, have low running costs, require less-skilled operators than conventional treatment plants and achieve bacterial and nematode egg discharge standard limits when efficiently operated. Conventional treatment plants would require an additional disinfection process to comply with bacterial guidelines.

Another problem frequently facing authorities comes from communities near proposed wastewater treatment systems, whether conventional or non-conventional. The majority of individuals agree with the necessity of treating wastewater, but do not want the treatment systems near their community, often due to bad smells or insects living around the treatment system. These problems are usually due to poor operation and can be avoided by ensuring personnel are trained to maintain an efficient treatment system.

Therefore, the challenge confronting authorities in Mexico, as in many countries, is to ensure legislation is realistic and promotes efficient wastewater reuse. This includes wastewater treatment policies and health protection measures for users and consumers, a program of control and monitoring of treatment and other measures, and finally, adequate water for agricultural users. All this needs to be achievable within current technological and financial restraints.

4. Evidence of health risks from recent studies in Mexico

In this section, a series of epidemiological and microbiological studies initiated in 1989 to assess the validity of the WHO (1989) guidelines are described and discussed. A more detailed account of these studies can be found in Annex C

4.1 Study area

Raw wastewater coming from Mexico City to the Mezquital valley, Hidalgo, is used to irrigate a restricted range of crops, mainly cereal and fodder crops through flood irrigation techniques. Some of the wastewater passes through storage reservoirs and the quality of the wastewater is improved before use; this is equivalent to partial treatment. The effluent from the first reservoir (retention time 1-7 months, depending on the time of year) meets the WHO Guideline for restricted irrigation (category B), even though a small amount of raw wastewater enters the effluent prior to irrigation (quality 10^5 FC/100ml and $\leq$1 nematode egg/litre). Effluent from the second reservoir is retained for an additional 2-6 months (>3 months of combined retention), and the quality improved further (quality 10^3 – 10^4 FC/100ml and no detectable nematode eggs). Part of the effluent from the first reservoir enters the river and is abstracted downstream to irrigate a large area of vegetable and salad crops, many of which are eaten raw; the river water is essentially partially treated wastewater (quality 10^4 FC/100ml). These crops are sold in the local markets and eaten by the rural populations in local villages, including those near the second reservoir. In a nearby area, vegetables are irrigated with borehole water.

4.2 Results: risks to farm workers related to restricted irrigation and effect of wastewater treatment

4.2.1 Exposure to raw wastewater

Farm workers and their children in contact with raw wastewater through irrigation or play have a significantly higher prevalence of *Ascaris* infection than those in a control group, who practice rain-fed agriculture (Fig 1a). The excess infection is greater in children than in adults (Blumenthal et al, 1996, Peasey, 2000). Young children (aged 1-4 yrs) also have a significantly higher rate of diarrhoeal disease (Fig 1b) (Cifuentes et al, 1993).

Figure 1a: Effect of exposure to wastewater on *Ascaris* infection: effect of raw wastewater

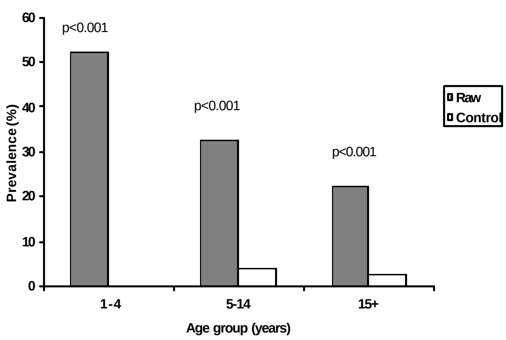
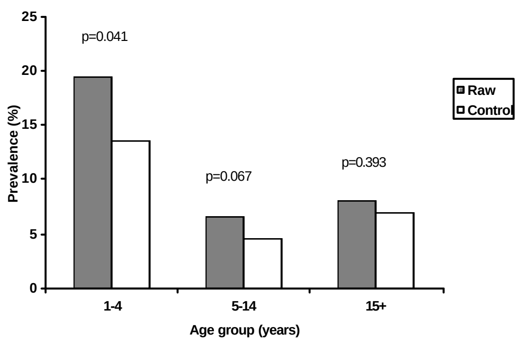
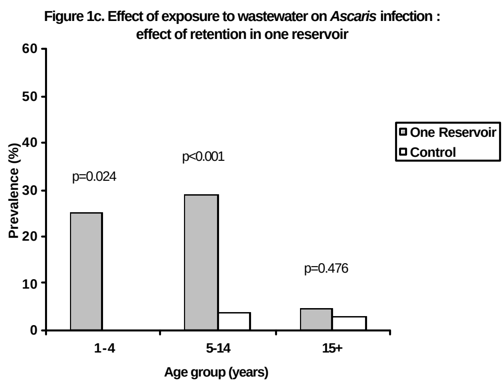


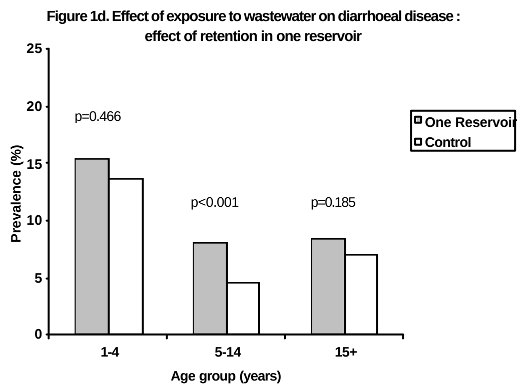
Figure 1b. Effect of exposure to wastewater on diarrhoeal disease : effect of raw wastewater



4.2.2 Exposure to partially treated wastewater

Contact with wastewater which has been retained in one reservoir before use (<1 nematode egg/l and 10^5 FC/100ml) results in excess *Ascaris* infection in children, but not in adults, where the prevalence was reduced to a similar level to the control group (Fig 1c) (Blumenthal et al, 1996). Children aged 5-14 years also have significantly higher rates of diarrhoeal disease (Fig 1d) (Cifuentes et al, 1993, Blumenthal et al, 2000a).

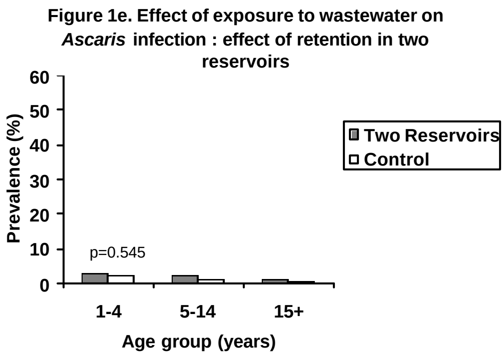


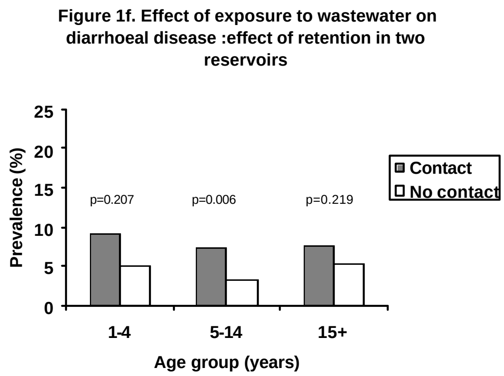


When wastewater has been retained in two reservoirs in series before use (no nematode eggs detected, geometric mean $4x10^3$ FC/100ml, maximum 10^5 FC/100ml) direct contact results in very little excess *Ascaris* infection in any age group (Fig 1e) (Cifuentes et al, 1994, Cifuentes, 1998). However, there is a significant excess of diarrhoeal disease in children aged 5-14 years (Fig 1f), and a four-fold increase in seroresponse to Human Norwalk-like Virus/Mexico in adults with high levels of contact with the effluent from the second reservoir (Annex A, Table 1c) compared with those with no contact with this effluent (Blumenthal et al, 1998, Blumenthal et al, 2000b).

Retention of water in two reservoirs in series, producing water of average quality 10^3 FC/100ml and no detectable nematode eggs, is therefore adequate to protect the children of farmworkers from *Ascaris* infection but not against increased diarrhoeal disease.

The results are presented in more detail in Annex C.





4.3 Risks to consumers related to unrestricted irrigation

Risks from bacterial and viral infections related to the consumption of specific vegetables (ie. courgette, cauliflower, cabbage, carrots, green tomato, red tomato, onion, chilli, lettuce, radish, cucumber and coriander) and to total consumption of raw vegetables irrigated with partially treated wastewater (average quality 10^4 FC/100ml) were investigated. Consumers (of all ages) had no excess infection with diarrhoeal disease, and no excess infection as measured by serological response to Human Norwalk-like Virus/ Mexico (Hu/NLV/Mx), or *Enterotoxigenic Escherichia coli* (ETEC) related to their total consumption of raw vegetables, that is, the number of raw vegetables eaten each week (Blumenthal et al, 1998, Blumenthal et al, 2000b).

However, there was an excess of diarrhoeal disease in those in the exposed area who ate increased amounts of onion compared with those who ate very little (Fig 2a). The effect was seen particularly in adults and children under 5 years of age. There were also higher levels of serological response to Hu/NLV/Mx in school-aged children who ate green tomato (Fig 2b) and in adults who ate salsa (containing green tomato). The increase in diarrhoeal disease associated with eating increased amounts of raw chillies (Fig 2c) was not related to use of partially-treated wastewater as the chillies eaten by the study population were grown in raw wastewater. Only the risks from eating onion and green tomato can be associated with using partially treated wastewater in irrigation. In the final analysis, consumption of onion, or green tomato, once a week or more was associated with at least a two-fold increase in diarrhoea or Hu/NLV/MX respectively. Enteroviruses were found on onions at harvest, giving support to this epidemiological evidence. The effects described were seen after allowance was made for other risk factors for diarrhoeal disease. No excess serological response to enterotoxigenic *E. coli* was related to raw vegetable consumption.

Consumption of vegetable crops irrigated with water of quality 10^4 FC/100ml therefore causes a significant risk of enteric infection in consumers.

The results are presented in more detail in Annex C.

Figure 2a. Effect of consumption of raw onion (times/month) on diarrhoeal disease

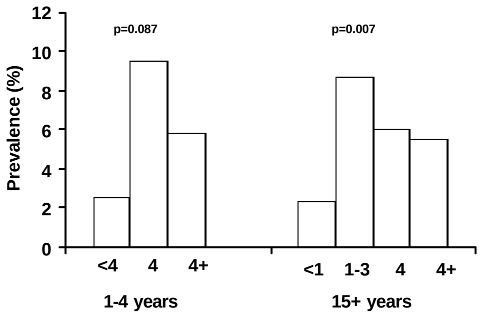


Figure 2b. Effect of consumption (times/fortnight) of raw green tomates on seroresponse to Human Norwalk-like Virus/Mx among 5-14 year olds

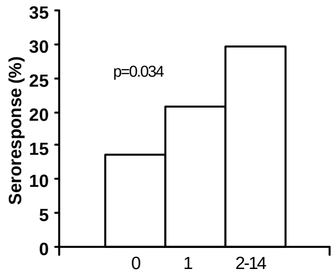
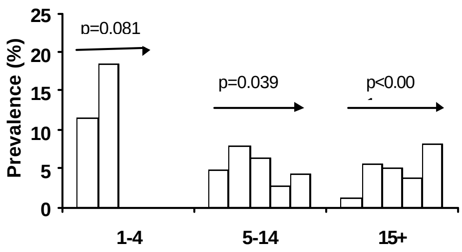


Figure 2c. Effect of consumption of raw chilles on diarrhoeal disease (increasing consumption)



5. Evidence of health risks from studies in other sites

In this section, studies that were not fully published at the time of the WHO Scientific Group meeting in 1987 and that shed light on the appropriateness of the WHO (1989) guidelines are reviewed.

5.1 Effects on farmworkers or wastewater treatment plant workers

Evidence of the beneficial effect of wastewater treatment, and particularly of the positive effect of wastewater storage in reservoirs, was found in the Lubbock Infection Surveillance Study, a study of farmworkers and residents living near the Lubbock land treatment system in Texas, USA. Here, a rural community was exposed to sprinkler application of partially treated wastewater from a much larger urban community (Camann et al, 1986). For the first year, mainly primary effluent and trickling filter effluent was used to irrigate cereals and industrial crops (quality 10^6 FC/100ml and virus 100-1000pfu/L)), and in the second year, the effluent was stored in reservoirs before use (quality 10^3-10^4 FC/100ml and virus <10pfu) (Camann et al, 1988).

There was no clear association between self-reported clinical illness episodes and exposure to wastewater (Camann et al, 1986). However, in the data on seroconversion to viral infections, a high degree of aerosol exposure was related to a slightly higher rate of viral infections (risk ratio of 1.5-1.8). A dose-response relationship was observed over the four irrigation seasons; the episodes of viral infection associated with wastewater exposure mainly occurred in the first year, before the reservoirs had come into use. More supporting evidence was found for the role of the wastewater aerosol route of exposure, than for direct contact with wastewater. Of the many infection episodes observed, few were conclusively associated with wastewater exposure and none resulted in serious illness. However, the authors could not determine whether wastewater exposure or identified alternative explanations were the actual risk factors for the enteric viral infections. Analysis of clinical viral infection data (from faecal specimens) also showed that aerosol exposure (high) was associated with new viral infections in the summer of the first year of irrigation, but the effect was of borderline significance (p=0.06) (Camann and Moore, 1988). However, when allowance was made for alternative risk factors, eating at local restaurants was identified as an alternative explanation for the viral infection episodes.

In a specific study of rotavirus infection, wastewater spray irrigation had no detectable effect on the incidence of infection (Ward et al, 1989). Altogether, the results do suggest that aerosol exposure to wastewater of quality 10^3-10^4 FC/100ml does not result in excess infection with enteric viruses. There is some evidence that exposure to wastewater of quality 10^6 FC/100ml results in excess viral infection (but not disease) but this is not conclusive.

A new study of wastewater treatment plant workers (Khuder et al, 1998) suggests that they have a significantly higher prevalence of gastroenteritis and gastrointestinal symptoms than controls (college maintenance and oil refinery workers). There was no association between extent of exposure and prevalence of symptoms. However, these results are not reliable since workers were asked about symptoms over the previous 12 months (retrospectively). The previous studies (Clark et al, 1981 and 1985, see Annex B) are more credible, involving ongoing collection of illness information and human samples (prospectively).

5.2 Effects on consumers of vegetable crops

No further epidemiological studies have been located which assess the risk of enteric infections to consumers of vegetable crops irrigated with treated wastewater.

5.2.1 Evidence from microbiological studies of crops irrigated with treated wastewater

5.2.1.1 Studies on bacterial contamination of vegetable crops

A study in Peru compared the microbiological quality of crops irrigated with water of differing qualities (Castro de Esparza & Vargas 1990). The presence of total coliforms, faecal coliforms

(FC), *Salmonella*, enterotoxigenic *E.coli* (ETEC), enteropathogenic *E.coli* (EPEC), protozoans and helminths was determined on crops and in water samples. Four water sources were compared, (1) domestic/industrial wastewater mix, (2) raw domestic wastewater (both 7 x 10^7 FC/100ml, 2 x 10^3 *Salmonella*/100ml, 10^2-10^3 micro-organisms / litre), (3) WSP treated wastewater (1.7 x 10^5 FC/100ml effluent, <10^2 *Salmonella*/100ml, no protozoans nor helminths detected in tertiary effluents) and (4) water from a local river (2 x 10^2 FC/100ml and no *Salmonella* detected in 10 litres). Crops were classified according to distance from soil (under soil, on soil or high) and the form eaten (raw, cooked or a mixture). They also noted the time since last irrigation. A total of 29 crops were studied, and 4375 analyses performed.

Salmonella was detected, on 20.5% of crops irrigated with water of quality 1, 13.9% of crops irrigated with water quality 2 water, and 5.7% of crops irrigated with water quality 3. No *Salmonella* was detected on crops irrigated with water quality 4. There was no difference in the prevalence of ETEC on crops irrigated with the 4 water qualities. ETEC was identified on 34.5% of crops and EPEC on 59.6% of crops. *Entamoeba coli* was the most common protozoan, identified on 37.8% of crops. *Ascaris lumbricoides* was identified on 30.7% of crops. The most contaminated crop was lettuce, then parsley, spinach and carrot in order of importance. Allowing 8 days between the last irrigation and harvest ensured a 25% increase in crops considered as acceptable for consumption (defined as all 5 unit samples having <10 *Escherichia coli*, and no *Salmonella* detected). The improvement in crop microbiological quality is most apparent in the "high" crops and to a lesser extent in those growing below or on the ground. A high degree of recontamination was observed in the markets.

Comparison of FC and *Salmonella* levels shows that a FC level of 10^4 FC/100ml to indicate 1 *Salmonella*/100ml of wastewater, and no *Salmonella* detectable on crops (ICMSF 1983). Though the WSPs did not in practice achieve 10^4 FC/100ml, optimum operation of WSPs would produce an effluent of 10^4 FC/100ml i.e. suitable for crop irrigation.

Work in Portugal during 1985 - 1989 (Vaz da Costa Vargas *et al*., 1996) also explored the effect of the irrigation of salad crops with treated wastewater of various qualities. When a very poor quality wastewater (trickling filter effluent with 10^6 FC per 100 ml) was used to spray-irrigate lettuces, the initial high levels of indicator bacteria on the lettuces (10^6 FC/100g) reflected the bacteriological quality of the irrigation water and exceeded the ICMSF (1974) recommendations for foodstuffs eaten raw (<10^5 FC per 100 g fresh weight, preferably < 10^3 FC per 100 g). Once irrigation ceased, no *Salmonella* could be detected after 5 days, and after 7 to 12 days FC levels were similar to or just above the level seen in lettuces irrigated with fresh water. Final levels were below the recommendations of ICMSF (1974) and the quality was better than that of lettuces on sale in the local markets (10^6 FC per 100 g), irrigated with surface waters. However, since farmers will probably not cease irrigation of leafy salad crops 5 days or more before harvest, then the contamination of harvested crops is likely to exceed the ICMSF recommendations. Data from an experiment which simulated an epidemic of *Salmonella typhi* (10^8 organisms per 100ml inoculated into the final effluent) indicated that there was a risk of infection with *S.typhi* if lettuces were consumed within a reasonable period of 8 days from the last irrigation.

In studies of drip and furrow irrigation of lettuces and radishes with waste stabilization pond effluent which had a FC count slightly higher than the WHO recommendation of 1000 per 100 ml (1700 - 5000 FC per 100 ml geometric mean count) crop contamination levels varied considerably. Under dry weather conditions they were at worst of the orders of 10^3 and 10^4 *E.coli* per 100mg for radishes and lettuces respectively, and *Salmonella*e were always absent. The quality was better than that of locally sold lettuces locally sold lettuces (which had a geometric mean FC count, based on 172 samples, of 1×10^6/100g) and fell within the recommendations of ICMSF (1974). However, when rainfall occurred, *Escherichia coli* numbers increased and *Salmonella*e were isolated from lettuce surfaces (Bastos and Mara, 1995).

Experiments in the UK assessed the effect of irrigation with final effluent from a conventional treatment plant (10^5-10^6 FC/100ml). When furrow irrigation was used, the quality of lettuces in covered plots improved to acceptable levels (10^3 FC/100g) within 3 days of cessation of irrigation and were *E.coli* free after 9 days. However, results indicated that crops in uncovered plots were recontaminated with bacteria from contaminated soils after significant rainfall and regrowth of *E.coli* on crop surfaces was observed. Radishes were prone to low level long-term contamination with *E.coli* (up to 20 days).

These studies show that irrigating salad crops with effluent from conventional treatment works can result in unacceptable levels of bacterial contamination of crops (unless a period of cessation of irrigation occurs before harvest), whereas use of better quality effluents from WSP results in acceptable levels of bacterial contamination.

Studies in Israel have investigated the use of effluent from wastewater storage reservoirs in unrestricted irrigation of vegetable and salad crops (Armon et al, 1994). When vegetables were irrigated with poor quality effluent (up to 10^7 FC/100ml of eluant solution) high levels of faecal indicator bacteria were detected (up to 10^5 FC/100ml). However, when vegetables were irrigated with better quality effluent (0-200 FC/100ml) from a storage reservoir with a lower organic loading, faecal coliform levels on crops were generally less than 10^3 FC/100ml and often lower (the data presented do not allow for greater specificity about the levels) with a maximum of 10^4 FC/100ml. The authors concluded that it is necessary to treat wastewater effluents to an extent that no residual contaminants are detected on the irrigated crops, but their results could alternatively be interpreted as showing that use of treated wastewater meeting WHO (1989) guideline levels results in acceptable levels (ICMSF 1974) of bacterial contamination on crops.

5.2.1.2 Studies on contamination of vegetable crops with nematode eggs

Experimental studies in NE Brazil and Leeds UK, investigated the consumer risk of nematode infection (*Ascaris lumbricoides* and *Ascaridia galli* respectively) from wastewater-irrigated lettuces (Ayres *et al*., 1992; Stott *et al*., 1994). In Brazil, when raw wastewater (>100 nematode eggs/l) was used to spray-irrigate lettuce, harvested crops were contaminated with mean values of up to 60 eggs /plant after 5 weeks irrigation. Irrigation with effluent from the anaerobic pond of a series of waste stabilisation ponds (>10 eggs/l) reduced levels of nematode contamination on lettuce to around 0.6 eggs/plant at harvest and produced a better quality of lettuce than that sold in the local market. When facultative pond effluent (<0.5 eggs/l) was used for irrigation, no eggs were detected on crops. Lettuces irrigated with maturation pond effluent (0 eggs/l) were also not contaminated despite growing uncovered plants in heavily contaminated soil containing >1200 *Ascaris* eggs/100g indicating that neither irrigation nor rainfall resulted in recontamination of crops. Indeed, the quality of crops was significantly improved after clean water events. Irrigation with freshwater successfully removed small levels of contamination on crops whilst rainfall events significantly reduced levels of contamination on crops.

In the UK trials, spray-irrigation of lettuce with poor quality wastewater (50 nematode eggs/l) resulted in contamination of around 2.2 eggs/plant at harvest. Improving the wastewater quality to 10 eggs/l resulted in reduced levels of nematode contamination on lettuce to a maximum of 1.5 eggs/plant. When wastewater at the WHO quality of $\leq$ 1 eggs/l was used for irrigation, very slight contamination was found on a few plants at around 0.3 eggs/plant. However, no transmission of *A. galli* infection was found from wastewater irrigated crops using animal studies, although the infective dose is very low at less than 5 embryonated eggs.

The results collectively show that irrigation with wastewater of WHO (1989) guideline quality resulted in no contamination of lettuce at harvest (0.5 eggs/l) or very slight contamination on a few plants (6%) with eggs that were either degenerate or not infective. However, a few nematode eggs on harvested plants were viable, but not yet embryonated (20% *A. lumbricoides* on >100 eggs/l irrigated crops; <0.1 *A. galli* eggs/plant irrigated with 1-10 eggs/l) and so crops with a long shelf life can represent a potential risk to consumers as these eggs might have time to become infective.

These results are presented in more detail in Annex C.

5.2.2 *Evidence from risk assessment studies*

Asano and Sakaji (1990) used the risk assessment methodology described by Haas (1983) to estimate the risks of consumption of market-garden produce irrigated with water containing 1 enteric virus in 40 litres (the Arizona standard). An individual's annual risk of infection was between 10^{-4} (i.e. one case per 10,000 persons) and 10^{-8} (though when 100ml of such water is accidentally ingested the risk of infection is between 10^{-3} and 10^{-7}). Asano et al (1992) estimated the risk of infection with 3 enteric viruses (poliovirus1 and 3, echovirus 12) related to use of *chlorinated tertiary effluents* and four scenarios of exposure to wastewater; (i) irrigation of market-garden produce, (ii) irrigation of golf courses, (iii) recreational uses of water and (iv) groundwater recharge. They used estimates of the amount of water ingested via the various scenarios, for example, 1 ml/day for 2 days per week all year by golfers handling and cleaning golf balls, 10ml per day for consumers of food crops. Allowance was made for viral reduction in the environment, for example, through stopping irrigation of crops 2 weeks before harvest. The annual risk of infection related to consuming irrigated market-garden produce was between 10^{-6} and 10^{-11} when the effluent contained one viral unit in 100 litres, and between 10^{-4} and 10^{-9} when water with a maximum concentration of 111 viral units/100 litres was used. The risk from the irrigation of golf courses is higher, between 10^{-2} and 10^{-5}. Even when *unchlorinated secondary effluents* were investigated (data taken from plants in California), risk assessment showed that for food crop irrigation and groundwater recharge, the annual risk of viral infection was less than 10^{-4} more than 95% of the time (Tanaka et al,1993). For golf courses, the risks are at acceptable levels when chlorinated secondary effluent (3.9 $\log_{10}$ removal) is used (10^{-4}-10^{-6}) but not when there is no chlorination (10^{-1}-10^{-2}). The estimated risks are higher when treated wastewater is used in recreational impoundments used for swimming.

More recently, Shuval *et al* (1997) used the drinking water model for infection risk developed by Haas *et al*. (1993) and combined this with laboratory data on the degree of viral contamination of vegetables irrigated with wastewater of various qualities. The annual risk of becoming infected with hepatitis A from eating cucumbers which had been irrigated with untreated wastewater was 10^{-3} but when the cucumbers were irrigated with treated wastewater containing $\leq$1000 FC per 100 ml the risk was 10^{-6} - 10^{-7}; for rotavirus infection the risk was 10^{-5} - 10^{-6}. Data from WSP in northeast Brazil (Oragui et al, 1987) suggests that rotavirus numbers are likely to be less than 30 per 100 litres when the faecal coliform content is below 10^{4} per 100ml. The results of these studies are therefore consistent with those obtained by Asano et al (1992).

6. Implications for wastewater reuse standards and policies in Mexico

Once the appropriate authorities have considered the public health and environmental risks, and adjusted standards for wastewater reuse in agriculture accordingly, appropriate treatment and intervention programs need to be re-enforced or initiated. The question, however, is whether the measures proposed are realistic for all Mexico or whether local conditions in many differing irrigation districts will to some extent dictate the health and environmental protection measures to be adopted.

The current microbiological standards NOM-001-ECOL-1996 (Table 3-2) were produced with the issues of public health, environmental protection, the needs of farmers and the technological and financial restraints of Mexico in mind. However the results of recent epidemiological studies in Mexico and elsewhere presented in this document, together with ever increasing financial pressures mean that it is now important to re-assess these standards.

In order to re-define wastewater reuse standards in Mexico, the appropriate approach to setting microbiological standards needs to be chosen. There are several possible approaches available which have different outcomes as their objective: -

I The absence of faecal indicator organisms in the wastewater - treat wastewater until there are no detectable faecal indicators. This has led to guidelines which require zero faecal coliforms/100ml. The USEPA/USAID (1992) guidelines have taken this approach,

II No measurable excess cases in the exposed population - that is there should be no risk of infection attributable to wastewater reuse. Such an approach uses scientific evidence, especially from epidemiological studies. Allowance can be made for local epidemiological, socio-cultural and environmental factors and the guidelines modified accordingly,

III A minimal risk which is below a defined 'acceptable' risk - a pre-defined level of risk of infection. For example, US-EPA (USEPA and USAID, 1992) accepts an annual risk of 10^{-4} for microbial contamination of drinking water, and drinking water is treated so that the risks do not exceed this level. Evidence from risk assessment approaches is applicable here, especially where the risks that are acceptable are below the level that can be measured in most epidemiological studies (unless extremely large populations are studied). Such assessments, as well as considering the costs to public health, take into account the social, legal and economic cost of achieving such levels.

IV Minimise disease among the exposed population i.e. consumers, agricultural workers and the population surrounding irrigation areas. Such an approach will aim to reduce disease rather than infection e.g. a specific reduction in mortality due to diarrhoea or in the number of hepatitis A cases hospitalised. Where economic constraints limit the level of wastewater treatment that can be provided, a country may choose disease control as the objective, where a certain risk of infection is accepted and the objective is to stop disease levels being reached, or where only the most vulnerable groups eg. young children, are protected. The implications of the studies are less clear, due to the paucity of disease data.

6.1 Implications for Unrestricted Irrigation Standards

6.1.1 Faecal coliform standard for unrestricted irrigation

There is no evidence, from the epidemiological studies reported here (section 4), nor other recent studies (section 5), to suggest that the Mexican faecal coliform standard for unrestricted irrigation (Table 3-2) of 10^3 FC/100ml (i.e. where crops eaten uncooked can be irrigated) is inadequate to protect the health of crop consumers. Studies from Mexico, in an area where enteric infections are endemic, suggest that consumption of vegetables irrigated with 10^4-10^5 FC/100ml results in significant, but low, enteric infection risks for consumers when the guideline is exceeded by a factor of 10 (Blumenthal et al, 1998, Blumenthal et al, 2000b). There was no risk associated with the total consumption of raw vegetables but consumption of onions, eaten by the majority of the study population, was associated with at least a two-fold increase in diarrhoeal disease. Microbiological studies also suggest that a guideline of $\leq 10^3$ FC/100ml is fine in hot climates, where crops irrigated with water just exceeding the guideline value fell within the quality recommendations of ICMSF (1974) (Vaz da Costas Vargas et al, 1996). Recontamination of crops in uncovered plots after significant rainfall, however, suggests that a stricter guideline may be necessary in countries where significant rainfall occurs during the growing season.

However, risk assessment studies in Israel (Shuval et al, 1997) have indicated that the annual risk of enteric virus and bacterial infection from eating lettuce irrigated with water meeting the WHO Guideline level ranges from 10^{-5} (rotavirus) and 10^{-6} (hepatitis A virus) to 10^{-9} (cholera). Data from risk assessment in the USA (Asano et al, 1992) support these conclusions, finding the annual risk of infection from enteric viruses was between 10^{-4} and 10^{-9} when water with a maximum viral concentration of 111 units per 100 litres was used to irrigate market garden produce. Data from waste stabilisation ponds in northeast Brazil (Vaz da Costa Vargas S et al. 1996) suggest that rotavirus numbers are likely to be less than 30 per 100 litres when the faecal coliform content is below 10^4 per 100ml. However, other enteric viruses such as adenovirus may significantly outnumber rotaviruses and enteroviruses, possibly by an order of magnitude (Bastos RKX, Mara DD). It can therefore be extrapolated from these data that use of water meeting the WHO guideline level of 1000 FC per 100 ml is likely to produce an annual risk of viral infection of less than 10^{-4}. Since the US microbial standards for drinking water are based on the criteria that human populations should not be subjected to the risk of infection by enteric disease greater than 10^{-4}, then the WHO (1989) wastewater reuse guidelines would appear to offer a similar level of protection. Furthermore, additional treatment to a FC level more stringent than 1000 per 100 ml is not cost effective, for example, Shuval et al*.* (1997) showed that the cost per case of hepatitis A avoided by irrigation with zero FC per 100 ml (as recommended by USEPA and USAID, 1992), rather than with 1000 FC per 100 ml, was of the order of US$ 3-30 millions.

Therefore both the Mexican standards and WHO guidelines are clearly adequate to protect the health of consumers within the irrigation areas (where enteric infections are endemic) and the much larger urban consumer populations (where enteric infection rates are lower).

6.1.2 Nematode egg standard for unrestricted irrigation

Evidence from epidemiological and microbiological studies (sections 4 and 5) suggests that the Mexican nematode egg standard of <1 ova/litre (Table 3-2) is not adequate to protect the health of consumers. Mexican studies indicated an increased risk of *Ascaris* infection among consumers of wild vegetables surface-irrigated with effluent from one reservoir which had <1 ova/litre (Peasey, 2000). Studies of lettuces irrigated with water containing ≤1 ova/litre (mean maximum temperatures exceeding 28°C) showed they were not contaminated or had only a minimal level of contamination at harvest with viable eggs. However, since a few eggs on the harvested plants were viable, crops with a long shelf life represent a potential risk to consumers. The difference in the epidemiological and microbiological results may have been influenced by the irrigation method, and the lower mean temperature (due to high altitude and semi-desert conditions).

It would be prudent, therefore, to adopt a stricter guideline of ≤0.1 ova/litre to prevent transmission of Ascaris infection in circumstances where conditions favour the survival of helminth eggs (lower temperatures, surface irrigation), and to allow for the risks to farmworkers involved in cultivating the vegetable crops (see below). In situations where crops with a short shelf life are grown in hot and dry conditions, and where workers are adequately protected from infection through direct contact with wastewater or soil, the original guideline of ≤1 ova/litre would appear to be adequate.

6.2 Implications for Restricted Irrigation Standards

6.2.1 Faecal coliform standard for restricted irrigation

The Mexican standards propose a faecal coliform standard of <10^3 FC/100ml for restricted irrigation.

Results from epidemiological studies in Mexico (section 4), in the USA (Camann et al 1988) and in Israel (Shuval et al 1989) support this faecal coliform standard for restricted irrigation. Data from USA and Israel suggest ≤10^5 FC/100ml would protect both agricultural workers and nearby populations from infection via direct contact or wastewater aerosols. However data from Mexico, in a situation where flood irrigation is used indicated that school children and adults in direct contact (during irrigation or play) with partially treated wastewater might still be at risk of enteric infection at a level of 10^3-10^4 FC/100ml. There was a significant excess of diarrhoeal disease in children aged 5-14 years, and a four-fold increase in seroresponse to Human Norwalk-like Virus/Mexico in adults with high levels of contact with the effluent from two sequential storage reservoirs (containing partially treated wastewater with 10^3-10^4 FC per 100ml) compared with those with no contact with this effluent (Blumenthal et al, 1998, Blumenthal et al, 2000b). There was also an excess of diarrhoeal disease in adults (OR=1.5) but this did not reach significant levels (p=0.12) probably due to sample size factors. WHO guidelines (1989) did not propose a faecal coliform standard for restricted irrigation due to the lack of evidence of a risk from bacterial and viral infections to agricultural workers and nearby residents. A faecal coliform level of 10^3 FC/100ml, as currently adopted by Mexico, would be advisable where large populations are at risk through agricultural work (especially where flood irrigation is used) and children are regularly exposed (see Annex F). This would also help to reduce the risks from epidemic infections which could be transmitted to effluent irrigating communities from an outbreak in the source community (Fattal et al, 1987).

Where there are insufficient resources to provide treatment to reach 10^3 FC/100ml, a guideline of 10^4 FC/100ml could be adopted, but should be supplemented by other health protection measures for children (for example, health education concerning avoidance of direct contact with wastewater, and the importance of handwashing with soap after wastewater contact).

6.2.2 Nematode egg standard for restricted irrigation

The Mexican nematode egg standard for restricted irrigation of ≤5 ova/l (Table 6-1) is not adequate to protect the health of agricultural workers and their families, especially children (under 15 years of age). This is particularly the case where wastewater treatment systems produce an effluent of variable quality, where the partially treated wastewater may be contaminated with small quantities of wastewater, and where children of farmworkers come into direct contact with the effluent. In such a situation in Mexico, children in contact with effluent from a storage reservoir with ≤1 ova/litre (even though it was contaminated with small quantities of raw wastewater) had increased prevalence and intensity of Ascaris infection. When the effluent had been stored in two reservoirs and no nematode eggs were detectable, there was very little excess Ascaris infection in any age group (Blumenthal et al, 1996, Cifuentes, 1998). Similar situations would arise where raw wastewater is allowed to bypass conventional treatment plants, especially during periods of peak flow, allowing untreated wastewater containing nematode eggs (where nematode infections are endemic) into the effluent that is reused for agriculture. Since this is often the case in reality, a stricter guideline of ≤0.1 eggs per litre is required for restricted irrigation where children are exposed to irrigation water. This would also be useful in circumstances where stable treatment systems, such as WSP are in use, and workers may come into contact with the soil, since egg levels are in soil can build up to high levels.

As with all standards, authorities must decide the risk approach to be adopted i.e. whether their objective is to remove excess risk, reduce risk or minimise morbidity. For example, if the public health objective in this endemic region is to remove excess risk then a standard of ≤0.1 ova/litre would be advisable. However a standard of ≤1.0 ova/litre would be sufficient where children do not come into direct contact with wastewater.

6.3 Implications for a Disease Control Approach

Where economic constraints limit the level of wastewater treatment that can be provided, a disease control approach could be adopted, where a certain risk of infection is accepted and the objective is to reduce disease levels, or where only particular target groups eg. young children, are protected.The implications of the studies are less clear, due to the paucity of disease data, and are discussed below.

6.3.1 Unrestricted irrigation

If the objective is to prevent clinical enteric disease (and not enteric infection), the studies in Mexico suggest that it may be possible to set a *faecal coliform guideline* for unrestricted irrigation of 10^4 FC/100ml in areas where enteric infections are endemic, immunity to viral infections exists and crops are only eaten locally. At this level, the serological studies in Mexico suggest there was transmission of viral infection but do not necessarily reflect a significant increase of disease. Risks of diarrhoeal disease were related to the consumption of onion and green tomato but not of other crops. If the guideline were set at this level, crop restrictions could be added e.g. to prevent growing of onion. However, it may be prudent to keep the guideline at 10^3 FC/100ml in order to (i) prevent the spread of infections causing national epidemics being transmitted to rural communities through sprinkler irrigation of partially-treated wastewater (Fattal et al, 1987), and (ii) grow crops which may be exported to countries where enteric infections are not highly endemic. A relaxation of the nematode egg guideline for unrestricted irrigation of $\leq$1 nematode egg/litre to 10 eggs/litre may be considered to be adequate if the goal is to prevent high intensities of helminth infections (worm load) rather than infection itself.

6.3.2 Restricted irrigation

In highly endemic areas, if the objective were to prevent enteric disease in the vulnerable children (under 5's) and not necessarily in older children, a faecal coliform guideline of $\leq 10^{\mathbf{5}}$ FC/100ml would be adequate. Contact with wastewater containing 10^5 FC/100ml led to increased diarrhoeal disease in older children and not young children (Cifuentes et al, 1993; Annex C Table C1 section b). School-aged children involved in farming activities would need to be protected using other measures, and children discouraged from playing in the fields. Where there is a difficulty in doing this, a relaxation of the guideline would not be recommended.

Where the goal is to prevent high intensities of helminth infections, it is conceivable that a less strict nematode egg guideline and additional health protection measures could be used. In Mexico, the current standard for restricted irrigation is 5 eggs/litre, designed to be achievable by conventional treatment plants. There is currently no epidemiological evidence, however, on which to base such a relaxed guideline. In fact, data from Mexico suggest that intensities of infection in school-aged children are as high when they are exposed to wastewater of $\leq$1 egg/litre as to raw wastewater suggesting that a stricter standard is necessary if treatment is the only health protection measure used. It is possible that a relaxed guideline could be used if it is supplemented by other measures, such as twice yearly de-worming chemotherapy for school-aged children (who have the highest intensity infections). This would only be suitable in countries where the infrastructure exists to mount anti-parasite campaigns that can be succesfully extended to cover areas where wastewater is used in agriculture. Disease control would be dependent on chemotherapy regularly reducing intensities of infection, which can easily return to pre-treatment levels after 6 months.

6.4 Proposed Standards for Mexico

Based on the results of the Mexican and other recent studies discussed above, the changes proposed in the Mexican standards for wastewater reuse in agriculture are displayed in Table 6-1, together with the current WHO Guidelines (1989). These proposals are considered to be neither technically nor financially testing for Mexico. In the following sections, options for achieving these standards are discussed, including the use of waste stablisation ponds (WSP) alone or in conjunction with storage reservoirs. Such systems do not require the investment needed for conventional treatment, nor highly qualified technical personnel to maintain them. The importance of implementing other health measures as well as treatment is also discussed. The proposed guidelines can be achieved through conventional or non-conventional treatment processes. For example, effluent complying with the unrestricted guideline of 10^3 FC/100ml and 0.1 ova/litre can be achieved through well-designed series of waste stabilization ponds (WSP), sequential batch-fed wastewater storage and treatment reservoirs (WSTR) or equivalent treatment (e.g. conventional secondary treatment supplemented by either polishing ponds or filtration and disinfection).

Table 6-1. Proposed changes to Mexican Standard NOM-001-ECOL-1996

Irrigation	Mexican Standards		Proposed standards for Mexico		WHO Guidelines	
	FC/100ml	ova/litre	FC/100ml	ova/litre	FC/100ml	ova/litre
Restricted	$\leq 10^3$	≤ 5	$\leq 10^3$-10^4	≤ 0.1-1.0	Not required	≤1
Unrestricted	$\leq 10^3$	≤ 1	$\leq 10^3$	≤ 0.1-1.0	$\leq 10^3$	≤1

Note : Where there are a range of standards, the level of acceptable risk to health will determine the standard adopted

6.5 Implications for Health Protection

6.5.1 Wastewater treatment

A full discussion of wastewater treatment methods appropriate to meet the proposed revised guidelines for wastewater reuse is given in Annex E. The main points are summarised here.

When wastewater is treated with the intention of using the effluent for agricultural irrigation and not disposal in receiving waters, the important quality criteria are those relevant to human health and the needs of the farmer rather than environmental criteria and those related to the well-being of aquatic life in receiving waters. In health terms, faecal coliform removal and nematode egg removal are more important than the removal of biodegradable organic compounds (eg BOD removal). Additionally for the farmer, the volume of suspended solids, and nutrients such as nitrogen and phosphate are important, because this increases top soil and reduces the need to apply fertilizers.

In many situations, the wastewater treatment option of first choice is waste stabilization ponds (WSP). The advantages of WSP are low cost, simplicity of construction, operation and maintenance, no energy costs, high ability to absorb organic and hydraulic loads and high efficiency especially with respect to the removal of nematode eggs and faecal bacteria. In tropical and subtropical regions, properly designed WSP (Mara, 1997; Mara & Pearson, 1998) can easily meet the WHO helminthological and bacteriological quality requirements for both restricted and unrestricted irrigation (Table 6-2). Many existing WSP do not achieve these qualities (Maynard et al 1999), but they may not have been so designed or are overloaded or poorly maintained. Pond systems incorporating anaerobic, facultative and maturation ponds, with an overall average retention time of 10-50 days (depending on the ambient temperature), can produce effluents in line with WHO guidelines (Hespanhol I. 1997). There can be problems with groundwater contamination, increased soil salinity, an increase in parasite vectors and smells. However these are usually a result of inappropriate initial planning and poor operation and maintenance. Oxidation ditches are generally the next best option, depending on the cost of land (see Arthur, 1983), but do not meet the microbiological requirements for agricultural reuse unless supplemented by tertiary treatment processes (which could include use of maturation ponds).

Land availability or the cost of land can limit the use of WSP, especially when dealing with effluent from large cities (population > 1 million), or in countries where lower temperatures mean that longer retention times, and therefore larger land areas, are required to meet the FC guideline for unrestricted irrigation. For example, for a flow of 1000 m^3 per day of a wastewater with a BOD_5 of 350mg/l and a faecal coliform count of $5x10^7$ FC/100ml, the total pond area required to produce an effluent containing $\leq$ 1000 FC/100ml would be 8,000 m^2 at 25^oC, 13,700 at 20^oC, and 25,400 at 15^0C.

Table 6-2. Mean annual performance of five waste stabilization ponds in series in northeast Brazil

Source (at 24-27^{o}C)	Retention (days)	BOD_5 (mg/l)	Suspended solids (SS) (mg/l)	Faecal Coliforms (per 100 ml)	Human intestinal nematode eggs (per litre)
Raw wastewater	-	240	305	4.6×10^7	804
Effluent from:					
Anaerobic pond	6.8[a]	63	56	2.9×10^6	29
Facultative pond	5.5	45	74	3.2×10^5	1
First maturation pond	5.5	25	61	2.4×10^4	0
Second maturation pond	5.5	19	43	450	0
Third maturation pond	5.8	17	45	30	0

Source: Mara and Silva 1986

[a] Later work showed the same performance for BOD and SS removals at retention times of ~ 1 day (Silva 1982)

Wastewater storage and treatment reservoirs (WSTR) are particularly useful in arid and semi-arid regions where agricultural production is limited by the quantity of water, including treated wastewater, for irrigation, since WSTR permit the whole year's wastewater to be used for irrigation, rather than just that produced during the irrigation season. Examples of WSTR exist in Israel (Shuval et al 1986), Brazil and Mexico. Recent research in Brazil has shown that sequential batch-fed WSTR's (in pilot scale) can remove faecal coliforms to less than 10^3 FC/100ml by three weeks into the rest phase (Mara et al, 1996), whereas single WSTR in Israel produce an effluent suitable for restricted irrigation. In the Mezquital valley, Mexico there are a series of sequential storage reservoirs. The first reservoir achieves a 2 to 4 log_{10} unit reduction in faecal coliform levels, from 10^{10}-10^{11} FC/100ml to 10^6-10^8 FC/100ml depending on the season (A. Peasey unpublished data). The effluent from the second reservoir has a mean quality of 10^3 FC/100ml, the quality varying depending on the retention time which varies according to irrigation demand (Cifuentes, 1995).

In situations where conventional treatment is being considered, it is essential to assess the cost of operation, maintenance and personnel training, all of which are considerably higher than for non-conventional treatment systems. Conventional wastewater treatment systems (such as activated sludge, trickling filters) are not good at removing faecal bacteria; at best they can achieve only a 2 log_{10} unit reduction of faecal coliforms, so they do not meet the microbiological requirements for agricultural reuse unless supplemented by tertiary treatment. Due to the retention time in primary and secondary sedimentation they are better at removing helminth eggs. A combination of advanced primary treatment (APT) and sand filtration has been shown to achieve required helminth removal, however an additional disinfection step is necessary to achieve faecal coliform standards (Jimenez-Cisneros B et al 1997). The particular case of Mexico city prompted investigations into alternative methods of filtration, instead of sand filtration. One of the areas designated for the proposed macro treatment plants has compressible organic clay, making the ground extremely unstable. Subsequent studies (Jimenez B et al 1999, in press) have demonstrated the advantages of synthetic medium filtration (Fuzzy filter®) over sand filtration, when in combination with APT. These included a reduction in backwashing and increased production rates, apart from the obvious reduction in space required. Maturation ponds (sometimes called "polishing" ponds in this context) can be used to upgrade conventional effluents prior to either restricted or unrestricted irrigation. Reservoirs can also be used for this purpose e.g. in the USA, reservoirs have produced a 2 to 3 $\log_{10}$ reduction in faecal coliform levels in trickling filter effluent, from 10^6 to 10^3-10^4 FC/100ml (Moore et al, 1988).

Where conventional treatment is opted for, treatment of the excess sludge must be considered. Treatment of excess sludge from conventional treatment plants provides a valuable source of plant nutrients. Organic and inorganic contaminants as well as pathogens are concentrated in the excess sludge, where helminth eggs can survive and remain viable for nearly 12 months. Therefore handling of the sludge requires care, to protect both workers and consumers. Sludge can be injected into subsoil or placed in furrows and covered with a layer of earth before the planting season and no tuberculous crops planted along such trenches. Alternatively there are a variety of treatment methods to make sludge safe including storage for 6-12 months at ambient temperature in hot climates, anaerobic digestion and forced-aeration co-composting of sludge (Hespanhol, 1997).

It is important when defining wastewater treatment policies to remember that treatment is not the only measure available to protect health; crop selection and restriction, wastewater irrigation techniques and human exposure control are equally important health protection measures. These non-treatment options should be considered as part of the initial response to health protection where wastewater irrigation policies are being proposed or modified. Often authorities opt to just treat the wastewater, as this seems a more straightforward and visible measure, rather than implementing an integrated approach to health protection.

6.5.2 Crop restriction

Crop selection and restriction is employed in conjunction with wastewater treatment so that lower quality effluents can be used to irrigate non-vegetable crops. Although this appears simple and straightforward, in practice it is often difficult to enforce. It can only be done effectively where there is a strong institutional framework controlling wastewater use, with the capacity to monitor and ensure compliance, where there is adequate demand for the crops allowed under crop restrictions and they fetch a reasonable price and where there is little market pressure in favour of excluded crops. Even where crop restriction is implemented successfully, a small percentage of farmers will fail to comply. It is not effective to control health risks from indirect reuse, where wastewater-contaminated surface waters are used directly by the farmers and do not come under the control of public bodies. Much unrestricted irrigation actually uses wastewater-contaminated surface waters rather than wastewater itself (either untreated or treated) and constitutes a particular challenge to the regulatory and public health authorities.

Several examples of crop restriction exist in Latin America, including Mexico, Chile and Peru, and of the probable benefits derived from its enforcement. Circumstantial evidence comes from Chile, where until 1992, wastewater from the city of Santiago was used to irrigate salad crops and vegetables. However following a national campaign to prevent and control cholera, crop restriction was enforced, together with a general hygiene education program. The result was a reduction by over 90% in cholera cases attributable to the consumption of salad crops or vegetables (Monreal 1993).

6.5.3 Irrigation technique

The irrigation technique has an effect on the health risks associated with using effluent of a particular microbiological quality. In general, health risks are greatest when spray or sprinkler irrigation is used, as this distributes contamination over the surface of crops and exposes nearby population groups to aerosols containing bacteria and viruses. This technique should be avoided where possible, and if used, stricter effluent standards should be applied as suggested by WHO (Table 1-1). Flood and furrow irrigation exposes field workers to the greatest risk, especially if earth moving is done by hand and without protection, as is often the case in the Mezquital Valley in Mexico. Furrow irrigation in many cases does not protect the crop from direct contact with the wastewater, as is the case with chillies, where the plants bow down under the weight of the chillies, dipping the chillies into the irrigation water. Localised irrigation (inc. drip, trickle and bubbler irrigation) can give the greatest degree of health protection by reducing the exposure of workers to the wastewater. A period of cessation of irrigation before harvest (≥8 days) can allow die-off of bacteria and viruses such that the quality of irrigated crops improves (Castro de Esparza and Moore, 1990). This is particularly effective in hot and dry conditions. However, compliance is hard to ensure, especially where the value of salad crops depends on their looking fresh at market. Replacing partially-treated wastewater with fresh water for a week or so before harvest is not a reliable way of improving crop quality since re-contamination of the crops from the soil has been found to occur (Kopshitz and Mara, 1992).

6.5.4 Human Exposure Control

The groups potentially most at risk from wastewater reuse in agriculture are the farmworkers, their families, crop handlers, consumers of crops, and those living near wastewater-irrigated areas. The approach required to minimise exposure depends on the target group.

Farmworkers and their families have higher potential risks of parasitic infections. Protection can be achieved by low-contaminating irrigation techniques (as above), together with protective clothing (eg footwear for farmers and gloves for crop handlers) and improved levels of hygiene both occupationally and in the home which help to control human exposure. Provision of adequate water supplies for consumption (to avoid consumption of wastewater) and for hygiene purposes (eg for handwashing) is important. Hygiene promotion could possibly involve agricultural extension services as well as health authorities where wastewater reuse occurs. For example in Peru, only a few out of more than 5000 farmers irrigating with wastewater try to avoid direct contact with the water and wash their hands after irrigating. Sanitary regulations stipulate that it is the responsibility of the wastewater user to protect the health of workers, however in practice this only applies to treatment plant workers, where the use of boots and gloves is required and the consumption of water from the ponds prohibited (Moscoso 1994). Consumers can be protected by cooking vegetables, high standards of personal and food hygiene, health promotion campaigns and ceasing irrigation of fruit trees at least 2 weeks before fruit is picked.

Human exposure control may be achieved through carefully planned Community Intervention Programs involving a multidisciplinary team, which includes health professionals, anthropologists and educators. Such programs could include (1) sensitisation of the farm worker population, their families and the nearby population to the possible risks from contact with wastewater, (2) regular medical attention at local health centres and through household visits, (3) organisation of bi-annual desparasitation campaigns for at-risk age groups, or (4) promotion of a few specific hygiene behaviours over a long period of time. Hygiene behaviours such as hand-washing with soap after work, after going to the toilet and before eating and safe disposal of excreta could possibly be addressed.

In Mexico, the infrastructure already exists for such intervention programs. The Council of Epidemiological Monitoring collates helminth incidence rates from health care facilities across the country. They had noted that the Mezquital Valley had above average incidence rates of Ascaris (personal comm. Dr. E. Garcia Rodriguez). The National Vaccination Council (NVC) carries out de-worming campaigns among 2-14 year olds in previously designated high-risk areas, and health education programs for women. The de-worming campaigns could be extended to wastewater reuse areas, and the value of mass de-worming campaigns in these regions considered. In a new initiative, women's clubs have been created at health centres, to promote health education, since past health education campaigns have not produced the expected results. For example, a recent census indicated that less than 50% of mothers of infants could identify the warning signs for dehydration (NVC 1997). The women's clubs could be used as a focal point to sensitise mothers to the risks from contact with wastewater. It would be beneficial to involve the National Water Commission and the Ministry of Education in such intervention programs. While children have been shown to be most at risk, the risks to adults also need to be addressed. Extension services within the National Water Commission could be employed to sensitise farmers to the risks from contact with wastewater, together with suggestions for reducing contact. The promotion of specific protective hygiene behaviours is generally now thought more effective when tackled separately from disease and risk. Studies have demonstrated that such behaviours are more easily and efficiently modified for social and cultural reasons, rather than through a fear of possible illness (Curtis et al, 1998). Such a campaign could be promoted jointly by the Ministry of Health, the Ministry of Education, and the National Water Commission. The effectiveness of current promotional techniques in environmental health, however, is not very encouraging, as few have had an impact on behaviour change or health status (Cave and Curtis, 1999). Better intervention design is needed and only a few specific behaviours should be targeted. Behaviour change can be slow and require intensive or prolonged intervention.

6.6 Implications for Policy

This document discusses the policy issues for wastewater reuse in agriculture in Mexico in the light of results from recent epidemiological studies. The problems experienced in Mexico, however, are not unique, but do give an excellent example of how developing countries can proceed forward, and take full advantage of wastewater as a valuable resource. A properly developed policy framework is essential in the management of water resources (Larson et al. 1997). Too many countries have omitted wastewater from legislation, or only consider issues of environmental degradation, water resource management and public health within their respective ministries. It is essential that a coherent policy framework, covering all aspects of wastewater be developed. One long-term goal should be introduction of pollution prevention based policies rather than treating the symptoms of pollution. The principle of "the polluter pays" is essential in the long term if this is to be achieved. Only through economic measures will industry gradually be induced to treat discharges, as in the example of legislation in Mexico. Realistic standards and regulations are essential. If standards are not achievable and regulations not enforceable, then there will be indifference towards them. In Mexico, current standards were adopted in the light of economic and technological constraints of conventional treatment processes. This decision was perhaps influenced by the special case of Mexico city, where alternative treatment processes were not considered practicable. However authorities in Mexico should perhaps consider standards in a broader panorama, since WSPs are a feasible option for much of the Mexican republic. Where economic, technological and administrative constraints determine standards, alternative health protection measures must be implemented alongside partial treatment. Such an integrated approach to health protection is essential. Application of single isolated measures will not provide full protection to at-risk groups. For example, crop restriction alone will only protect consumers; worker risks will remain unless supplementary measures to reduce worker exposure are taken.

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Annex A

The History of Wastewater Reuse Policy in Mexico

Microbiological standards for wastewater reuse in agriculture have developed considerably in Mexico over the last 10 years (Table 3-1, page 11). Standards for wastewater reuse take into account the General Law for Ecological Balance and Environmental Protection (1988). This states that in order to utilize or take advantage of wastewater, the technical and ecological guidelines of the Ministry of Urban Development and Ecology (SEDUE) must be conformed with.

In 1991, taking into account the General Law of Ecological Balance de Environmental Protection, the 1971 standards establishing the maximum permissible limits for physical and chemical parameters in urban or municipal wastewater destined for use in agricultural irrigation were revised by the then Ministry for Agriculture and Water Resources through the National Water Commission and by the Ministry for Health. In the text of the revised standard (NTE-CCA-032/91), a number of interesting statements were made:

(1) that untreated urban and municipal wastewater was currently being used in agricultural irrigation, and more importantly that a significant proportion relates to cultivation of vegetables and other crops eaten raw;

(2) that reuse of urban or municipal wastewater in agriculture could be considered a form of wastewater treatment and disposal;

(3) that the limits set could be achieved through one or a combination of treatment processes, including waste stabilization ponds, sedimentation, aeration, filtration, coagulation or anaerobic treatment.

The standard listed 17 physical and chemical parameters requiring monitoring. It gave SEDUE the ability to make stricter limits and to include certain additional parameter limits, including faecal coliforms, should it be shown that they were associated with public health or environmental risks. One month later, SEDUE produced a specific microbiological guideline NTE-CCA-033/91 to complement the NTE-CCA-032/91 guideline. The statements made in NTE-CCA-032/91 were reiterated and several additional issues addressed including:

(4) to prevent ecological damage and protect public health it is necessary to control the bacteriological parameters of wastewater and of national waters containing wastewater;

(5) since the wastewater is predominantly urban or municipal, the microorganisms are pathogenic and could affect the health of the general public and those in contact with the wastewater;

(6) in order to determine the appropriate use of the wastewater it is necessary to consider bacterial content, type of crop, form of irrigation and the interval between irrigation and harvest.

Four microbiological qualities of wastewater were specified: - Type 1: <1000 TC/100ml + 0 ova/l, Type 2: 1-1000 FC/100ml + <= 1ova/l, Type 3: 101-100,000 FC/100ml and Type 4: >100,000 FC/100ml. The guideline then specified for each crop (Table A1), the form of irrigation, wastewater quality, and time interval between the last irrigation and the harvest (Table A2). Clearly the Mexican authorities were well aware of the possible health risks associated with wastewater reuse in agriculture; however the standards adopted were complicated and it was difficult to ensure compliance.

Table A1. Restricted crops in standard NTE-CCA-033/91

Specified crops
Garlic, celery, beetroot, broccoli, onion, coriander, cabbage, cauliflower, spinach, mint, mushroom, lettuce, radish, carrot, and native greens (acelga, berro, epazote, papalo, quelites and quintonil), parsley, and cucumber. Courgette, red tomato and green tomato are exempt when grown on espaliers. Plus fruits: - strawberries, sweet turnip, melon, water melon and blackberries.

Table A2. Mexican standard NTE-CCA-033/91

Irrigation	Water quality	Interval between last irrigation and harvest (days)	Crops NOT permitted
Flood	1	20	All in Table A1, except for garlic, cucumber, sweet turnip, melon and water melon
	2	20	All in Table A1, except melon and water melon
	3	20	All in Table A1
	4	20	All in Table A1plus all vegetables and fruits in general
Furrow	1	15	All in Table A1, except for garlic, cucumber, green tomato, sweet turnip, melon and water melon
		20	All crops allowed
	2	20	All in Table A1, except for garlic, cucumber, sweet turnip, green tomato, melon and water melon
	3	20	All in Table A1, except melon and water melon
	4	20	All in Table A1, plus all vegetables and fruits in general
Sprinkler	1	20	All in Table A1, except for garlic, cucumber, sweet turnip, melon and water melon
	2,3,4	20	All in Table A1, plus all vegetables and fruits in general

In 1992, the procedure for establishment of standards was altered with the introduction of the Federal Law for Metrology and Regulation (1992) and the National Waters Law (1992). As a result the 032 and 033 standards were reviewed. Many of the chemical parameter limits were considerably relaxed in the revised standard, NOM-CCA-032-ECOL-1993, however the microbiological standard NOM-CCA-033-ECOL-1993 was not altered, except for the addition of gherkins and green beans to the list of restricted vegetables; however chillies continued to be omitted from the list of restricted crops, despite their being commonly eaten raw in Mexico.

These microbiological standards were revised in 1996 (Table 3-2, page 12), and were included within the current standard NOM-001-ECOL-1996 "that establishes the maximum permissible limits of contaminants in wastewater to be discharged into national waters and onto national soil".

This was part of a major reorganisation of standards for industrial and domestic discharge into national waters and soils. Previously 44 separate standards existed, the majority of which governed discharges from municipal drains, hospitals, factories and food and drink manufacturers. For example, one standard set down the maximum limits of numerous parameters for any wastewater destined for reuse in agriculture, while another standard determined the bacteriological limits for municipal wastewater used in salad crop or fruit irrigation. This array of regulations depending on the source of the wastewater, each with their own parameter limits made regulation virtually impossible. After an initial revision of these 44 previous standards by the Department of Basic Engineering and Technical Standards within the National Water Commission, a proposal was presented to the National Institute of Ecology for review and approval. There were 12 governmental departments, 15 private sector groups or 1 academic institution represented on the subcommittee responsible for the creation of the current standard (NOM-001-ECOL-1996).

The new standard, with a single set of parameter limits regardless of the discharge source, was designed to be achievable with the technology and resources available at present and in the near future in Mexico and to be more realistically policed, by reducing the amount of monitoring required. The limits imposed within the standard were designed to be sufficient to protect at-risk groups according to currently available literature. Revision of many possible treatment processes, resulted in the proposed microbiological standards. A stricter helminth standard would have required conventional treatment plants to use filters and this would carry significant financial implications (personal comm. Ing E.Mejia). Some on the subcommittee would have liked the standard to have been stricter, but it was generally agreed that this was not practical, with the technology and resources available. The standard is aimed to be workable, understandable, compact and clear for the general public. Its main objective being to reduce microbial and chemical contamination of rivers, lakes, aquifers and other water sources.

As well as stipulating microbiological standards for wastewater destined for agricultural irrigation, the standard also imposed limits for wastewater disposed of through discharge into rivers and other water sources. The limits imposed are the same as for restricted irrigation i.e. a daily mean of no more than 2000 FC/100ml and a monthly mean of no more than 1000 FC/100ml. Municipalities and industry were given time limits for compliance with the standard (Table A3), and the discharger was given 6 months, following publication of the new guideline, to present a plan of action to ensure compliance with the standard within the stated time-scale.

Table A3. Time limits for compliance with NOM-001-ECOL-1996

Source	Population	Discharge characteristics		Limit for compliance
		BOD (10^3kg/day)	TSS (10^3kg/day)	
Municipal	>50,000	NA	NA	1st Jan 2000
	20,001-50,000	NA	NA	1st Jan 2005
	2,501-20,000	NA	NA	1st Jan 2010
Non-municipal	NA	> 3.0	> 3.0	1st Jan 2000
	NA	1.2 - 3.0	1.2 - 3.0	1st Jan 2005
	NA	< 1.2	< 1.2	1st Jan 2010

Apart from the standards, a technical manual providing guidance for efficient wastewater reuse was produced by the National Water Commission (CNA 1998), which recommends consideration of several factors prior to wastewater reuse for crop irrigation: - (i) the quality of the wastewater in terms of salts, toxic ions, heavy metals, bacteria and pesticide residuals, (ii) the type of crops, (iii) the method of irrigation, (iv) the soil characteristics, (v) the possibility of groundwater contamination, (vi) whether there are sites for receiving any excess wastewater, (vii) location of nearby communities and (viii) environmental impact. The manual also provides more detailed specifications of permitted crops according to the quality of the wastewater (Table A4).

Table A4. CNA internal wastewater reuse standards

Irrigation	FC/100ml (NMP)	Helminth ova/litre	Crops permitted	Interval between last irrigation and harvest (days)
Restricted	$<10^5$	Not specified	Fodder, grains, seeds, fruit trees	20
Semi-restricted	10^3-10^5	Not specified	Rice, vegetables consumed cooked, vegetables consumed raw and with no wastewater contact	20
Unrestricted	$< 10^3$	<1	All crops, except salad crops or those without a skin and in contact with the soil and wastewater	15

There is currently a decentralisation of the irrigation districts to the water user organisations throughout Mexico. The aim is to enable the water users to have greater control over irrigation plans, and to transfer many responsibilities from federal to state and municipal level, with the formation of state Water Commissions. In 1994, 38 irrigation districts had been transferred completely and 19 partially, leaving 26 irrigation districts still to be decentralised.

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Annex B

Summary of evidence supporting WHO guidelines for safe use of water in agriculture (1989)

Shuval et al (1986) reviewed all the available epidemiological evidence on the health effects of agricultural use of wastewater. Their main conclusions were reported in the technical report of the WHO Guidelines (1989). They are summarised here, with some supporting details.

1. Effects of use of untreated wastewater

1.1 Effects on farm workers or wastewater treatment plant workers

Use of untreated wastewater for crop irrigation causes significant excess infection with intestinal nematodes in farmworkers, in areas where such infections are endemic. In India, sewage farm workers had a significant excess of Ascaris and hookworm infections, compared with farm workers irrigating with clean water (Krishnamoorthi et al, 1973). The intensity of the infections (number of worms per person) and the effects of infection were also higher eg. the sewage farm workers suffered more from anaemia, one of the symptoms of severe hookworm infection. There is some evidence that sewer workers may be at increased risk of protozoan infections such as amoebiasis and giardiasis (Dolby et al, 1980, Knobloch et al, 1983) but other studies have not found such an effect (Clark et al,1984). There is no reliable data on the impact on amoebiasis on farmworkers in contact with untreated wastewater.

Cholera can be transmitted to farmworkers if they irrigate with raw wastewater coming from an urban area where a cholera epidemic is occurring. This was the case in the outbreak of cholera in Jerusalem in 1970, where cholera is not normally endemic and the level of immunity to cholera was low (Fattal et al 1986).

There is limited evidence of increased bacterial and viral infections among wastewater irrigation workers or wastewater treatment plant workers exposed to untreated wastewater or wastewater aerosols. Sewage treatment plant workers from 3 cities in USA did not have excess gastrointestinal illness (compared to controls) but inexperienced workers had more gastrointestinal symptoms than experienced workers or controls (municipal workers); however, these were mild and transitory, and there was no consistent evidence of increased parasitic, bacterial or viral infections from stool examinations or antibody surveys (Clark et al, 1981). In a follow up study, there were no excess seroconversions to Norwalk virus or rotavirus in the inexperienced workers with gastroenteritis, but inexperienced workers had higher rates of antibody to Norwalk virus (Clark et al, 1985).

1.2 Effects on consumers of vegetable crops

Irrigation of edible crops with untreated wastewater can result in the transmission of intestinal nematode infections and bacterial infections. The transmission of Ascaris and Trichuris infections through consumption of wastewater irrigated salad crops has been demonstrated in Egypt (Khalil, 1931) and Jerusalem (Fattal et al, 1994), where the infections fell to very low levels when wastewater irrigation was stopped.

Transmission of cholera can occur to consumers of vegetable crops irrigated with untreated wastewater, as during the outbreak of cholera in Jerusalem in 1970. It appears that typhoid can also be transmitted through this route, as seen in Santiago, Chile, where the excess of typhoid fever in Santiago compared with the rest of Chile, and in the summer irrigation months, has been attributed to irrigation with river water containing untreated wastewater (Ferrecio et al, 1984, Shuval et al, 1986). In both cases, transmission has occurred in communities with relatively high sanitation levels where transmission through common routes such as contaminated drinking water and poor personal hygiene is minimal.

Cattle grazing on pasture irrigated with raw wastewater can become heavily infected with the larval stage of the tapeworm *Taenia saginata* (Cysticercus bovis), as has occurred in Australia. There is no epidemiological evidence of human infection through the consumption of raw or undercooked meat from such cattle, but the risk of infection through this route probably exists.

Many outbreaks of enteric infection have been associated with faecally contaminated foods, but of the very few which were associated with wastewater irrigation, untreated wastewater was used in all but two cases (Bryan, 1977).

2. Effects of use of treated wastewater

2.1 Effects on farm workers or nearby populations

There is very limited risk of infection among workers using partially treated wastewater for irrigation. At Muskegon, USA, workers exposed to partially treated wastewater (from aeration basins and storage lagoons) had no increase in clinical illness or infection with enteroviruses. Only highly exposed workers (nozzle cleaners) had excess antibodies to one enterovirus but no seroconversion and no excess in clinical illness (Linneman et al, 1984).

Sprinkler irrigation with partially treated wastewater can create aerosols containing small numbers of excreted viruses and bacteria but there is no conclusive evidence of disease transmission through this route. Several studies in kibbutzim in Israel have addressed this question. Here, wastewater is partially treated in oxidation ponds before use for irrigation. The first study (Katzenelson et al , 1976) suggested increases in salmonellosis, shigellosis, typhoid fever and infectious hepatitis in farmers and their families working on or living near fields sprinkler irrigated with effluent from oxidation ponds (retention 5-7 days), but the study was methodologically flawed. The second study (Fattal et al, 1986) found a twofold excess risk of clinical 'enteric' disease in young children (0-4 years) living within 600-1000m from sprinkler irrigated fields, but this was in the summer irrigation months only, with no excess illness found on an annual basis. The third study (Fattal et al, 1986 and Shuval et al, 1989) found that episodes of enteric disease were similar in kibbutzim most exposed to treated wastewater aerosols (sprinkler irrigation within 300-600m of residential areas) and those not exposed to wastewater in any form. The wastewater was partially treated in ponds with 5-10 days retention reaching a quality of 10^4-10^5 coliforms/100ml. No excess of enteric disease was seen in wastewater contact workers or their families, as well as in the general population living near the fields. This prospective study is considered conclusive, having a superior epidemiological design.

However, it does seem that transmission of enteric viral pathogens to populations living near fields sprinkler irrigated with partially treated wastewater can occur under some circumstances, though this may not result in significant excess clinical infection. In a seroepidemiological study associated with the third Israeli study (Fattal et al, 1986 and Shuval et al, 1989) the results suggested that a nonendemic strain of ECHO 4 virus, which was causing a national epidemic in urban areas, was transmitted to rural communities through aerosols produced by sprinkler irrigated of wastewater, though no excess clinical disease was detected (Fattal et al ,1987). The fact that no similar excess of the other viral antibodies studied was found suggests that exposure to wastewater aerosols does not lead to an excess in enteroviral infection under nonepidemic conditions.

2.2 Effects on consumers of vegetable crops

When vegetables are irrigated with treated wastewater rather than raw wastewater, there is some evidence from Germany that transmission of Ascaris infection is drastically reduced. In Berlin in 1949, where wastewater was treated using sedimentation and biological oxidation prior to irrigation, rates of Ascaris infection were very low, whereas in Darmstadt where untreated wastewater was used to irrigate vegetable and salad crops, the majority of the population was infected (Baumhogger,1949 and Krey,1949). Rates were highest in the suburb where wastewater irrigation was practiced, suggesting farm workers and their families were infected more through direct contact than consumption.

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ANNEX C

Epidemiological studies of wastewater reuse in Mexico

A series of epidemiological studies were conducted in Mexico to assess, firstly, the occupational and recreational risks associated with exposure to wastewater of different qualities, and secondly, the risks of consuming vegetable crops irrigated with partially treated wastewater. In the first set of studies, infections (from helminths, protozoa and diarrhoeal disease) in persons from farming families in direct contact (through irrigation or play) with effluent from storage reservoirs or raw wastewater, were compared with infections in a control group of farming families engaged in rain-fed agriculture. In the studies on consumer risks, infections with diarrhoeal disease, Human Norwalk-like Virus/Mx and *Enterotoxigenic E. coli (LT)* in persons from a rural population eating raw vegetables irrigated with partially treated wastewater were compared with infections in persons (in the same area) not eating these vegetables. Comparison was also made with infections in persons in a nearby area where vegetables were irrigated with borehole water. In all studies, the effects of wastewater exposure were assessed after adjustment for many other potential confounding factors (including socio-economic factors, water supply, sanitation and hygiene practices).

1. Study area

Raw wastewater coming from Mexico City to the Mezquital valley, Hidalgo, is used to irrigate a restricted range of crops, mainly cereal and fodder crops through flood irrigation techniques. Some of the wastewater passes through storage reservoirs and the quality of the wastewater is improved before use; this is equivalent to partial treatment. The effluent from the first reservoir (retention time 1-7 months, depending on the time of year) met the WHO guideline for restricted irrigation (category B), even though a small amount of raw wastewater enters the effluent prior to irrigation. Some effluent from the first reservoir passes into the second reservoir and is retained for an additional 2-6 months (>3 months of combined retention), and the quality improved further. Local farming populations are exposed to the wastewater and effluent through activities associated with irrigation, domestic use (for cleaning, not for drinking) and play. Part of the effluent from the first reservoir enters the river and is abstracted downstream to irrigate a large area of vegetable and salad crops, many of which are eaten raw; the river water is essentially partially treated wastewater. These crops are sold in the local markets and eaten by the rural populations in local villages, including those near the second reservoir. In a nearby area, vegetables were irrigated with borehole water.

2. Wastewater quality

Untreated wastewater contained a high concentration of faecal coliforms (10^6-10^8 FC/100ml) and nematode eggs (90-135 eggs per litre). Retention in a single reservoir reduced the number of helminth ova substantially, to a mean of = 1 eggs/litre (so meeting the WHO Guideline for restricted irrigation) whereas faecal coliform levels were reduced to 10^5 FC/100ml (average over the irrigation period) or 10^4 FC/100ml, with annual variations depending on factors such as rainfall. The concentration of helminth ova remained below 1 ova/litre (monthly monitoring) even after a small amount of raw wastewater entered the effluent downstream of the reservoir. Retention in the second reservoir reduced the faecal coliform concentration further (mean $4x10^3$ FC/100ml) and no helminth ova were detected. Faecal coliform levels varied over the year depending on the retention time in each reservoir which varied according to demand for irrigation water.

The geometric mean quality of the river water at the point where it is abstracted for use in irrigation was $4x10^4$ FC/100ml, with little variation occurring over the year. Enterovirus and hepatitis A virus were present for most of the year (95% and 69% monthly samples respectively), whereas rotavirus was detected during the peak months for rotavirus cases. Limited data on virus levels on crops at harvest showed that enterovirus was detected on all crops tested (onion, radish, lettuce, cauliflower and coriander) whereas hepatitis A virus was detected on lettuce, radish and onion (on which rotavirus was also detected).

3.1 Risks to workers related to restricted irrigation and effect of wastewater treatment

3.1.1 Exposure to raw wastewater

Exposure to raw wastewater over one year (following chemotherapy) was associated with a significantly increased prevalence (percentage) and intensity of *Ascaris* infection (mean egg load) in all age groups (Table A1 section a). Exposure was related to a 20 fold increase in infection in children (compared to the control group) and a 10 fold increase in adults (Blumenthal et al, 1996, Peasey, 2000). Increased morbidity, as shown by increased wheezing and difficulty in breathing, was detected among those with higher intensity infections. The specific behaviour which was most risky for adults was irrigating chillies (6 fold increase) which was done by furrow irrigation and involved earth moving, done by hand or by spade. For children, the most risky behaviour was eating local plants (irrigated with wastewater). Exposure to raw wastewater was shown to account for over 80% of *Ascaris* infection in the commmunity.

Table C1: Effect of direct contact with wastewater of different qualities on enteric infections

Infection	Age Group (years)	Odds Ratio	95% C.I.	p value
(a) Untreated Wastewater				
Ascaris[1]	2-14	19.41	6.93-54.39	<0.0001
	15+	10.01	4.00-25.02	<0.0001
Diarrhoea[2]	0-4	1.75	1.10-2.78	0.01
	5+	1.34	1.00-1.78	0.04
(b) Partially Treated (one reservoir)				
Ascaris[1]	2-14	13.89	4.94-39.08	0.030
	15+	2.71	0.96-7.65	<0.0001
Diarrhoea[2]	0-4	1.13	0.70-1.83	0.466
	5+	1.50	1.15-1.96	0.003
(c) Partially Treated (two reservoirs)				
Ascaris[3]	0-4	1.29	0.49-3.39	0.544
	5+	1.94	1.01-3.71	0.01
Diarrhoea[4]	0-4	2.00	0.75-5.32	0.38
	5-14	2.18	1.13-4.24	0.02
	15+	1.51	0.91-2.48	0.28
Human Norwalk-like Virus/Mexico[4]	1-4	0.60	0.44-1.54	0.54
	5-14	0.72	0.50-1.11	0.14
	15+			
	Level of Contact +	1.23	0.55-2.77	
	Level of Contact ++	4.21	1.62-10.96	0.0096

[1]Source: Peasey, 2000., Peasey et al, 2000a
[2]Source: Cifuentes, 1995., Blumenthal et al, 2000a
[3]Source: Cifuentes et al, 1994., Cifuentes, 1998
[4]Source: Blumenthal et al, 1998., Blumenthal et al, 2000b

Over 1.5 times as many young children (aged 1-4 yrs) exposed to raw wastewater had an episode of diarrhoeal disease (in the last two weeks) than in the control group (Table A1 section a) (Cifuentes, 1995, Blumenthal et al, 2000a). The increase was less in those aged 5-14 years (1.3 times). A small increase in infection with *Entamoeba histolytica* was seen in children aged 5-14 years, but this was probably not exclusively disease-causing amoebic infection (Cifuentes et al 1994). Rates of *Trichuris* and hookworm were very low and unrelated to wastewater contact.

3.2 Exposure to partially treated wastewater

Exposure over one year to wastewater which was retained in one reservoir resulted in a 14 fold increase in *Ascaris* infection in children (especially those aged 5-14 years) and a much smaller increase (3 fold) in infection in adults (Table C1 section b) (Peasey 2000 and Peasey et al, 2000). For adults, planting chillies was associated with increased infection. The intensity of *Ascaris* infection in adults was reduced to the level in the control group, but in children was similar to levels in the raw wastewater group (Table C2) (Blumenthal et al, 1996). Older children (aged 5-14 years) also had significantly higher rates of diarrhoeal disease (Table C1 section b) (Cifuentes, 1995, Blumenthal et al, 2000a)

Table C2: Intensity of infection (mean egg load in eggs per gram of faeces ± standard error of the mean).

Age Group (years)	*Ascaris* intensity in those exposed to:		
	Raw Wastewater	Wastewater retained in one reservoir	Control group
2-4	2,726 ± 1127 [a]	35 ± 20	0 ± 0
5-14	1,954 ± 513 [c]	2,110 ± 664 [b]	3 ± 2
≥15	638 ± 223	88 ± 47	197 ± 131

[a] = <0.05, [b] = <0.01 and [c] = <0.001 *Source: Blumenthal et al 1996*

When wastewater was retained in two reservoirs in series, direct contact with the effluent resulted in very little excess *Ascaris* infection in any age group (Cifuentes et al,1994). In those over 5 years, the prevalence was twice as high as in the control group, but the excess infection was less than 1% (Table C1 section c). Initially, it was found that there was no excess of diarrhoeal disease related to exposure with this water (Cifuentes et al, 1994, Cifuentes, 1998) compared to the level in the control group, where rain-fed agriculture was practised. However, in a later study, when children with contact with the effluent from the second reservoir were compared with children from the same population but with no contact with the effluent, a two-fold or greater increase in diarrhoeal disease in children aged 5-14 years, and a four-fold increase in seroresponse to Human Norwalk-like Virus/MX in adults with high levels of contact was found (Table C1 section c) (Blumenthal et al, 1998, Blumenthal et al, 2000b).

Retention of water in two reservoirs in series, producing water of average quality $4x10^3$ FC/100ml and no detectable nematode eggs, is therefore adequate to protect the children of farm workers from *Ascaris* infection but not against increased diarrhoeal disease.

3.3 Risks to consumers related to unrestricted irrigation

In the above studies, there was some evidence that eating local plants (wild greens such as spinaches) was associated with an increased risk of *Ascaris* infection in children (2-14 years) in families exposed to raw wastewater and to effluent from one reservoir.

Risks from bacterial and viral infections related to the consumption of specific cultivated vegetables (ie. courgette, cauliflower, cabbage, carrots, green tomato, red tomato, onion, chilli, lettuce radish, cucumber and coriander) and to total consumption of raw vegetables irrigated with partially treated wastewater (quality 10^4 FC/100ml) were investigated in a separate study. The results indicated that consumers of all ages had no excess infection with symptomatic diarrhoeal disease (Table C3), and no excess serological response (defined as 50% increase in antibody titre over one year) to Human Norwalk-like Virus/MX or enterotoxigenic *E. coli* related to their total consumption of raw vegetables, that is, the frequency of eating raw vegetables. (Blumenthal et al, 1998, Blumenthal et al, 2000b).

However, there was an two-fold or greater excess of diarrhoeal disease in those who ate increased amounts of onion compared with those who ate very little (Table C4). The effect was particularly seen in adults and children under 5 years of age. Similar results were found for the consumption of chillies.

Table C3: Effect of total consumption of raw vegetables on prevalence of diarrhoea (%)

5.2 Age Group (years)	No of days on which vegetables eaten during the last week				
	0	**1-2**	**3-5**	**6+**	**p value**
1-4	20.7	13.8	14.5	16.8	0.407
5-14	9.0	5.6	4.9	4.2	0.279
15+	5.5	3.6	3.8	4.7	0.047

Source: Blumenthal et al, 1998., Blumenthal et al, 2000

Data on the consumption of foods prepared from raw vegetables also supported these results, since foods containing chilli or onion were associated with increased infection. Frequently eating ‘salsa’ (chilli sauce) was associated with increased diarrhoea in adults and older children, an increased seroresponse to Human Norwalk-like Virus/Mexico and a significant rise in antibody titre to ETEC in children (1-14 years). Consumption of ‘picadillo’ (choppped onions, chilli and red tomato) by adults was associated with increased diarrhoea whereas frequent consumption of ‘guacamole’ was associated with a significant rise in antibody titre to ETEC in children (1-14 years). There were also higher levels of serological response to Human Norwalk-like Virus/Mexico in school-aged children who ate green tomato, but this effect was not seen in other age groups (Table C5). No excess serological response to enterotoxigenic *E. coli* was related to individual raw vegetable consumption; the increased seroresponse related to eating foods prepared from raw vegetables could be due to contamination introduced via the chillies, but it could also have been introduced during preparation and bacteria multiplied to reach an infective dose during storage.

Data on the source of vegetables show that the chillies eaten by the study population were grown in raw wastewater, so the risk of diarrhoea associated with eating chillies (Table C4 section b) was related to *raw* wastewater irrigation. Therefore, it is only the risks from eating onion and possibly green tomato that can be associated with using *partially-treated* wastewater for irrigation. However, since 83% of adults and 56% of children under 5 years of age ate onion more than once a month, the majority of the study population had a two-fold or greater risk of diarrhoea. Enteroviruses were found on onions at harvest, giving support to this epidemiological evidence.

In contrast, we have evidence that eating some other raw vegetables was associated with a decrease in diarrhoea. The evidence is strongest for eating carrots, which was associated with a 60% or greater reduction in diarrhoea in all age groups (Table C4 section c). Protective effects of 50% or greater were also related to eating red tomato, salad and the total amount of raw vegetables eaten by the older children. Consuming a high number of foods containing raw vegetables was also associated with a 75% reduction in seroresponse to Human Norwalk-like Virus/Mexico.

In summary, these results indicate that there is a year round potential for transmission of enteric infections through consumption of vegetable crops irrigated with water of quality 10^4 FC/100ml, and consumption of some vegetables is associated with a significant risk of enteric infection in consumers in the rural population studied. However, the risks associated with consumption of some vegetables, particularly onion, may be balanced by the protective effects associated with consumption of other vegetables.

In the communities studies, factors other than consumption of contaminated vegetables are equally or more important as risk factors or protective factors against these infections. In particular, there is evidence supporting the importance of hygiene behaviour; hand washing is protective against diarrhoea (symptomatic) and Human Norwalk-like Virus/Mexico, especially in adults and when soap is used (Table C6). There is also evidence of risk associated with drinking water from public supplies. Chlorination of drinking water supplies in the area is often inadequate such that the water is often effectively untreated. Prevention of contamination in the home is also important.

Table C4: Effect of consumption of specific raw vegetables on risk of diarrhoea

Age Group (years)	1.1.1 Consumption (times per week/month)	Odds Ratio	C.I.	P value
(a) Onion				
1-4	<4/month	1.00		
	4/month	3.80	1.24-11.68	
	>4/month	2.19	0.54-8.89	0.047
15+	<1/month	1.00		
	1-3/month	3.99	1.62-9.82	
	4/month	2.54	1.05-6.39	
	>4/month	2.24	0.88-5.71	0.007
(b) Chilli				
1-4	=4/month	1.00		
	>4/month	1.72	0.95-3.12	0.081
5-14	<1/month	1.00		
	1-3/month	1.84	0.72-4.70	
	1/week	1.40	0.53-3.69	
	2-4/week	0.63	0.22-1.75	
	>4/week	0.92	0.32-2.62	0.039
15+	<1/month	0.19	0.06-0.63	
	1-3/month	1.00		
	1/week	0.91	0.52-1.60	
	2-4/week	0.68	0.39-1.21	
	>4/week	1.55	0.91-2.64	<0.001
(c) Carrot				
1-4	0	1.00		
	1-7/week	0.36	0.11-1.19	0.055
5-14	<1/month	1.00		
	≥1/month	0.33	0.14-0.76	0.006
15+	0	1.00		
	1-7/week	0.41	0.16-1.03	0.032

Source: Blumenthal et al, 1998, Blumenthal et al, 2000

Table C5: Effect of consumption of green tomato on seroresponse to Human Norwalk-like Virus/Mexico in children of 5-14 years

1.1.2 Times/2 Weeks	5.3 Odds Ratio	C.I.	P value
0	1.00		
1	1.44	0.76-2.75	
2-14	2.52	1.03-6.13	0.034

Source: Blumenthal et al, 1998, Blumenthal et al, 2000

Table C6: Effect of handwashing on diarrhoea and seroresponse to Human Norwalk-like Virus/Mexico in adults

Infection	5.4 Method	Odds Ratio	P value
Diarrhoea	Water Water + Detergent Water + Soap	1.00 0.90 0.58	 0.04
Calicivirus-Mx	Water Water + Detergent Water + Soap	1.00 1.06 0.46	 0.06

Source: Blumenthal et al, 1998

Annex D
Experimental studies on microbiological contamination of wastewater–irrigated crops in Brazil and UK

Experimental studies in northeast Brazil and Leeds, UK were conducted to investigate the risks to consumers from nematode infection (*Ascaris lumbricoides* and *Ascaridia galli* respectively) from crops irrigated with wastewater of varying qualities. In both studies, spray irrigation of lettuce was chosen to reflect the worst case situation for consumers in which the most contaminating irrigation method is used for a raw edible crop. Irrigation trials related wastewater quality to levels of crop contamination during irrigation and at harvest, survival of nematode eggs on irrigated plants (in terms of egg development and viability) and transmission of nematode infection from ingestion of irrigated crops using animal models to assess the potential risk to consumers.

1. Experimental design

In Brazil, raw and treated wastewaters from an anaerobic, facultative and maturation pond of a pilot-scale series of waste stabilisation ponds were used to spray-irrigate lettuce crops. A manual irrigation system was employed to imitate that used locally for commercial production. Lettuces were irrigated from transplanting (as 4-week old seedlings) twice a day for the first week and then once a day thereafter for five weeks until harvest. Lettuces were sampled at weekly intervals and enumerated for eggs using a specifically developed washing method (Stott, in preparation). The number, species and viability of nematode eggs on plants was determined during irrigation to evaluate the potential risks from ingestion of wastewater irrigated crops (Ayres, 1991; Ayres *et al*., 1992).

In complementary studies in the UK lettuces were spray-irrigated with wastewater containing eggs of the chicken roundworm *Ascaridia galli* (as a nematode model for *Ascaris lumbricoides*). Crops were irrigated using a hand-held irrigation system with treated effluent artificially seeded with eggs of *A.galli* to reflect wastewaters of poor medium and WHO qualities. Crops were irrigated at least three times a week from transplanting for five weeks until harvest. The transmission of nematode infection from ingestion of irrigated crops was assessed using chicken bioassays: two harvested plants were fed to a pair of immunosuppressed chickens once a week for five weeks. Chickens were examined for *A.galli* infection six weeks from the first feeding date and worm burdens used as the criterion of infection (Stott *et al*., 1994; Stott, 1995).

2. Wastewater quality

In Brazil, a variety of helminth ova were found in wastewaters including eggs of *A.lumbricoides*, *Trichuris trichiura*, hookworm, *Hymenolepis nana* and *Hymenolepis diminuta*. All species of nematode eggs were found in raw and anaerobic pond wastewaters, but only *Ascaris* eggs were detected in facultative pond effluent. Eggs of *A.lumbricoides* predominated (>95%) in all wastewaters. Raw wastewater contained a high number of nematode eggs (166-202 eggs per litre). Treatment in the anaerobic pond greatly reduced the number of nematode ova to around 14-18 eggs/l. The concentration of nematode ova in facultative pond effluent was on average <0.5 eggs/l (thus satisfying WHO nematode quality criteria). Retention in a maturation pond consistently removed all nematode ova during the irrigation programme.

In UK studies, final effluent was collected from a local conventional treatment plant. The effluent was seeded with an appropriate sample from a homogenous suspension of *A.galli* eggs to produce mean wastewater qualities of 50, 10 and 1 egg/l.

3. Nematode egg contamination on wastewater-irrigated crops

Wastewater quality had a significant effect on crop contamination with greater levels of contamination found on plants irrigated with higher numbers of eggs. In Brazil, only eggs of *A.*

lumbricoides were found on the wastewater-irrigated crops. When raw wastewater (>100 eggs/l) was used for irrigation the level of contamination increased with time. However, the increase in the total number of eggs on the plant was in proportion to the increase in weight and plant surface area, and egg density in terms of eggs per gram fresh weight stayed the same indicating that no accumulation per se was found on plants. At harvest, raw-wastewater irrigated crops were contaminated with on average <60 eggs/plant (Table D1). When anaerobic pond effluent (>10 eggs/l) was used for irrigation, contamination levels on the plants were greatly reduced to around 0.6 eggs/plant. No contamination was found on lettuces spray-irrigated with facultative pond effluent (<0.5 eggs/l) nor on lettuce irrigated with maturation pond effluent (0 eggs/l).

Table D1: Mean number of *A.lumbricoides* eggs per lettuce after irrigation for five weeks with raw and treated WSP wastewaters containing 0-202 eggs per litre (NE Brazil)

	WSP effluent			
	Raw wastewater >100 eggs/l	**Anaerobic pond >10 eggs/l**	**Facultative pond <0.5 eggs/l**	**3rd Maturation pond 0 eggs/l**
Mean no. of eggs per lettuce (Trial 1):	59.74	0.56	0	0
Mean no. of eggs per lettuce (Trial 2):	29.26	0.58	0	0

The quality of irrigated crops was found to be significantly improved by rainfall or clean water irrigation prior to harvesting. Contamination on raw wastewater irrigated crops was reduced by 98% following heavy rainfall and all nematode eggs were removed from plants irrigated with anaerobic pond effluent. When clean water was used to spray irrigate crops contaminated by raw or partially treated wastewater irrigation, the majority of eggs were removed after 3 days and all eggs were removed from raw wastewater irrigated crops after 7 days. However, lower levels of contamination were removed more readily from crops irrigated with anaerobic pond effluent; all eggs were removed within a single application of clean water irrigation. These results suggest that, at least in the case of *A.lumbricoides* eggs, crop recontamination does not occur as a result of rain or splash from overhead irrigation systems unlike that suggested for bacterial recontamination of crops. No eggs were found on lettuce crops irrigated with facultative or maturation pond effluent despite being grown in contaminated soil containing up to an average of 1200 *Ascaris* eggs per 100 g.

In the UK studies, levels of crop contamination were also related to wastewater quality. Levels of contamination increased during irrigation on crops irrigated with wastewater containing >10 eggs/l. However, there was no evidence for egg accumulation on the plants. Low levels of contamination were found on plants harvested after 5 weeks irrigation. When poor-quality wastewater (50 eggs/l) was used to irrigate lettuce crops, 23 percent of the plants were contaminated with around 2.2 eggs/plant at harvest. Irrigation with better quality effluent (10 eggs/l) improved the quality of crops as the levels of nematode contamination were reduced to around 1.5 eggs/plant and the incidence of contamination was also reduced to 15%. When the plants were irrigated with wastewater at the WHO guideline of $\le$1 egg/l, only very slight contamination was found on a few plants (6%). Levels of contamination were around 0.3 eggs/plant at harvest suggesting that a few eggs may remain on plant surfaces despite successive irrigation or the effects of environmental weathering.

The number of eggs on the plants was found to be highly aggregated in the UK studies: the majority of plants were uncontaminated and only a few plants were contaminated with eggs. Irrigation with 50 eggs per litre significantly increased the level of nematode contamination compared to plants irrigated with the WHO guideline of ≤ 1 egg/l. There was also weak evidence to suggest that irrigation with 10 eggs per litre resulted in a mean increase of 0.5 egg per plant, compared with plants irrigated with the WHO guideline level.

Collectively the results show that levels of nematode contamination on crops at harvest do not reflect the nematode quality of the irrigation wastewater (Ayres *et al*., 1992). Irrigation with raw or poor-quality wastewater containing high numbers of eggs did not result in heavily contaminated crops at harvest. Cultivating plants under apparently highly contaminating conditions may not lead to great levels of contamination on plants. A similar observation has been reported in Morocco where raw wastewater containing 90-2200 *A.lumbricoides* per litre was used to irrigate tomatoes and resulted in a contamination level at harvest of only 2 eggs per kg (Rhallabi *et al*., 1990). The lack of accumulation on plants during irrigation suggests that the irrigation water itself might have a "wash on/off" effect by removing and replacing eggs at the next application. Irrigation with partially treated wastewater (>10 eggs/l) improved the quality of irrigated crops compared to plants irrigated with poor quality wastewaters (>50 eggs/l) although plants were still contaminated at harvest albeit with low levels of contamination. Irrigation with wastewater of the WHO guideline quality resulted in no contamination of lettuce at harvest or very slight contamination on a few plants.

4. Development of nematode eggs on wastewater-irrigated crops

Eggs recovered from contaminated plants were examined for stages of development in order to interpret the risk of infection from eggs found on plants. Studies in Brazil and UK found that the eggs did not develop to the infective stage on wastewater-irrigated crops. The majority of eggs remaining on plants at harvest were either unembryonated or developing, but the farthest stage of development reached on plants was the gastrula intermediate stage. No embryonated eggs were recovered from wastewater-irrigated crops.

The absence of embryonated eggs on the plants may have been due to the eggs being continually washed off and replaced from subsequent irrigation, or eggs degenerating before crop harvesting. Mean maximum temperatures ranged from 28-33°C for each harvesting occasion in Brazil and temperatures in the glasshouse in the UK study were usually in excess of 33°C, suggesting that environmental factors, particularly desiccation, may facilitate rapid egg degeneration and removal from the plants.

5. Viability of nematode eggs on wastewater irrigated crops

The viability of nematode eggs remaining on wastewater-irrigated crops decreased significantly with weeks of irrigation in both the Brazil and UK irrigation trials indicating a rapid degeneration of eggs on the plants. However, a few nematode eggs on harvested plants were still viable. In particular, plants irrigated with WHO quality wastewater (1 egg/l) were contaminated with very low numbers of viable eggs (0-0.15 egg per plant). Since viable eggs can remain on crops for up to 35 days, there is a risk that crops harvested within the egg survival period may be contaminated with viable eggs. Wastewater-irrigated vegetables may thus represent a potential risk to consumers.

6. Transmission of nematode infection from wastewater-irrigated crops

In the UK studies, ingestion of lettuces spray-irrigated with wastewater containing embryonated eggs of *A.galli* resulted in worm infections in immunocompromised chickens. The threshold level of infection was found to be low, with an infective dose of fewer than 10 embryonated eggs per pair of birds being required to establish an infection. However, whilst studies showed that there was an actual risk of infection from edible crops contaminated with embryonated eggs, no actual risk of infection was found from crops spray irrigated with unembryonated eggs. No transmission of *A.galli* infection was found in chickens fed contaminated crops spray-irrigated with wastewater, although the estimated egg dose received from spray-irrigated plants of 1.2-20 eggs per plant exceeded the minimum infective dose of <5 embryonated eggs for *A.galli*. The results indicate that the potential risk of nematode infection to consumers from contaminated plants appears to be minimal at or shortly after harvest.

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Annex E

Wastewater treatment

This Annex briefly describes wastewater treatment in:

- waste stabilisation ponds,
- wastewater storage and treatment reservoirs, and
- polishing ponds for upgrading conventional effluents,

for the production of effluents with a microbiological quality suitable for either restricted or unrestricted irrigation. For wastewater-fed aquaculture a system for minimal wastewater treatment and maximal fish production is also described.

1. Waste Stabilisation Ponds

Waste stabilisation ponds (WSP) are shallow man-made basins into which wastewater continuously flows and from which, after a retention time of many days (rather than several hours in conventional treatment processes), a well treated effluent is discharged. WSP systems comprise a series of anaerobic, facultative and maturation ponds, or two or more such series in parallel. In essence, anaerobic and facultative ponds are designed for BOD removal and maturation ponds for pathogen removal, although some BOD removal occurs in maturation ponds and some pathogen removal occurs in anaerobic and facultative ponds. The functions and modes of operation of these three different types of pond are described in Sections 1.2 – 1.4.

1.1 Advantages of WSP

The advantages of WSP systems, which can be summarised as *simplicity, low cost* and *high efficiency*, are as follows:

Simplicity. WSP are simple to construct: earth moving is the principal activity; other civil works are minimal – preliminary treatment, inlets and outlets, pond embankment protection and, if necessary, pond lining. WSP are also simple to operate and maintain: routine tasks comprise cutting the embankment grass, removing scum and any floating vegetation from the pond surface, keeping the inlets and outlets clear, and repairing any damage to the embankments. Only unskilled, but carefully supervised, labour is needed for pond operation and maintenance.

Low cost. Because of their simplicity, WSP are much cheaper than other wastewater treatment processes. There is no need for expensive electromechanical equipment (with its attendant problems, in developing countries, of foreign exchange and spare parts), nor for a high annual consumption of electrical energy.

The cost advantages of WSP were analysed in detail by Arthur (1983) in a World Bank Technical Paper. Arthur compared four treatment processes – trickling filters, aerated lagoons, oxidation ditches and WSP, all designed to produce the same quality of final effluent, and he found that WSP systems were the cheapest treatment process at land costs of US$ 50,000-150,000 (1983 $) per hectare, depending on the discount rate used (5-15 percent). These figures are much higher than most land costs, and so land costs are unlikely to be a factor operating against the selection of WSP for wastewater treatment (but, of course, land availability may be).

High efficiency. BOD removals > 90 percent are readily obtained in a series of well designed ponds. The removal of suspended solids is less, due to the presence of algae in the final effluent (but, since algae are very different to the suspended solids in conventional secondary effluents, this is not cause for alarm: indeed the European directive on urban wastewater treatment (Council of the European Communities, 1991) permits WSP effluents to contain up to 150 mg suspended solids/l, and it also allows sample filtration prior to BOD analysis to remove the algae). Total nitrogen removal is 70-90 percent, and total phosphorus removal 30-50 percent.

WSP are particularly efficient in removing excreted pathogens, whereas in contrast all other treatment processes are very inefficient at this and require a tertiary treatment process, such as chlorination (with all its inherent operational and environmental problems; see Feachem *et al.,* 1983) or ultra-violet treatment (which may not always be effective — see *Report*, 1998), to achieve the destruction of faecal bacteria. Activated sludge plants may, if operating very well, achieve a 99 percent removal of faecal coliform bacteria: this might, at first inspection, appear very impressive, but in fact it only represents a reduction from 10^8 per 100 ml to 10^6 per 100 ml (that is, almost nothing). A series of WSP, on the other hand, can easily be designed to reduce faecal coliform numbers from 10^8 per 100 ml to below the guideline value for unrestricted irrigation of 1000 per 100 ml, which is a removal of 99.999 percent (or 5 $\log_{10}$ units). WSP can also easily achieve the current and proposed guideline values for restricted irrigation of no more than 1 and 0.1 intestinal nematode egg per litre (Annex F Table F1). A general comparison between WSP and conventional treatment processes for the removal of excreted pathogens is shown in Table E1; detailed information is given in Feachem *et al*. (1983).

Table E1. Removals of excreted pathogens achieved by waste stabilization ponds and conventional treatment processes

Excreted pathogen	Removal in WSP	Removal in conventional treatment
Bacteria	up to 6 log units *	1 - 2 log units
Viruses	up to 4 log units	1 - 2 log units
Protozoan cysts	100%	90-99%
Helminth eggs	100%	90-99%

Source : Feachem *et al.* (1983)

* 1 log unit = 90 percent removal; 2 = 99 percent; 3 = 99.9 percent, and so on.

1.2 Anaerobic Ponds

Anaerobic ponds are 2-5 m deep and receive such a high organic loading (usually > 100 g BOD/m^3 d, equivalent to > 3000 kg/ha d for a depth of 3 m) that they contain no dissolved oxygen and no algae. They function much like open septic tanks, and their primary function is BOD removal. They work extremely well in warm climates: a properly designed and not significantly underloaded anaerobic pond will achieve around 60 percent BOD removal at 20°C and as much as 75 percent at 25°C. Retention times are short: for wastewaters with a BOD of up to 300 mg/l, 1 day is sufficient at temperatures > 20°C. Indeed, as noted by Marais (1970), "pre-treatment in anaerobic ponds is so advantageous that the first consideration in the design of a series of ponds should always include the possibility of anaerobic treatment."

1.3 Facultative Ponds

Facultative ponds are designed for BOD removal on the basis of a relatively low surface loading (100-400 kg BOD/ha d) to permit the development of a healthy algal population as the oxygen for BOD removal by the pond bacteria is mostly generated by algal photosynthesis. Due to the algae facultative ponds are coloured dark green, although they may occasionally appear red or pink (especially when slightly overloaded) due to the presence of anaerobic purple sulphide-oxidising photosynthetic bacteria. The concentration of algae in a healthy facultative pond depends on loading and temperature, but it is usually in the range 500-2000 μg chlorophyll *a* per litre. The algae are responsible for introducing conditions that kill faecal bacteria; Curtis *et al.* (1992) found that pH values >9 and the combination of a high dissolved oxygen concentration and a high visible light intensity were rapidly fatal to faecal coliforms.

Helminth eggs, which can number up to 2000 per litre of wastewater depending on the endemicity of intestinal nematode infections, are removed by sedimentation and thus most egg removal occurs in the anaerobic and facultative ponds. It is sensible to check whether the facultative pond effluent complies with the recommendations for restricted irrigation (Annex F Table F1); if it does not, then one (or more) maturation ponds will be necessary to reduce egg numbers to not $\ngtr$ 1 or 0.1 per litre and, if required, faecal coliform numbers to not $\ngtr$ 10^5 per 100 ml.

BOD removal in facultative ponds is usually in the range 70-80 percent based on unfiltered samples (that is, including the BOD exerted by the algae), and above 90 percent based on filtered samples.

1.4 Maturation Ponds

A series of maturation ponds receives the effluent from the facultative pond, and the size and number of maturation ponds is governed mainly by the required bacteriological quality of the final effluent (Annex F Table F1). The removal of excreted pathogens is extremely efficient in a properly designed series of ponds (Table E2). Maturation ponds achieve only a small removal of BOD, usually around 10-25 percent in each pond. The method of Marais (1974) is generally used to design a pond series for faecal coliform removal — see Section 1.6.

Table E2. Geometric mean bacterial and viral numbers per 100 ml in raw wastewater and the effluents of five waste stabilization ponds in series in northeast Brazil at 26°C

Organism	RW*	A	F	M1	M2	M3
Faecal coliforms	2×10^7	4×10^6	8×10^5	2×10^5	3×10^4	7×10^3
Campylobacters	70	20	0.2	0	0	0
Salmonellae	20	8	0.1	0.002	0.01	0
Enteroviruses	100	60	10	4	0.5	0.09
Rotaviruses	8	2	0.7	0.3	0.1	0.03

Source: Oragui *et al.* (1987).

* RW, raw wastewater; A was an anaerobic pond with a mean hydraulic retention time of 1 day; F and M1-M3 were a facultative pond and maturation ponds, respectively, each with a retention time of 5 days.

1.5 Pond design for helminth egg removal

Helminth eggs are removed in WSP by sedimentation very efficiently. Ayres *et al.* (1992) give the following design equation for egg removal in a single pond:

$$R = 100\,[1 - 0.4 \exp(-\,0.49\theta + 0.0085\theta^2)] \qquad (1)$$

where R = percentage egg removal
θ = mean hydraulic retention time (defined as pond volume/flow), days

This equation is applied to each pond in the series in turn. In practice anaerobic and facultative ponds have to be first designed on the basis of the maximum design BOD loading allowed to be applied to them (which depends on temperature); this, together with the BOD of the wastewater entering them, establishes their retention time, and hence the percentage egg removal they achieve. If the facultative pond effluent contains more than the required egg numbers (Annex F Table F1), then one or more maturation ponds are added to the series.

A design example is given in Box A.

Helminth eggs in pond sludges. Anaerobic and facultative ponds need to be desludged every 2-3 and 10 years, respectively. As *Ascaris* eggs can remain viable for > 5 years, the sludges removed from WSP must be disposed of carefully by, for example, on-site burial, in a sanitary landfill or deep ploughing into agricultural land.

1.6 Pond design for faecal coliform removal

Faecal coliform bacteria are removed in a series of WSP according to the equations given by Marais (1974):

$$N_e = N_i/(1 + k_T\,\theta_a)\,(1 + k_T\,\theta_f)\,(1 + k_T\,\theta_m)^n \qquad (2)$$

$$k_T = 2.6\,(1.19)^{T-20} \qquad (3)$$

where N_e = required number of faecal coliforms per 100 ml of final effluent;
N_I = number of faecal coliforms per 100 ml of raw wastewater;
k_T = first order rate constant for faecal coliform removal, day^{-1} (see equation 3 below);
θ = retention time, days; subscripts a, f and m refer to the anaerobic, facultative and maturation ponds, respectively;
n = number of maturation ponds (assumed at the design stage to be equally sized).
T = temperature, ^oC.

A design example is given in Box B.

2. Wastewater Storage and Treatment Reservoirs

Wastewater storage and treatment reservoirs (WSTR), also called effluent storage reservoirs, are especially useful in arid and semi-arid areas. They were developed in Israel to store the effluent from a WSP system during the period (8 months in Israel) when it is not required for irrigation (Juanico and Shelef, 1991). It is thus a method of conserving wastewater so that, during the irrigation season, the whole year's wastewater can be used for irrigation. Thus 2-3 times the land area can be irrigated and 2-3 times the quantity of crops produced. WSTR would be used in preference to WSP when the economic value of water is high enough to justify their use.

Current Israeli practice is to treat the wastewater in an anaerobic pond and discharge its effluent into a single 5-15 m deep WSTR with an 8-month retention time. This is perfectly satisfactory, as the WSTR effluent is only used to drip-irrigate cotton and so this usage complies with the guideline in Annex F Table F1 for restricted irrigation category B2, since any helminth eggs settle out in the anaerobic pond and the WSTR. If the restricted irrigation category is B1, rather than B2 as above, then there is the additional requirement that the faecal coliform number should not exceed 10^5 per 100 ml. The above single WSTR cannot achieve this during the irrigation season since the anaerobic pond effluent is discharged into a continuously decreasing WSTR volume, such that towards the end of the irrigation season — i.e. closest to crop harvest — the irrigation water is of increasingly poorer bacteriological quality and will eventually contain > 10^5 faecal coliforms per 100 ml. The solution in this case is to have two batch-fed reservoirs in parallel, each half the volume of the above single reservoir. The contents of one reservoir are used for irrigation until it is half empty, when the contents of the other are used and the anaerobic pond effluent discharged into the first reservoir until the second reservoir is half empty, when the cycle is repeated.

If the WSTR effluent is to be used for unrestricted irrigation, or for unrestricted irrigation category B3, then it should contain ≤ 1000 FC per 100 ml, which the above single WSTR cannot achieve, at least not during the irrigation season (Liran *et al.*, 1994). Instead several sequential batch-fed WSTR in parallel are required (Mara and Pearson, 1992). These receive anaerobic pond effluent and are each operated on a sequential cycle of fill, rest and use, with faecal coliform die-off to < 1000 per 100 ml occurring during the fill and rest periods. Recent research in northeast Brazil (Mara *et al.*, 1996) has shown that batch-fed WSTR are very efficient at removing faecal coliforms: at temperatures of 25°C die-off to < 1000 per 100 ml throughout the whole reservoir depth of 6 m occurred 3 weeks into the rest phase. WSTR were found to behave much like deep facultative ponds with an algal biomass of around 500 µg chlorophyll *a* per litre (as with WSP, such algal concentrations in WSTR effluents are beneficial for crop irrigation as the algae act as slow-release fertilisers in the soil). The much greater depth of WSTR (5-15 m, compared with 1-2 m for WSP) reduces evaporative losses; in northeast Brazil such losses amounted to under 14% of the inflow to a 6 m deep WSTR during a 4-month rest phase in the hottest part of the year (25-27°C), with a corresponding increase in electrical conductivity to 160 mS/m. Wastewaters of such conductivity have been successfully used to irrigate local cash crops, including lettuce.

WSTR are a very flexible system of wastewater treatment and storage. Juanico (1995) details several arrangements, including two WSTR in series, with effluent from the first being used for restricted irrigation and that from the second, for unrestricted irrigation. An alternative "hybrid" WSP-WSTR system is to treat the wastewater in anaerobic and facultative ponds, the effluent from the latter being discharged into a WSTR during the non-irrigation season, but used for restricted irrigation during the irrigation season when the WSTR contents are used for unrestricted irrigation (Mara *et al*., 1996).

Design procedures for WSTR are given in Mara (1997) and Mara and Pearson (1998).

3. Upgrading Conventional Effluents

The effluents from conventional secondary wastewater treatment systems (activated sludge and its variants such as aerated lagoons and oxidation ditches, and trickling filters) do not meet the microbiological quality requirements for agricultural use (Table F1), unless supplemented by a tertiary treatment process. These include chlorination, UV disinfection (both problematic — see Feachem *et al.,* 1983 and *Report*, 1998), sand filtration and maturation ponds (often calling polishing ponds in this context). Sand filtration can remove helminth eggs to < 0.1 per litre, and can also reduce faecal coliform numbers to < 10^5 per 100 ml (see Strauss *et al.,* 1995 and Chen *et al*, 1998), but it requires very careful operation and maintenance. Maturation ponds will often be the most appropriate way to reduce both helminth eggs and faecal coliforms to the required levels (see Ayres *et al.,* 1992; Mara, 1997; Mara and Pearson, 1998).

Box A: Egg removal in WSP – design example

Assume that the number of eggs in the raw wastewater is 100, its BOD (L_i) is 300 mg/l and the design temperature is 20^{o}C.

Solution – outline only; further details are given in Mara *et al.* (1991), Mara (1997) and Mara and Pearson (1998).

Anaerobic pond. For 20^{o}C the design volumetric BOD loading (λ_v) is 300 g/m^3 day, and the retention time is given by

$$\theta_a = L_i / \lambda_v$$

$$= 300 / 300, = 1 \text{ day}$$

From equation 1 the percentage egg removal for 1 day retention time is 75 percent, so the number of eggs in the anaerobic pond effluent is 25 per litre.

Facultative pond. BOD removal in the anaerobic pond is taken as 60 percent at 20^{o}C, so its effluent BOD is 120 mg/l. The design surface BOD loading on the facultative pond is 250 kg/ha day at 20^{o}C. Taking its depth (D) as 1.8 m, then its retention time is given by:

$$\theta_f = 10\, L_i\, D / \lambda_s$$

$$= 10 \times 120 \times 1.8 / 250, = 8.6 \text{ days}$$

Thus, from equation 1 R = 98.9 percent and so the facultative pond effluent contains 0.3 egg per litre. This is < 1 egg per litre and so suitable for reuse categories A2, B1 and B2 (Table F1), but not categories A1 and B3, for which the guideline is 0.1 egg per litre. To achieve this, a maturation pond is needed; the minimum retention time in maturation ponds is 3 days, for which R = 89.8 percent and thus the number of eggs in its effluent is 0.03 per litre, which is satisfactory for categories A1 and B3.

If the number of eggs in the raw wastewater were 10 per litre, then the facultative pond effluent in the above example would contain 0.03 per litre, which is suitable for all categories. If the egg count was 1,000 per litre, then the facultative pond effluent would contain 3 per litre. Thus one 3-day maturation pond would be required for categories A2, B1 and B2; and two would be required for categories A1 and B3.

For temperatures <20^{o}C the design BOD loadings are lower; this results in longer retention times and thus higher egg removals. At higher temperatures egg removals are lower as a result of the lower retention times (but minimum retention times of 1 and 5 days are used for anaerobic and facultative ponds, respectively). Similarly, for stronger wastewaters (i.e. L_i > 300 mg/l), retention times are longer and thus egg removals higher; and *vice versa* for weaker wastewaters (for example, for a BOD of 500 mg/l), θ_a and θ_f would be 1.7 and 14.4 days, respectively, for which R = 81.7 and 99.8. Thus for 100 eggs per litre of raw wastewater, the facultative pond effluent would contain 0.04 egg per litre. If the egg count were 1000 per litre, then a 3-day maturation pond would be necessary for ≤ 0.1 egg per litre, but not ≤ 1 egg per litre).

Box B: Faecal coliform removal in WSP – design example

Assume that the number of faecal coliforms in the raw wastewater is 5×10^7 per 100 ml, with all other parameters as in the example in Box A. Thus θ_a = 1 day and θ_f = 8.6 days. For 20°C the value of k_T is given by equation 3 as 2.6 day^{-1}.

Solution – outline only; further details are given in Mara *et al.* (1991), Mara (1997) and Mara and Pearson (1998).

Design for 10^5 faecal coliforms per 100 ml – i.e. for reuse category B1

The number of faecal coliforms per 100 ml of facultative pond effluent is given by the following version of equation 2:

$$N_e = N_i / (1 + k_T \theta_a)(1 + k_T \theta_f)$$

$$= 5 \times 10^7 / [1 + (2.6 \times 1)] [1 + (2.6 \times 8.6)]$$

$$= 5.9 \times 10^5$$

This is too high for any of the reuse categories (Table F1), and so maturation ponds are required. A single 3-day pond would reduce the count to:

$$N_e = 5.9 \times 10^5 / [1 + (2.6 \times 3)]$$

$$= 6.7 \times 10^4 \text{ per 100 ml, which is satisfactory.}$$

If the number of faecal coliforms had been 1×10^7 per 100 ml, then the facultative pond effluent would just be suitable for reuse category B1. If the temperature had been 26°C or above, then the facultative pond effluent would also be suitable for this category. Stronger wastewaters result in longer retention times in the anaerobic and facultative ponds, and therefore faecal coliform removals are slightly higher. For example, if L_i = 500 mg/l, then θ_a = 1.7 day and θ_f = 14.4 days, so the effluent from the facultative pond would contain 2.5×10^5 per 100 ml, and a 3-day maturation pond would be required, as above.

Design for 1000 faecal coliforms per 100 ml – i.e. for reuse categories A1 and B3

The following version of equation 2 can be used to design the series of n maturation ponds:

$$N_e = N_i / (1 + k_T \theta_m)^n$$

where N_i is now the number of faecal coliforms per 100 ml of facultative pond effluent and N_e = 1000 per 100 ml of final effluent.

This equation is rearranged as follows:

$$\theta_m = [(N_i / N_e)^{1/n} - 1] / k_T$$

Here $N_i = 5.9 \times 10^5$, N_e = 1000 and k_T = 2.6; thus:

$$\theta_m = [(5.9 \times 10^5 / 1000)^{1/n} - 1]/2.6$$

Box B, continued

This equation is solved for n = 1, 2, 3 etc. until θ_m is < 3 days (the minimum retention time in maturation ponds):

For	n = 1,	θ_m =	227 days
	= 2	=	9
	= 3	=	2.8

In this example the chosen series of maturation ponds would comprise three ponds each with a retention time of 3 days.

Effect of temperature

As shown by equation 3, the value of k_T is extremely sensitive to temperature, changing by 19 percent for each change in temperature of 1 degC. If the above example were for 25°C , then the anaerobic pond retention time would remain at 1 day (the design minimum), the facultative pond retention time would decrease to 4.6 days (as the BOD removal in the anaerobic pond would increase to 70 percent and the permissible loading on the facultative pond would increase to 350 kg BOD/ha day) and the value of k_T would be 6.2 day^{-1}. The number of faecal coliforms in the facultative pond effluent would be given by:

$$N_e = 5 \times 10^7 / [1 + (6.2 \times 1)] [1 + (6.2 \times 4.6)]$$

$$= 2.4 \times 10^5 \text{ per 100 ml}$$

Only two 3-day maturation ponds would now be required to achieve < 1000 faecal coliforms per 100 ml:

$$N_e = 2.4 \times 10^5 / [1 + (6.2 \times 3)]^2$$

$$= 625 \text{ per 100 ml}$$

So the overall retention time at 25°C would be 11.6 days, rather than 18.6 days at 20°C.

Restricted or unrestricted irrigation?

The 1-day anaerobic pond and 8.6-day facultative pond achieve ≤ 1 egg per litre (assuming 100 eggs per litre of raw wastewater), as shown in Box A, i.e. a total retention time of 9.6 days for reuse categories A2, B1 and B2. A 3-day maturation pond is required for ≤ 0.1 egg per litre for categories A1 and B3, i.e. a total retention time of 12.6 days.

For unrestricted irrigation the above example shows that three 3-day maturation ponds are needed to follow the anaerobic and facultative ponds, i.e. a total retention time of 18.6 days, which is 48-94 percent more than required for unrestricted irrigation. Thus it is very important to decide — in conjunction with the local farmers — whether to select restricted irrigation or unrestricted irrigation as this has such a huge influence on pond land area requirements and hence costs.

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Annex F

Proposed revisions to the WHO guidelines based on using the epidemiological perspective

In light of the epidemiological and microbiological studies reviewed above, it is possible to evaluate the WHO (1989) Guidelines, and propose alternative guidelines where the evidence supports a change (see Table 5).

Unrestricted irrigation - Category A

The results of studies of consumer risks do not provide any evidence to suggest a need to change the WHO *faecal coliform guideline* of =10^3 FC/100ml for irrigation of vegetable and salad crops eaten uncooked (*Category A1*). Epidemiological studies in an area in Mexico where enteric infections are endemic suggest that risks of enteric infections are significant, but low, when the guideline is exceeded by a factor of 10 (Blumenthal et al, 1998, Blumenthal et al, 2000b). There was no risk associated with the total consumption of raw vegetables but consumption of onions, eaten by the majority of the study population, was associated with at least a two-fold increase in diarrhoeal disease Microbiological studies also suggest that a guideline of =10^3 FC/100ml is appropriate in hot climates, where crops irrigated with water just exceeding the guideline value fell within the quality recommendations of ICMSF (1974) (Vaz da Costas Vargas et al, 1996). Recontamination of crops in uncovered plots after significant rainfall, however, suggests that a stricter guideline may be necessary in countries where significant rainfall occurs during the growing season. However, risk assessment studies in Israel (Shuval et al, 1997) have indicated that the annual risk of enteric virus and bacterial infection from eating lettuce irrigated with water meeting the WHO Guideline level ranges from 10^{-5} (rotavirus) and 10^{-6} (hepatitis A virus) to 10^{-9} (cholera). Data from risk assessment in the USA (Asano et al, 1992) support these conclusions, finding the annual risk of infection from enteric viruses was between 10^{-4} and 10^{-9} when water with a maximum viral concentration of 111 units per 100 litres was used to irrigate market garden produce. Data from waste stabilisation ponds in northeast Brazil (Vaz da Costas Vargas et al, 1996) suggest that rotavirus numbers are likely to be less than 30 per 100 litres when the faecal coliform content is below 10^4 per 100ml. However, other enteric viruses such as adenovirus may significantly outnumber rotaviruses and enteroviruses, possibly by an order of magnitude (*30*). It can therefore be extrapolated from these data that use of water meeting the WHO guideline level of 1000 FC per 100 ml is likely to produce an annual risk of viral infection of less than 10^{-4}. Since the US microbial standards for drinking water are based on the criteria that human populations should not be subjected to the risk of infection by enteric disease greater than 10^{-4}, then the WHO (1989) wastewater reuse guidelines would appear to offer a similar level of protection. Furthermore, additional treatment to a FC level more stringent than 1000 per 100 ml is not cost effective, for example, Shuval et al*.* (1997) showed that the cost per case of hepatitis A avoided by irrigation with zero FC per 100 ml (as recommended by USEPA and USAID, 1992), rather than with 1000 FC per 100 ml, was of the order of US$ 3-30 millions.

The *nematode egg guideline* of =1 nematode egg/litre appears to be adequate to protect consumers of cultivated vegetables spray-irrigated with effluent of consistent quality and at high temperatures, but not necessarily consumers of vegetables surface-irrigated with such effluent at lower temperatures. Studies have shown that lettuces spray-irrigated with water of =1 nematode egg/litre (mean maximum temperatures exceeding 28^{o}C) were not contaminated (when quality <0.5 eggs/litre) or only lightly contaminated at harvest, and any eggs present were not infective (Annex B; Ayres et al, 1992; Stott et al, 1994). However, since a few eggs on the harvested plants were viable, crops with a long shelf life represent a potential risk to consumers. Epidemiological studies of wastewater-related risk factors for *Ascaris* infection in central Mexico showed that there was an increase of *Ascaris* infection among men consuming crops surface-irrigated with raw wastewater infection compared to those who did not each such crops, but there was no increased risk when crops were irrigated with sedimented wastewater (from a reservoir) with ≤1 nematode egg per litre. However, children under 15 years who ate crops from local fields had a two-fold increase in *Ascaris* infection compared with those who did not eat such crops, when either raw wastewater or sedimented wastewater was used in irrigation (Peasey, 2000). The increased risk in these circumstances may have been influenced by the irrigation method (surface, rather than spray), and the lower mean temperature (due to high altitude and semi-desert conditions). It would be sensible, therefore, to adopt a stricter guideline of ≤ 0.1 eggs per litre to prevent transmission of *Ascaris* infection in circumstances where conditions favour the survival of helminth eggs (lower temperatures, surface irrigation), and also to allow for the risks to farmworkers involved in cultivating the vegetable crops (see below). In situations where crops with a short shelf life are grown in hot and dry conditions, and where workers are adequately protected from infection through direct contact with wastewater or soil, the original guideline of ≤1 nematode egg per litre would appear to be adequate. However, use of the revised guideline may be considered prudent even in these circumstances, adding a greater margin of safety.

Restricted irrigation - Category B
In the WHO (1989) guidelines there was no *faecal coliform guideline* for restricted irrigation due to the lack of evidence of a risk of bacterial and viral infections to farm workers and nearby residents. Recent evidence of enteric infections in farming families in direct contact with partially treated wastewater (Mexico) and in populations living nearby sprinkler irrigated fields (USA) when the water quality exceeds 10^6 FC/100ml suggests that a faecal coliform guideline should now be added. Data from Israel (Shuval et al, 1989) and Lubbock, USA (Camann et al, 1986) on situations where spray/sprinkler irrigation is used suggest that a level of =10^5 FC/100ml would protect both farm workers and nearby population groups from infection via direct contact or wastewater aerosols (*Category B1*).

However, data from Mexico on a situation where flood irrigation is used showed that there was a significant excess of diarrhoeal disease in children aged 5-14 years, and a four-fold increase in seroresponse to Human Norwalk-like Virus/Mexico in adults with high levels of contact with the effluent from two sequential storage reservoirs (containing partially treated wastewater with 10^3-10^4 FC per 100ml) compared with those with no contact with this effluent (Blumenthal et al, 1998, Blumenthal et al, 2000b). There was also an excess of diarrhoeal disease in adults (OR=1.5) but this did not reach significant levels (p=0.12) probably due to sample size factors. A reduced guideline level of ≤10^3 FC per 100ml would be safer where adult farmworkers are engaged in flood or furrow irrigation (*Category B2* in Table 2) and where children are regularly exposed (*Category B3* in Table 2). This would also help to reduce the risks from epidemic infections which could be transmitted to effluent-irrigating communities from an outbreak in the source community (Fattal et al, 1987). Where there are insufficient resources to provide treatment to reach this stricter guideline, a guideline of 10^5 FC per 100ml should be supplemented by other health protection measures (for example, health education concerning avoidance of direct contact with wastewater, and the importance of handwashing with soap after wastewater contact).

The *nematode egg guideline* of =1 nematode egg/litre does not appear to sufficiently protect farm workers and their families, especially children (under 15 years of age). This is particularly the case where wastewater treatment systems produce an effluent of variable quality, where the partially treated wastewater may be contaminated with small quantities of wastewater, and where children of farm workers come into direct contact with the effluent. In such a situation in Mexico, children in contact with effluent from a storage reservoir which met the WHO Guideline (even though it was contaminated with small quantities of raw wastewater) had increased prevalence and intensity of *Ascaris* infection. When the effluent had been stored in two reservoirs and no nematode eggs were detectable, there was very little excess *Ascaris* infection in any age group (Cifuentes, 1998, Blumenthal et al, 2000a). Similar situations would arise where raw wastewater is allowed to bypass conventional treatment plants, especially during periods of peak flow, allowing untreated wastewater containing nematode eggs (where nematode infections are endemic) into the effluent that is reused for agriculture. Since this is often the case in reality, a stricter guideline of =0.1 eggs per litre is required for restricted irrigation where children are exposed to irrigation water (*Category B3*). This would also be useful in circumstances where stable treatment systems, such as waste stabilisation ponds are in use, and workers may come into contact with the soil, since eggs in soil can accumulate to high numbers (Annex B).

Table 5. Recommended revised microbiological guidelines for treated wastewater use in agriculture [a]

Category	Reuse Conditions	Exposed group	Irrigation technique	Intestinal nematodes [b] (arithmetic mean no of eggs per litre[c])	Faecal coliforms (geometric mean no per 100ml[d])	Wastewater treatment expected to achieve required microbiological quality
A	*Unrestricted irrigation* A1 Vegetable and salad crops eaten uncooked, sports fields, public parks [e]	Workers, consumers, public	Any	≤0.1 [f]	$\leq 10^3$	Well designed series of waste stabilization ponds (WSP), sequential batch-fed wastewater storage and treatment reservoirs (WSTR) or equivalent treatment (e.g. conventional secondary treatment supplemented by either polishing ponds or filtration and disinfection)
B	*Restricted irrigation* Cereal crops, industrial crops, fodder crops, pasture and trees [g]	B1 Workers (but no children <15 years), nearby communities	(a) Spray/sprinkler	≤ 1	$\leq 10^5$	Retention in WSP series inc. one maturation pond or in sequential WSTR or equivalent treatment (e.g. conventional secondary treatment supplemented by either polishing ponds or filtration)
		B2 As B1	(b) Flood/furrow	≤ 1	$\leq 10^3$	As for Category A
		B3 Workers including children < 15 years, nearby communities	Any	≤0.1	$\leq 10^3$	As for Category A
C	Localised irrigation of crops in category B if exposure of workers and the public does not occur	None	Trickle, drip or bubbler	Not applicable	Not applicable	Pretreatment as required by the irrigation technology, but not less than primary sedimentation.

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

b Ascaris and Trichuris species and hookworms; the guideline is also intended to protect against risks from parasitic protozoa

c During the irrigation season (if the wastewater is treated in WSP or WSTR which have been designed to achieve these egg numbers, then routine effluent quality monitoring is not required).

d During the irrigation season (faecal coliform counts should preferably be done weekly, but at least monthly).

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

f This guideline can be increased to ≤1 egg per litre if (i) conditions are hot and dry and surface irrigation is not used, or (ii) if wastewater treatment is supplemented with anthelmintic chemotherapy campaigns in areas of wastewater re-use.

g In the case of fruit trees, irrigation should cease two weeks before fruit is picked and no fruit should be picked off the ground. Spray/sprinkler irrigation should not be used.

Where fruit trees are irrigated with treated wastewater, a less strict guideline can be adopted if spray or sprinkler irrigation is not used (*Category A2*). When other irrigation methods are used, there is less chance of contamination of the fruit, and the main concern will be to protect the health of the farmworkers. If children are not involved, the criteria would be equivalent to those in B2 (Table 5), for restricted irrigation.

A stricter faecal coliform guideline of =200 FC/100ml was adopted by WHO (1989) for the irrigation of public parks and hotel lawns than for the irrigation of raw vegetables. This was based on the recommendations of Durand et al (1986) following the Colorado Springs Study, even though the results indicated that people who visited the parks irrigated with non-potable water derived from wastewater did not report gastro-intestinal symptoms more frequently than people visiting parks irrigated with potable or non-potable water originating from runoff. Risk assessment studies in the USA (Tanaka et al, 1998) have indicated that the annual risks of infection from enteric viruses related to contact with golf courses irrigated with treated wastewater were 10^{-4} to 10^{-6} when the wastewater was treated using secondary treatment plus chlorination (4 log removal, therefore approximately 10^{3}-10^{4} FC/100ml). There is therefore no direct evidence to suggest that a guideline of 1000 FC/100ml is inadequate to protect against the risks from irrigation of public parks, sports fields (including golf courses) and hotel lawns.

Restricted irrigation - Category B

In the WHO (1989) Guidelines there was no *faecal coliform guideline* for restricted irrigation due to the lack of evidence of a risk of bacterial and viral infections to farmworkers and nearby residents. Recent evidence of enteric infections in farming families in direct contact with partially treated wastewater (Mexico) and in populations living nearby sprinkler irrigated fields (USA) when the water quality exceeds 10^{6} FC/100ml suggests that a faecal coliform guideline should now be added. Data from Israel (Shuval et al, 1989) and Lubbock, USA (Camann et al, 1986) on situations where spray/sprinkler irrigation is used suggest that a level of =10^{5} FC/100ml would protect both farmworkers and nearby population groups from infection via direct contact or wastewater aerosols (*Category B1*). However, data from Mexico on a situation where flood irrigation is used suggest that where school-aged rural children are in direct contact (during irrigation or play) with the partially treated wastewater originating in an urban area, there may still be at risk of diarrhoeal disease at a level of 10^{3}-10^{4} FC/100ml (Blumenthal et al, 1998). A reduced guideline level of =10^{3} FC/100ml would be safer where large populations are involved in farm work and children are regularly exposed (*Category B3*). This would also help to reduce the risks from epidemic infections which could be transmitted to effluent irrigating communities from an outbreak in the source community (Fattal et al, 1987). Where there are insufficient resources to provide treatment to reach this stricter guideline, a guideline of 10^{5} FC/100ml should be supplemented by other health protection measures for children. Where spray/sprinkler irrigation is not used, and children are not exposed, then there is no evidence of a risk to adults from enteric infections. In Mexico, where a risk of diarrhoeal disease in those over 5 years in contact with effluent of 10^{5} FC/100ml (from one reservoir) was demonstrated, this was related to an increased prevalence of diarrhoea in ages 5-4 years and not those over 15 years (Cifuentes et al; 1993, Cifuentes, 1995). In situations where no children are involved in farm work, no faecal coliform guideline is needed (*Category B2*).

The *nematode egg guideline* of =1 nematode egg/litre does not appear to sufficiently protect farmworkers and their families, especially children (under 15 years of age). This is particularly the case where wastewater treatment systems produce an effluent of variable quality, where the partially treated wastewater may be contaminated with small quantities of wastewater, and where children of farmworkers come into direct contact with the effluent. In such a situation in Mexico, children in contact with effluent from a storage reservoir which met the WHO Guideline (even though it was contaminated with small quantities of raw wastewater) had increased prevalence and intensity of Ascaris infection. When the effluent had been stored in two reservoirs and no nematode eggs were detectable, there was very little excess Ascaris infection in any age group (Cifuentes, 1998, Blumenthal et al, 1996,). Similar situations would arise where raw wastewater is allowed to bypass conventional treatment plants, especially during periods of peak flow, allowing untreated wastewater containing nematode eggs (where nematode infections are endemic) into the effluent that is reused for agriculture. Since this is often the case in reality, a stricter guideline of =0.1 eggs per litre is required for restricted irrigation where children are exposed to irrigation water (*Category B3*). This would also be useful in circumstances where stable treatment systems, such as waste stabilisation ponds are in use, and workers may come into contact with the soil, since eggs in soil can accumulate to high numbers (Annex B).

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Annnex G

Wastewater reuse guidelines in Andalucia, Spain

Nematode guideline (ova/l)	Bacterial guideline (FC/100ml)	Type of Crop or Area irrigated	Irrigation method permitted	Other conditions to be fulfilled
<1	<200	Sports fields and green areas with public access	Any	Irrigation must be carried out when public absent
<1	<1000	Vegetables consumed raw	Any	None
<1	No limit set	Vegetables eated cooked, fruit trees, industrial crops, wood, fodder, cereals, seeds and oleaginous seeds	Any, except spray or flood irrigation for vegetables, and spray irrigation for fruit trees	Suspend irrigation of fruit trees at least 2 weeks prior to harvest, and fruit must not be picked up off the ground. Suspend irrigation of pasture at least 2 weeks prior to consumption by livestock.
No limit set, but at least primary sedimentation required	No limit set, but at least primary sedimentation required	Industrial crops, wood, fodder, cereals, seeds, oleaginous seeds and greens areas not accessible to the public	Localised	None

Source: Consejería de Salud, Andalucía, Spain (1994). Reutilización de aguas residuales depuradas en el riego agrícola y de zonas verdes - criterios sanitarios.

Annex H

List of participants at Technical meeting on wastewater reuse in agriculture and its health impact.

No.	Name	Position	Organization
1	Dr Guillermo Ruiz-Palacios	Jefe del Departamento de Infectologia	Instituto Nacional de Nutrition "Salvador Zubiran", Mexico
2	Dr Ursula Blumenthal	Senior Lecturer in Tropical Environmental Epidemiology	London School of Hygiene and Tropical Medicine, UK
3	Ms Anne Peasey	Research Fellow in Environmental Health	London School of Hygiene and Tropical Medicine, UK
4	Ing. Julio Moscoso Cavallini	Asesor en Reuso de Aguas residuales	Centro Panamericano de Ingenieria Sanitaria y Ciencias del Ambiente (CEPIS), Peru
5	Ing. Humberto Romero Alvarez	Subgerente de Ingenieria Sanitaria y Ambiental, Consultivo Tecnico	Comision Nacional de Agua, Mexico
6	Dr Enrique Cifuentes	Programa de Salud Ambiental Centro de Investigaciones en Salud Poblacional	Instituto Nacional de Salud Publica, Mexico
7	Ing. Enrique Mejia M.	Gerente de Ingenieria Basica y Normas Tecnicas	Comision Nacional de Agua, Mexico
8	Ing. Hector Rodriguez Regero	Subgerente de Construccion de la planta de tratamiento de Coyotepec	Comision Nacional de Agua, Mexico
9	Enrique S. Ortiz Espinosa	Director del Centro de Orientacion para la Atencion de Emergencias Ambientales (PROFEPA)	Comision Nacional de Agua, Mexico
10	Profesora Gabriela Moeller Chavez	Coordinacion de agua potable y agua residual	Instituto Mexicana de Tecnologia del Agua, Mexico
11	Luis Fernando Mondragon M.	Evaluador	Instituto Nacional de Ecologia, Mexico
12	Dra. Margarita Nava Frias	Jefe, Depto de Investigacion, Consejo Nacional de Vacunacion	Secretaria de Salud, Mexico
13	Dr Jose I. Santos Preciado	Secretario Tecnico, Consejo Nacional de Vacunacion	Secretaria de Salud, Mexico
14	Dra. Ma. Del Carmen Gonzalez Almeida	Directora de Saneamineto Basico, Direccion de Salud Ambiental	Secretaria de Salud, Mexico
15	Ing. Rosaura Sanchez	Ing. Quimica, Direccion de Salud Ambiental	Secretaria de Salud, Mexico
16	Dra. Ma. Esperanza Garcia Rodriguez	Jefe, Depto de Investigacion Economica y Intervenciones Preventivas	Secretaria de Salud, Mexico
17	Dra. Blanca E. Jimenez C.	Subdirectora del Instituto de Ingenieria	Universidad Nacional de Mexico

The technical meeting was organised jointly by the National Institute of Nutrition (Mexico) and the London School of Hygiene and Tropical Medicine (UK) with the assistance of Ing. Romero Alvarez at the Comision Nacional de Agua (Mexico). It was held on Dec 4th 1998 at Fundacion Mexicana para la Salud, Mexico City, Mexico.