12

Effluent reuse

12.1 MICROBIOLOGICAL QUALITY GUIDELINES

Crop irrigation

The World Health Organization's (1989) guidelines for the microbiological quality of treated wastewaters to be used for crop irrigation are given in Table 12.1. They are based on a rigorous appraisal of the available epidemiological evidence (Blum and Feachem, 1985; Shuval *et al.*, 1986; see also Mara and Cairncross, 1989), which showed that the excreted pathogens of most concern in crop irrigation are the human intestinal nematodes and faecal bacteria. The nematode guideline of no more than one egg per litre is required for both restricted and unrestricted irrigation to protect fieldworkers and, in the latter case, also the consumers (restricted irrigation refers to crops not grown for direct human consumption and food crops not eaten uncooked; unrestricted irrigation covers vegetables and salad crops eaten raw). (There is, however, some evidence that, for restricted irrigation only, the guideline could be safely relaxed to 10 eggs per litre; see Ayres *et al.*, 1992*b*.) WSP are especially efficient in removing helminth eggs (Mara and Silva, 1986; Schwartzbrod *et al.*, 1989).

Irrigation with untreated wastewater is very hazardous to health, with both fieldworkers and crop consumers being at high risk of helminthic infections; consumers are also at high risk of bacterial infection such as cholera and typhoid fever (see Shuval *et al.*, 1986). The faecal coliform guideline of no more than 1000 per 100 ml is to protect consumers from these bacterial diseases. This is much less stringent than earlier WHO (1973) recommendations (≤100 per 100 ml), but is justified because:

(a) the data presented in Table 2.2 show that pond effluents containing 7000 FC per 100 ml do not contain bacterial pathogens;

(b) swimming (i.e. whole body immersion) in recreational waters containing up to 2000 FC per 100 ml is permitted in Europe (Council for the European Communities, 1976);

(c) irrigation with river water containing up to 1000 FC per 100 ml is allowed in the United States (EPA, 1973); and

(d) food eaten raw is allowed to contain up to 100,000 FC per 100 g (wet weight), but preferably less than 1000 FC per 100 g (ICMSF, 1974; see also Mara, 1995).

Table 12.1 Microbiological quality guidelines for treated wastewater used for irrigation

Reuse conditions	Exposed group	Intestinal nematodes[a] (arithmetic mean no. of eggs per litre)	Faecal coliforms (geometric mean no. per 100 ml)
Unrestricted irrigation (crops likely to be eaten uncooked, sports fields, public parks)	Workers, consumers, public	≤1[b]	≤1000[c]
Restricted irrigation (cereal crops, industrial crops, fodder crops, pasture and trees[d])	Workers	≤1	No guideline required

[a] *Ascaris lumbricoides, Trichuris trichiura* and the human hookworms.
[b] Not applicable in the case of localised (i.e. drip, trickle) irrigation (but see Teltsch *et al*., 1991).
[c] 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.
[d] In the case of fruit trees, irrigation should cease two weeks before fruit is picked, and no fruit should be picked off the ground. Sprinkler irrigation should not be used.
Source: WHO (1989).

Health risks

Shuval *et al.* (1997) quantified the annual health risks which result from the consumption of raw salad crops irrigated with wastewaters treated to various faecal coliform levels, and these are compared to the EPA's (1989) acceptable annual risk of waterborne disease from drinking treated drinking water complying with current US microbial standards, as follows:*

(a) EPA's (1989) acceptable annual risk of waterborne disease: 10^{-4}
(b) Consumption of raw salad crops irrigated with raw wastewater (10^7 FC per 100 ml):
- annual risk of hepatitis A: 10^{-2}

(c) Consumption of raw salad crops irrigated with wastewater treated to the WHO (1989) guideline level of 1000 FC per 100 ml:
- annual risk of hepatitis A: $10^{-6} – 10^{-7}$
- annual risk of rotavirus infection: $10^{-5} – 10^{-6}$

Thus, as noted by WHO (1989), irrigation with untreated wastewaters is dangerous. However, the consumption of salad crops irrigated with wastewaters treated to 1000 FC per 100 ml is safer than drinking treated drinking water by 1-3 orders of magnitude.

* An annual risk of, for example, 10^{-4} means that an individual has a 1 in 10,000 chance per year of contracting the disease in question.

Shuval *et al.* (1997) also showed, in their study which estimated the cost-effectiveness of meeting various microbiological quality standards for agricultural irrigation, that the additional cost of preventing one case of enteric disease by meeting the very strict USEPA/USAID guideline of zero faecal coliforms per 100 ml (EPA, 1992) rather than the WHO guideline of 1,000 per 100 ml was of the order of US$ 1-10 millions (0.9-9 million ecu). Such an expenditure would be difficult to justify on either economic or public health grounds.

Fishpond fertilization

The WHO guidelines for effluents to be used for fishpond fertilization are an absence of trematode eggs (*Schistosoma* spp. are the only trematodes of interest in the Region) and no more than 1000 FC per 100 ml of fishpond water. No trematodes eggs are permitted because of the high asexual multiplication of the parasite in its intermediate aquatic host (water snails).

12.2 PHYSICOCHEMICAL QUALITY GUIDELINES

The microbiological quality guidelines are for the protection of human health; those for physicochemical quality are to protect plant health and maintain crop yields. In general the physicochemical quality of treated wastewaters used for crop irrigation should comply with FAO's recommendations for the quality of *water* used for irrigation (Ayers and Westcot, 1985; see also Rhoades *et al.*, 1992). For effluents from WSP treating industrial wastewaters (or municipal wastewaters containing an appreciable proportion of industrial wastes) these recommendations should be carefully checked, particularly with respect to heavy metals and other toxicants. For effluents from WSP treating domestic or normal municipal wastewaters it is generally only necessary to consider the following five parameters:

(a) electrical conductivity (as a convenient measure of total dissolved solids and hence of the salinity hazard to the crop), measured in millisiemens per metre at 25ºC;

(b) sodium absorption ratio (as a measure of the sodium or alkali hazard to the crop), defined as:

$$SAR = Na/[{}^{1}/_{2}(Ca + Mg)]^{1/2}$$

where Na, Ca and Mg are expressed in milli-equivalents per litre (= concentration in mg/l × 0.044, 0.050 and 0.082 for Na, Ca and Mg respectively).

The values of EC and SAR are interdependent – see Figure 12.1.

(c) pH : the permissible range is 6.5 – 8.4.

(d) Total nitrogen: too much nitrogen can reduce some crop yields, even though there may be a more luxuriant growth of the non-useful parts of the crop. Most crops are unaffected by up to 30 mg N/l, but sensitive crops (refer to Ayers and Westcot, 1985) can tolerate only up to 5 mg N/l.

(e) Boron: citrus and deciduous fruits and nuts are sensitive to concentrations of boron (derived from synthetic detergents) above 0.5 mg/l, but most crops can tolerate up to 2 mg/l (Ayers and Westcot (1985) give more detailed information).

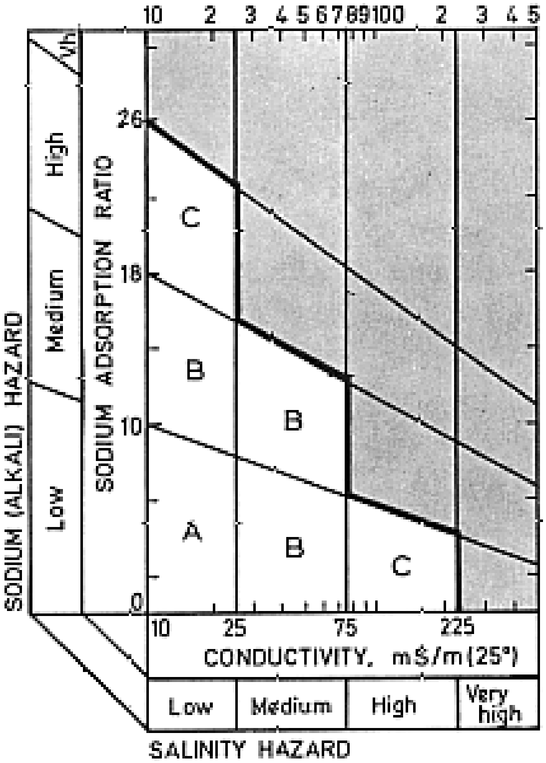

Figure 12.1 Classification of irrigation waters based on EC and SAR. Waters in regions A and B are suitable for almost all purposes. Those in region C should be avoided wherever possible, or used only under expert advice, and those in the shaded area should not be used at all (USDA, 1954)

With effluents from WSP treating domestic or normal municipal wastewaters there are few, if any, physicochemical problems. Nonetheless it is always prudent to analyse samples regularly for the above five parameters.

There is no need to consider, in the case of agricultural reuse, the effluent BOD. However, when the effluent is to be reused in aquaculture, its unfiltered BOD should not exceed 50 mg/l to prevent deoxygenation and subsequent fish kills.

12.3 AGRICULTURAL REUSE

Irrigation with WSP effluents, as with other suitability treated wastewaters, provides a good balance of plant nutrients (principally N, P and K salts), which can markedly increase crop production and reduce the requirements for expensive artificial fertilizers. For example, experiments in Cyprus (Papadopoulos and Stylianou, 1988; see Figure 4.5) showed that lint cotton yields were 2,775 kg/ha with freshwater irrigation, but 3,585 kg/ha with treated wastewater irrigation – an increase of 29 per cent.

WSP effluents bring additional benefits since the algae they contain add to the organic (humus) content of the soil and improve soil structure and its water-holding capacity. The algae also act as "slow-release" fertilizers, releasing plant nutrients as they slowly decompose in the soil even after irrigation has ceased.

An important point to consider in the design of WSP systems is that overall retention times, and therefore the land areas required, can be greatly reduced if the effluent is to be reused for restricted irrigation as opposed to unrestricted irrigation (see Design Example Nos. 2 and 3 in Annex I).

12.4 AQUACULTURAL REUSE

Although aquaculture (literally "water farming") can also refer to the cultivation of aquatic vegetables, the term is primarily used to describe the cultivation of fish. Wastewater-fed aquaculture is an age-old practice throughout Asia, and it has also been practised on a commercial scale for more than 50 years in Germany and Hungary and there is now increasing interest in many other countries (Edwards, 1992; Edwards and Pullin, 1990).

Wastewater-fed fisheries produce large amounts of fish, often up to 7–8 t/ha yr. Improved design (see Section 12.4.2) has the potential of increasing yields to over 12 t/ha yr, while at the same time ensuring the microbiological safety of the fish.

In order to be able to be more certain about the safety of wastewater-fed aquaculture, Mara *et al.* (1993) proposed a rational design procedure for wastewater-fed fishponds. This design procedure (modified to include consideration of the free ammonia concentration in the fishpond) is for the *minimal* treatment of the wastewater (in anaerobic and facultative ponds) and the *maximal* production of microbiologically safe fish.

The design steps that should be followed are:

(a) Design an anaerobic pond and a facultative pond, as detailed in Sections 6.3 and 6.4.

(b) Use equation 6.21 to determine the total nitrogen concentration in the facultative pond effluent (C, mg N/l).

(c) Design the wastewater-fed fishpond, which receives the facultative pond effluent, on the basis of a surface loading of total nitrogen of 4 kg total N per ha day. Too little nitrogen results in a low algal biomass in the fishpond and consequently small fish yields. Too much nitrogen gives rise to high concentrations of algae, with the resultant high risk of severe dissolved oxygen depletion at night and consequent fish kills. A loading of around 4 kg total N/ha day is optimal.

The fishpond area is given by the following version of equation 6.4:

$$A_{fp} = 10\ CQ/\lambda_s^{TN} \qquad (12.1)$$

Use equation 6.0 to calculate the retention time in the fishpond (θ_{fp}, days), with a fishpond depth of 1 m.

(d) Use the following version of equation 6.12 to calculate the number of faecal coliform bacteria per 100 ml of fishpond water (N_{fp}):

$$N_{fp} = N_i/(1 + k_T\theta_a)(1 + k_T\theta_f)(1 + k_T\theta_{fp}) \qquad (12.2)$$

Check that N_{fp} is ≤1000 per 100 ml. If it is not, increase θ_{fp} until it is (or consider having a maturation pond ahead of the fishpond).

(e) Use equation 6.19 or 6.20 to determine the concentration of NH_3 – N first in the facultative pond effluent (assume that the conversion of total nitrogen in the anaerobic pond to ammonia produces an ammonia concentration in the effluent of the anaerobic pond – that is, in the influent to the facultative pond – equal to 75% of the total nitrogen concentration in the raw wastewater), and then in the fishpond. The ammonia concentration is the total concentration of NH_3 and NH_4^+, sometimes termed "free and saline ammonia". In order to protect the fish from free ammonia (NH_3) toxicity, the concentration of NH_3 should be less than 0.5 mg N/l. The percentage (p) of free ammonia in aqueous ammonia solutions depends on temperature (T, K) and pH, as follows (Emerson *et al.*, 1975; see also Erickson, 1985):

$$p = 1/[10^{(pK_a - pH)} + 1] \quad (12.3)$$

where pK_a is given by:

$$pK_a = 0.09018 + (2729.92/T) \quad (12.4)$$

In equation 12.4 the temperature T is given in degrees Kelvin (K = ℃ –273.15).

Equations 12.3 and 12.4 (or Table 12.2 which is derived from them) should be used to determine the free ammonia concentration in the fishpond, assuming a pH of 7.5 (the pH range in wastewater-fed fishponds is usually 6.5-7.5).

Design Example No. 5 in Annex I shows how these equations are used.

Table 12.2 Percentage of free ammonia (NH_3) in aqueous ammonia (NH_3 + NH_4^+) solutions for 10–25˚C and pH 7.0-8.5)

Temperature (ºC)	Percentage of free ammonia in aqueous ammonia solutions at pH			
	7.0	7.5	8.0	8.5
10	0.186	0.586	1.83	5.56
11	0.201	0.633	1.97	5.99
12	0.217	0.684	2.13	6.44
13	0.235	0.738	2.30	6.92
14	0.253	0.796	2.48	7.43
15	0.273	0.859	2.67	7.97
16	0.294	0.925	2.87	8.54
17	0.317	0.996	3.08	9.14
18	0.342	1.07	3.31	9.78
19	0.368	1.15	3.56	10.50
20	0.396	1.24	3.82	11.20
21	0.425	1.33	4.10	11.90
22	0.457	1.43	4.39	12.70
23	0.491	1.54	4.70	13.50
24	0.527	1.65	5.03	14.40
25	0.566	1.77	5.38	15.30

Source: Emerson *et al.* (1975).

Fish yields

Good fishpond management can be achieved by having small ponds, up to 1 ha in area, that can be stocked with fingerlings, fertlized with facultative pond effluent and then harvested 4 months after stocking. During this time the fingerlings will have grown from 20 g to 250 g. Partially draining the pond will ensure that almost all the fish can be harvested. This cycle can be done once or twice per year. Allowing for a 30% fish loss due to mortality, poaching and consumption by fish-eating birds, the annual yield is:

(3 × 250 g fish per m^2) (10^{-6} tonnes/g) (10^4 m^2/ha)

× (1–2 harvests per year) (0.7, to allow for the 30% loss)

= 5–10 tonnes of fish per hectare per year.