USERS MANUAL

For

IRRIGATION WITH TREATED WASTEWATER

FAO Regional Office for the Near East

Cairo 2003

USERS MANUAL
For
IRRIGATION WITH TREATED WASTEWATER

FAO Regional Office for the Near East

Cairo 2003

TC/D/Y5009F/1/10.03/100

ACKNOWLEDGEMENT

The FAO Regional Office would like to sincerely thank the following parties for their valued efforts in the preparation, editing, translation and the proof reading of this Manual.

- Mr. Ioannis Papadopoulos, Agricultural Research Center in Cyprus.
- Mr. Selim Sarraf, former FAO Regional Irrigation and Water Resources Officer, RNE.
- Mr. Yusri Sultan, former FAO Regional Translation and Publications Officer, RNE.
- Mr. Ghassan Hamdallah, Regional Soils Officer, RNE.
- Mr. Kumars Khosh-Chashm, Regional Adviser, Water Supply, Sanitation and Housing, WHO/CEHA, Alexandria.
- Mr. Saqr Al-Salem, Information and Technology Transfer Adviser, WHO CEHA, Amman, Jordan.
- Members of the IATF, representatives of these organizations:
  - ACSAD (Regional Office in Cairo)
  - AOAD (Regional Office in Cairo)
  - CEDARE
  - ESCWA
  - ICARDA (Regional Office in Cairo)
  - UNESCO (Regional Office in Cairo, ROSTAS)
  - WHO (Regional Office in Alexandria, EMRO)

FOREWORD

Water scarcity is a widely acknowledged fact throughout the Near East. Some 16 counties in the Region fall below the deficiency level of 500 m^3 per capita per annum of the renewable water resources. Because almost all accessible fresh water resources in the Region have been already committed, it is only natural to turn to non-conventional water resources for satisfying the accelerated rates of demand for fresh water. Several countries in the Region (like the GCC states) made wide steps towards desalination of seawater for meeting the urban demands of their people. However, due to the high cost attached to this technology; its adoption is, generally, limited to domestic purposes in high-income countries. Other options of utilizing drainage water or blending it with fresh water for irrigation, is already common in several countries.

The treated wastewater produced as effluents form sewage systems of urban communities represents another non-conventional renewable water, which could be an attractive and cheap source to be used for agriculture, nearby the urban centers. However, due to the different nature of this water (its load of mineral, organic and biological constituents); its reuse should be carefully administered and professionally monitored and managed to check its potential risks and threats to the soil, water, crops irrigated with it, as well as to the whole environment.

The present Manual which is produced in the Arabic and English languages, by the FAO Regional Office, in coordination with the WHO Regional Office, is a step towards promoting the use of treated wastewater for agriculture (mainly irrigation), with adequate technical information given for the safe and efficient use of this "special" water, with the minimum risk and maximum environmental protection.

CONTENTS

1. INTRODUCTION

The Near East population has increased considerably and the need for food and water is continually growing. Traditionally, this situation has been met by simply increasing water supply and/or expanding agriculture. Today this solution is nearing its natural limits. In a number of countries in the Region, the actual consumption of water is fast approaching the limits of resources available. Moreover, agricultural land is becoming rare. For most countries of the Region water thus became the main factor limiting their development and consequently a major economic, social and political challenge. Therefore, the use of non-conventional water resources and the overall management of water in an efficient and effective way, became pressing problems in most of the Near East Countries. Treatment of wastewater and its use for irrigation is an attractive option, particularly in arid and semi-arid areas of the Region as it represents an additional, renewable, reliable source of water and fertilizer as well. Solid wastes are less used and more difficult to be applied. More precautions, therefore is needed due to the sludge load of heavy metals and of parasite eggs.

The use of wastewater and solid wastes, besides positive effects may also have adverse impacts on public health and the environment, largely depending on wastewater and sludge characteristics, the degree of purification and the method and location of use. Soil, groundwater and surface water pollution are among the most important potential disadvantages of the wastewater use. However, scientifically sound planning and effective management of the irrigation or fertilization regimes can minimize these disadvantages to the level of environmental insignificance effects. Because of this, it is important to provide farmers with the information needed to help them improve management of treated wastewater used for irrigation and solid wastes used for fertilization. It is now feasible since considerable information and experience have been acquired at country and regional levels from successfully implemented reuse projects. In this manual an attempt was made to:

- Consolidate the knowledge and experience gained on reuse in countries of the Region,
- Provide sets of agronomic practices, within an integrated farm management approach.

In 1989, WHO published the "**Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture**". In the same year, UNEP and WHO, jointly published the "**Guidelines for the Safe Use of Wastewater and Excreta in Agriculture and Aquaculture**", with emphasis on environmental and public health protection. In 1991 UNEP and FAO, jointly published the **"Environmental guidelines for wastewater reuse in the Mediterranean Region"**. These were followed by an FAO publication on "**Wastewater Treatment and Use in Agriculture**" in 1992. These guidelines have been supporting many developing countries to implement or upgrade environmentally sound and safe wastewater use systems adapted to their own technical, socio-economic and cultural conditions. The FAO Regional Office in Cairo also produced in 1995 a publication on **"Wastewater management and environmental protection in the Near East Region"** and during 1991-93 seven technical bulletins intended to help the countries of the Region for best use of wastewater in agriculture. The current FAO/WHO publication on **"Treated Wastewater Users Manual"** is intended to help farmers, irrigation operators, and the extentionists who are in close contact with the farmers, irrigationists, other users in the forestry and landscaping.

1.1 Objectives

Wastewater reclamation and reuse has proved to be a realistic option for new sources of water to meet shortage and cover increasing water needs in the Near East countries, but also to meet wastewater disposal regulations in these countries aimed at protecting the environment and public health. In addition, from the environmental viewpoint, reclamation and reuse of treated municipal wastewater for irrigation could be probably the most safe and feasible disposal approach.

The transfer of the available research data, management experiences and know-how gained during the last years were used in the preparation of this manual. Different from other manuals on "Treatment and Reuse" this manual is meant to provide the end-users, farmers, with recommendations, guidelines and management procedures to optimize crop production in a safe and environmentally sound ground. In this respect, this manual provides an integrated preventive management measures to potential problems. The present manual:

- is written in a simple way;
- literature in the text is limited;
- legal, institutional and similar aspects are very concisely presented; and
- agronomic aspects of interest to the farmer like irrigation, fertilization, selection of crops, are extensively covered.

Aspects of planning, design, operation and maintenance of wastewater treatment plants are not covered. This manual assumes that treated wastewater of a certain quality is already available for irrigation, and therefore, the “Best Management Practices” (BMP) are proposed to achieve best possible results on sustainable basis.

We do hope that this manual will contribute positively to efficient and safe water reuse and that it will secure sustainability in a way to combine environmental and public protection with economic results.

1.2 Overall water demand in the Near East

While the Near East covers 14% of the total area of the world and contains 10% of its population, its water resources are only about 2% of the total renewable water resources of the world.

Reuse of municipal wastewater is not a new concept. With the increase in water demand as population grows and the improvement of standard of living, wastewater reuse is getting an increasing role in the planning and development of additional water supplies. This is particularly important for the Near East countries since they are mostly arid or semi-arid. They have low rainfall, mostly seasonal and with erratic distribution. Moreover, quality of water is steadily deteriorating.

Use of wastewater for beneficial purposes such as irrigation has been practiced, although without control, in many countries of the Region. Currently, the quantity of treated wastewater used for irrigation in Near East countries is estimated to be 1 200 million m^3/year (Table 1). In several countries of the Region, there are growing problems of providing adequate water supply and new approaches i.e. desalination and wastewater reuse are adopted. This will help solving partially the problem of water scarcity and coping with the pressing environmental problem of wastewater disposal. In several countries of the Near East, the need for water is becoming even more acute and pressing. Because of this, wastewater treatment and its use is becoming a necessity. However, protecting public health and the environment are concerns associated with reuse, which have not been seriously considered in a number of countries. The health and overall risks should be within acceptable levels, safeguarding public health and protecting the environment.

Table 1. Near East countries using the largest quantities of treated wastewater (Aquastat, FAO, 1997)

Country	Treated wastewater $10^6 m^3/yr$	In % of total	In % of water withdrawal of the country
Egypt	200	16.7	0.36
Kuwait	52	4.3	9.67
Saudi Arabia	217	18.1	1.28
Syria	370	30.8	2.57
United Arab Emirates	108	9.0	5.12
Other 24 countries	253	21.1	0.06
Total Near East	1 200	100.0	0.23

1.3 Benefits and limitations of wastewater reuse

Wastewater and other low quality waters are significant in the overall water resources management. By releasing fresh water sources for domestic supply and other priority uses, reuse makes a contribution to water and energy conservation and improves quality of life. Wastewater can have positive agronomic results. Moreover, wastewater use schemes, when properly planned and managed, can have positive environmental and health impact, besides providing increased agricultural yields. However, reuse of wastewater may also have adverse effects on the environment and public health.

2. SUITABILITY OF TREATED WASTEWATER FOR IRRIGATION

Wastewater is unique in composition. Physical, chemical and biological constituents which occur in this water must be taken into consideration. In this chapter the problems are shortly presented and more emphasis is attached to the solutions and some integrated management approaches are presented in order to alleviate and/or overcome these problems.

2.1 Chemical and physical characteristics of wastewater

The constituents of concern in wastewater are given in Appendix I. However, for proper management approaches, the main constituents of concern to farmers in Near East countries are:

- **Suspended solids** since filtration may be needed particularly with micro-irrigation systems;
- **Nutrients** in order to adjust fertilization;
- **Salinity** in order to estimate leaching fraction and select appropriate cropping pattern; and
- **Pathogens** for precautionary measures, selecting cropping pattern and choosing the appropriate irrigation system.

2.1.1 Wastewater treatment

The main objective of treatment is to produce treated effluents of suitable and acceptable level of risk for human health and the environment. In this respect, the most appropriate wastewater treatment is that which provides and secures effluents with the chemical and microbiological quality required for a certain specific use at low cost and minimal operational and maintenance requirements. Wastewater treatment plants, regardless of the type treatment, reduce organic and suspended solids, remove wastewater chemical constituents that may be toxic to crops as well as biological constituents (i.e. pathogens) which are of main concern to public health in general.

The different degrees of conventional treatment are:

- **Preliminary**. Removal of coarse solids and other large fragments from the raw wastewater.
- **Primary**. Removal of settleable organic and inorganic solids as well as floating materials.
- **Secondary**. Removal of the residual organic and suspended solids from primary treated wastewater.
- **Tertiary and/or advanced**. Removals of specific wastewater constituents like nutrients and heavy metals, which are not removed by secondary treatment. Disinfection, usually with chlorine, is used to reduce microbiological constituents.

The most widely used natural biological treatment is the "Wastewater Stabilisation Ponds", which may be designed to achieve different degrees of wastewater purification. The system consists of three phases:

- Anaerobic ponds, normally having earth embankments with depth between 2 and 5 m and function as open septic tanks with gas release to the atmosphere;

- Facultative ponds also formed by earth embankments, where aerobic biological reactions could proceed in the middle layer through facultative bacteria; and
- Maturation ponds providing tertiary treatment and further pathogen reduction.

2.1.2 Treatment and wastewater quality considerations

In an integrated approach of treatment and use of the wastewater for irrigation, the assurance of treatment reliability and continuous monitoring are highly desirable since these are out of the farmer's control. In the planning and implementation of new wastewater reclamation and reuse projects, the intended wastewater reuse application should govern the degree of wastewater treatment required and the reliability of wastewater treatment process and operation. However, in existing treatment plants the quality of treated effluent is already known and the farmers are obliged to modify their management to the water quality provided to them. In general, in countries of the Near East little intervention if any at all, is done concerning the chemical composition of treated wastewater. In this respect, the management approaches proposed to the farmers to alleviate potential problems, are mostly presented and discussed.

2.1.3 Wastewater quality criteria for irrigation

The chemical and physical quality characteristics are the same as applied to any irrigation water. In this respect, the general guidelines presented in (Table 2) can be used to evaluate treated wastewater for irrigation purposes in terms of the chemical constituents such as the dissolved salts, relative sodium content and toxic ions. The procedure remains the same as with other waters.

Salinity

In most countries the water used for municipal supply is the best water quality available and it is usually of low salinity. However, under water scarcity conditions salinity may be a problem. The quantity and kind of salts present are important to assess the suitability of treated wastewater for irrigation. Potential problems are related to the total salt content, to the type of salt or to excessive concentration of one or more elements (Ayers and Westcot, 1985).

To overcome the problem of salinity, at farmers level, more emphasis must be given to the following approaches:

a) Select crops tolerant to the wastewater salinity and still be on the profitable site. (Table 3) may help farmers to select appropriate cropping pattern depending on the salinity of wastewater and salt tolerance of crops. With salinity less than 3 dS/m, and good management, most fruits and vegetables can be produced. As salinity rises the selection of crops becomes difficult and, except for certain vegetables, the choice is mostly restricted to fodder crops.

b) Select salt tolerant crops with the ability to absorb high amounts of salts without particular toxicity effects (salt harvesting crops). In case of irrigation with treated wastewater of high salinity, particularly in areas with limited rain and natural leaching, for long term sustainable reuse salt harvesting crops may help reduce salinity build-up in the soil. Some recommended crops are sudax, sorghum, bermuda grass and barley.

c) Select irrigation system with uniform application, high efficiency and providing the possibility for more frequent irrigation. With pressurised irrigation systems particularly with drip and minisprinklers, the salinity permissible levels of irrigated crops could be higher. With such systems the guidelines concerning crop tolerance to salinity (Maas, 1974), are only rough estimates. Better yields can be achieved with those critical levels when appropriate management with modern irrigation systems are used (Goldberg et al., 1971; Papadopoulos et al. 1987).

d) Scheduling of irrigation. The amount of irrigation water and the frequency of water application are crucial factors to control salinity. With micro-irrigation systems, irrigation could be more frequent and soil salinity in the vicinity of the irrigated plant could be maintained at a lower level.

Table 2. Guidelines for interpretation of water quality for irrigation (FAO 1985)

Potential Irrigation Problems	Units	Degree of restriction on use		
		None	Slight to Moderate	Severe
Salinity				
EC_w[1]	dS/m	< 0.7	0.7 - 3.0	> 3.0
or				
TDS	mg/l	< 450	450 – 2000	> 2000
Infiltration				
SAR[2] =0 - 3 and EC_w =	dS/m	> 0.7	0.7 - 0.2	< 0.2
=3 – 6 =		> 1.2	1.2 - 0.3	< 0.3
=6 – 12 =		> 1.9	1.9 - 0.5	< 0.5
=12 – 20 =		> 2.9	2.9 - 1.3	< 1.3
=20 – 40 =		> 5.0	5.0 - 2.9	< 2.9
Specific ion Toxicity				
Sodium (Na)				
Surface Irrigation	SAR	< 3	3 – 9	> 9
Sprinkler Irrigation	meq/l	< 3	> 3	
Chloride (Cl)				
Surface Irrigation	meq/l	< 4	4 – 10	> 10
Sprinkler Irrigation	meq/l	< 3	> 3	
Boron (B)	mg/l	< 0.7	0.7 - 3.0	> 3.0
Miscellaneous effects				
Nitrogen (NO_3-N)[3]	mg/l	< 5	5 – 30	> 30
Bicarbonate (HCO_3)	meq/l	< 1.5	1.5 - 8.5	> 8.5
pH		Normal range 6.5 - 8.4		

1 EC_w means electrical conductivity in deciSiemens per meter at 25° C.
2 SAR means sodium adsorption ratio.
3 NO_3 - N means nitrate nitrogen reported in terms of elemental nitrogen. NH_4-N and organic-N should be also tested with wastewater.

e) Leaching is a common approach by farmers but not the best probable solution in the case of water scarcity, inadequate drainage or shallow water table. In a long term the total quantity of salt applied in the soil with the wastewater (salt in) and the rate at which salt is removed by leaching and crop uptake (salt out) should be approximately the same. Which approach is to be accepted for the "salt out" is very important in selecting cropping pattern and management for the effective use of wastewater for irrigation (Papadopoulos, 1991). Salt harvesting crops of economical value like sudax and sorghum give good results. Cultivating a salt harvesting-crop every year or periodically is recommended.

f) Soil polymers and/or other soil conditioners although effective under certain conditions for a certain period for open field crops are not recommended. Their half-life is usually short and their price is high.

g) Drainage. One of the measures necessary to prevent irrigation-induced waterlogging and salinization in arid and semi-arid regions is the installation of **drainage facilities**. Drainage, in combination with adequate irrigation scheduling, allows for the leaching of excess salts from the plant root zone.

Table 3. Tolerance to salinity of some cultivated crops (Adapted from FAO, 1985)

Electrical Conductivity of irrigation water (dS/m, and mg/l)*					
<2 <1280	**2-3 1280-1920**	**3-4 1920-2560**	**4-5 2560-3200**	**5-7 3200-4480**	**>7 >4480**
Citrus	Fig	Sorghum	Soybean	Safflower	Cotton
Apples	Olives**	Groundnut	Date palm***	Wheat	Barley
Peach	Broccoli	Rice	Harding grass	Sugar beet	Wheat grass
Grapes	Tomato	Beets	Trefoil	Rye grass	
Strawberry	Cucumber	Tall fescue	Artichokes	Barley grass	
Potato	Cantaloupe			Bermuda grass	
Pepper	Watermelon			Sudax	
Carrot	Spinach				
Onion	Vetch				
Beans	Sudan grass				
Corn	Alfalfa				

*1dS/m = 640 mg/l
** Much higher EC levels were reported (up to 6dS/m) for olives in Tunisia
*** Similar higher EC levels were also reported for date palm trees in Algeria (up to 7-8 dS/m).G. Abdel-Gawad, ACSAD

Alkalinity

Dispersion of soil colloidal phase, stability of aggregates, soil structure and permeability for water, are very sensitive to the type of exchangeable ions present in irrigation water. The increase in soil alkalinity, which may occur with treated wastewater due to high Na concentration even though leaching is allowed, reduces soil permeability for water, particularly at the soil surface, since soil clays tend to disperse and swell from the increased level of exchangeable Na. However, at certain sodium adsorption ratio (SAR) the infiltration rate increases or decreases with the salinity level. Therefore, SAR and EC_w should be used in combination to evaluate eventual potential problems (Rhoades, 1977).

The following management solutions are recommended:

a) Chemical amendments. The use of calcium source amendment such as gypsum is widely accepted for amelioration of soils with high percentage of Na in the Cation Exchange Capacity (CEC) or whenever water high in SAR is used for irrigation. Na in soil is exchanged by Ca from gypsum and dispersion of the colloidal phase is reduced. Application of gypsum should be repeated periodically depending on the Na content in water and the CEC of the soil. The farmers are advised to seek professional help to estimate the amount and frequency of the gypsum application required.

b) Adapted Irrigation system. Crust formation at the soil surface is the result of irrigating with water high in SAR. The degree of the problem, however, is not the same with all irrigation systems. In general, *the surface irrigation systems* with water high in SAR create thick surface crust. Similar results are obtained with sprinklers of high discharge capacity. This way, the soil permeability for water as well as soil aeration and emergence of the seeds are affected. With low capacity minisprinklers and drippers of low discharge rate the formation of surface soil crusting is reduced, the duration of irrigation is extended and sufficient time is allowed for water penetration into the soil (Papadopoulos and Stylianou, 1988a).

c) Organic matter. The alkalinity problem could also be solved by addition of organic matter like straw, other plant materials and organic manure.

Specific ion toxicity

The most toxic ions generally occurring in treated wastewater are sodium (Na), chloride (Cl), and boron (B) which is causing most prevalent toxicity cases. Boron is one of the essential elements to plants; hence, B concentrations exceeding 0.5 mg/l could be toxic to sensitive crops (Table 4).

Measures recommended to overcome ion-toxicity:

- With sensitive crops, B-toxicity is difficult to correct without changing the crop or the water supply (Ayers, 1977). For water with certain level of boron, one should select crops which can tolerate that concentration.
- Leaching may help to maintain boron concentration in the soil at levels comparable to those of the water used for irrigation (Bernstein and Francois, 1973). Depending on the soil, a certain additional amount of irrigation water is usually added to the estimated irrigation requirement.
- The frequent irrigation dilutes boron in the soil solution.
- With the use of micro-irrigation systems, water application could be more uniform and frequency of irrigation could also be controlled.

Table 4. Relative tolerances of plants to boron in irrigation water (Adapted from Ayers, 1977)

Sensitive (1mg/l)	**Semitolerant (2 mg/l)**	**Tolerant (3 mg/l)**
Citrus	Bean	Carrot
Avocado	Bell pepper	Lettuce
Apricot	Tomato	Cabbage
Peach	Corn	Onion
Cherry	Olives	Sugar beet
Grapes	Radish	Date palm
Apple	Pumpkin	Asparagus
Pear	Wheat	Turnip
Plum	Potato	
Strawberries	Sunflower	

Chloride (Cl) and sodium (Na) are less toxic than boron. In arid and semiarid regions due to the relatively high Na and Cl contents of the domestic water, treated wastewater may have high concentration of these elements. With proper irrigation management, (irrigation system, frequency of irrigation, leaching) toxicity effects can be reduced significantly, presenting no real constraint for reuse.

Trace elements and heavy metals

They are the main problem with treated wastewater reuse in countries with heavy industry. The metals that may be present in sewage {Cadmium (Cd), copper (Cu), molybdenum (Mo), nickel (Ni) and zinc (Zn)} can pose significant health hazards to humans and animals and also may affect the irrigated crops. These metals in most cases are accumulated in the crop, and could adversely affect humans or domestic animals, feeding on these crops. Because of this, many developed countries have set maximum permissible cumulative loading of metals to agricultural lands. Heavy metals are discussed in more details in connection with sludge. Biswas (1987) reported permissible heavy metal loading in some European countries (Table 5).

Table 5. Maximum permissible cumulative loading with metals in kg/ha for agricultural land per year (Adapted from Biswas, 1987).

Country	Cd	Cu	Cr	Pb	Hg	Ni	Zn
France	5.4	210	360	210	2.7	60	750
Germany	8.4	210	210	210	5.7	60	750
Netherlands	2.0	120	100	100	2.0	20	400
UK	5.0	280	1000	1000	2.0	70	560

Table 6. Recommended limits for trace elements in reclaimed water use for irrigation[a]

Constituent	Long- term Use[b] (mg/l)	Short- term Use[c] (mg/l)
Aluminium	5.0	20.0
Arsenic	0.10	2.0
Beryllium	0.10	0.5
Boron	0.75	2.0
Cadmium	0.01	0.05
Chromium	0.1	1.0
Cobalt	0.05	5.0
Copper	0.2	5.0
Fluoride	1.0	15.0
Iron	5.0	20.0
Lead	5.0	10.0
Lithium	2.5	2.5
Manganese	0.2	10.0
Molybdenum	0.01	0.05
Nickel	0.2	2.0
Selenium	0.02	0.02
Vanadium	0.1	1.0
Zinc	2.0	10.0

[a]Adapted from : National Academy of Sciences - National Academy of Engineering (1973)
[b]For water used continuously on all soils
[c]For water used for a period of up to 20 years on fine - textured neutral or alkaline soils

Recommended maximum concentrations of metals in irrigation water are presented in (Table 6).

Considerations and management aspects for trace elements and heavy metals

The question, for the Near East countries, is whether heavy metals represent a serious health and/or environmental problem. In general, heavy metals and trace elements should not be considered as a pressing or a serious problem for two main reasons:

- The concentration of heavy metals in municipal wastewater is low due to low heavy industry activities, and
- The soils of the Region are mostly with high CaCO3 and of pH above 7, which inactivate the heavy metals and reduce their mobility and availability to crops. In such conditions the metals are rendered unavailable and loading and concentration higher than those presented in Tables 6 and 7 could be accepted.

Therefore:

1. Heavy metals in treated wastewater under calcareous soil conditions should not be considered, as real problem and no particular management is required.
2. Under acid conditions (few cases in the Region :pH<7) heavy metals could be a problem and the following measures at farmers level are recommended:
   - Liming (use of calcium carbonate). In this way soil pH is increased and thus the solubility of heavy metals is reduced.
   - Avoid using acid fertilizers.
   - Select crops tolerant to certain heavy metals.
   - Select crops having no biomagnification characteristics (accumulation of certain heavy metals by specific crops and/or parts of the crop).

Farmers should be encouraged to consult professionals before making the final decision on the measures needed.

Crop nutrients in treated wastewater

The fertilizing potential of treated wastewater due to nutrients might be an asset for crops but might also be a source of pollution for the environment depending mainly on the farmers management. Nutrients are a specific characteristic of treated wastewater of particular interest to the farmers. Because of this, a Code of Good Fertilization Practice is developed and introduced in this manual. It is intended to give new dimensions to the use of treated wastewater for irrigation in a rational, profitable and environmentally sound way.

Nutritional value of treated wastewater

The suspended, colloidal and dissolved solids present in wastewater contain macro- and micronutrients, which are essential for crop nutrition. However, the nutrient content of the wastewater may exceed the plant needs and thus pose a potential source for underground water pollution. It may also cause problems related to excessive vegetative growth, delayed or uneven maturity, or reduced quality of the irrigated crops. Calculating the nutrients present in the treated effluent as part of the overall fertilization program of the irrigated crops is necessary. In this respect wastewater analysis is required at least once at the beginning of the growing season.

Nutrients in wastewater occurring in quantities important to agriculture and landscape management include nitrogen, phosphorus and occasionally potassium, zinc, boron, and sulphur. Other macro and micronutrients may also be present. In addition, the organic matter in the wastewater beside its long-term effect on soil fertility, it can also contribute to the soil structure stability.

For correct estimation of the nutrient capacity of wastewater, based on its chemical analysis, (Table 7) could be used.

For certain crops perhaps no additional fertilizers are needed. Similarly, in places where fertilizers are of concern, wastewater, if available, could give the answer for a high yield of good quality.

Nitrogen content of municipal wastewater following secondary treatment ranges from 20 to 60 mg/l. The N in treated wastewater could be in excess of the crop needs. Knowledge about the N concentration in the wastewater and the proper management of the load of NPK are essential to overcome problems associated with eventual high N concentration.

Phosphorus in wastewater from secondary treatment systems varies from 6 to 15 mg/l (15-35 mg/l P_2O_5) unless removal is accomplished during treatment. Evaluation of P in the treated wastewater should be made in conjunction with soil testing for fertilisation planning.

Potassium concentration in wastewater is not known to cause adverse effects on plants or the environment. It is an essential macronutrient and affects positively soil fertility, crop yield and quality. The range of K in secondary treated wastewater is 10 to 30 mg/l (12-36 mg/l K_2O). This amount must be taken into consideration in formulating the fertilization programme according to crop needs.

Table 7. Load of nutrients with various quantities of irrigation water applied

Irrigation water m^3/ha/year	Concentration of a nutrient in wastewater (mg/l)								
	5	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**50**
	Nutrients added (kg/ha/year)								
1000	5	10	15	20	25	30	35	40	50
2000	10	20	30	40	50	60	70	80	100
3000	15	30	45	60	75	90	105	120	150
4000	20	40	60	80	100	120	140	160	200
5000	25	50	75	100	125	150	175	200	250
6000	30	60	90	120	150	180	210	240	300
7000	35	70	105	140	175	210	245	280	350
8000	40	80	120	160	200	240	280	320	400
9000	45	90	135	180	225	270	315	360	450
10000	50	100	150	200	250	300	350	400	500

Other nutrients. Most of wastewaters usually contain adequate sulphur, zinc, copper and other micronutrients. Attention must be given to boron. Treated wastewater contains enough boron to correct any boron deficiencies. Of greater concern, however, that this element is usually found in excess in certain wastewater's creating problems of phytotoxicity. (Table 4) may help the farmers to select crops in relation to their tolerance to boron. To overcome the B problem the same measures for highly soluble salts are recommended (selection of crop, leaching, scheduling of irrigation, and the irrigation system).

In general, farmers should remember about boron that:

- **Fruit trees are more sensitive to B than vegetables**
- **In case of relatively high B concentration the wastewater annual crops are to be preferred.**

Nutrient load of NPK

The concentration of N and P in the secondary treated wastewater could vary substantially depending on the source of the primary wastewater and the treatment process. From conventional treatment plants, the N and P concentrations are usually higher than with the aerated lagoons and oxidation ponds. In general, N and P are reduced during treatment but K remains approximately at levels found in untreated wastewater.

The amounts of N, P and K applied per hectare with 1000mm irrigation by wastewater with concentration as shown in (Table 8) are given. Evidently, the load of nutrients depends on the overall amount of water applied. It is assumed that for high nutrient efficiency, irrigation should be based on crop water requirements.

Table 8. Fertilization potential through wastewater (FAO/RNEA, 1992)

	N	P	K
Nutrient concentration (mg/l)	40	10	30
Yearly nutrient added (kg/ha) through application of 10 000 m^3 water/ha (1000mm)	400	100	300

Such fertilizer application rates supply all or more of the N normally required by a number of agricultural crops and also much of the P and K. In this respect, careful consideration should be given to each crop separately for estimating eventual supplementary fertilizer requirements. In some cases some nutrients in wastewater may be in excess of that required for a balanced crop growth and may potentially stimulate excessive growth of the vegetative parts of the crops rather than the flowers and seeds. This may be a problem for crops as sunflower, cotton and some fruits. In case of excess of nutrients an appropriate cropping pattern and/or mixing of the treated wastewater with fresh water to reduce the nutrient application are methods suggested to solve the problem.

Control of the problem of eventual excess N in wastewater

a) Estimate the concentration of N. The chemical analysis for elemental N is required. Based on this analysis the farmer could calculate the amount of N added to the soil through the quantity of wastewater used. This amount should be subtracted from the fertilizer amount needed by crops. For easy estimations the farmer should remember that:

- **1 ppm (part per million) = 1 mg/l = 1 g/m3 in irrigation water**

Therefore, the amount of N and other nutrients applied to the soil with wastewater depends on the amount of irrigation water. The farmers should be aware how to irrigate.

b) Select the crop based on the N level. Selection of crop depending on N in treated wastewater is needed for two purposes:

- **Making the best possible use of N from wastewater.**

  If nitrogen present in wastewater is not adequate, supplemental fertilizer nitrogen is needed for satisfactory crop yields. From the standpoint of long-term application of wastewater, N input levels should be adjusted to compensate for N removal by the harvested portion of the crop plus expected losses from the system by volatilization and leaching. The N, P, K requirement of main crops is given in the following chapters.

- **Avoiding nitrate pollution.**

  Some crops are highly effective in removing nitrogen from soil, which may eventually move down in the form of NO3-N deeper in soil and contaminate underground water. Grasses such as Sudan grass, Bermuda grass, Sudax, and Rhodes grass remove N efficiently from the soil. These crops are effective in removing nitrates for the following reasons:

  - they have abilities to accumulate nitrate;
  - several cuts are possible in one season so that more growth of the crop can be achieved;
  - their nitrate content does not decrease with age; and
  - they are deep-rooted crops

c) Scheduling of irrigation. Since nutrients are always present in treated wastewater, then any amount of irrigation water above the crop water requirement may create a problem. The problem could be an environmental or an agronomic one or both. The farmer should remember that with wastewater irrigation it is even more important to follow proper scheduling of irrigation than that with water of good quality.

- **Amount of water.**

  Crops must be irrigated according to their crop water requirements. It could be stressed that since the amount of irrigation water is different from place to place due to climatic conditions, the nutrients in wastewater could be in excess or inadequate for the same crop under the same soil fertility conditions in different places. Similarly, wastewater of the same quality could have adverse environmental impact in one place but be very safe in another place. Because of this, it is difficult to give absolute numbers for fertilization with wastewater, while with fresh water it is different case.

- **Frequency of irrigation.**

  The farmers should be also aware that with crops at full growth stage, the amount of water per irrigation must be always the same to reach a certain soil depth where the active roots are concentrated. However, since the absolute amount of irrigation water varies with climatic conditions the frequency of irrigation should be changed. The amount of water per irrigation must remain the same.

d) Irrigation system. To avoid pollution from nitrates the irrigation system should provide a uniform water application. Evidently, the higher the efficiency of irrigation system, the higher N uptake efficiency by crops is obtained and the less is the potential for nitrate losses and pollution. Proper designed, installed, and managed drip and micro-irrigation systems give higher irrigation efficiency. With furrow irrigation the farmers are advised to create short furrows especially if laser leveling is unavailable.

e) Mixing treated wastewater with fresh water, if available.

Other problems

Attention should be given to treated wastewater constituents which cause clogging of the irrigation systems. Clogging problems with sprinkler, minisprinkler and drip irrigation systems might be a serious problem. Growths (slimes, bacteria, etc.) in the sprinkler head, emitter orifice or supply line, cause plugging as do heavy concentrations of algae and suspended solids. The most serious clogging problems occur with drip systems. Filtration may be required just before use. This makes management of drip irrigation system using treated wastewater needing more attendance.

Solutions suggested to the plugging problem are:

- To avoid problems due to suspended algae that are accumulated on the water surface and those problems due to sludge accumulation in the bottom of the reservoir, water should be pumped at a depth of about one meter from the water surface.
- Filtering. Depending on the concentration of suspended solids, algae and other impurities, gravel, sand or other filters are required with micro-irrigation systems.
- Selection of the irrigation method. In case of impurities and in absence of filtering system, micro-irrigation systems should be avoided. Depending on the crop, sprinklers could be a better choice. Even surface irrigation might be the preferred one.

2.2 Biological quality criteria

Water quality criteria and guidelines are essential foundations for successful implementation of any reclamation project with wastewater. Microbiological water quality is most important for field workers as well as for the public who might be exposed to reclaimed water directly or indirectly. Reuse, depending on microbiological quality, could be restricted or unrestricted. In this manual, the microbiological quality criteria are not developed. It is assumed that each country has some guidelines and/or regulations with which the farmers are obliged to conform with. The farmers, however, should be aware of these guidelines as well as with the quality of wastewater provided to them in order to apply appropriate management within acceptable health and environmental risk. Countries which have not yet developed their national guidelines are advised to apply the WHO guidelines (Table 9). It should be stressed that every country should have its own guidelines and code of practices. In this context, the guidelines used in Cyprus are presented as an example (Appendix II).

2.3 Good Code of Practice

In every country a **"Good Code of Practice"** is even more important for the farmers than the quality guidelines for wastewater reuse. The Code of Practice consists of suggestions and recommendations, supplementing the guidelines or standards, intended to help farmers to better manage the use of reclaimed wastewater in the best possible way. The Code of Practice refers to the management of the wastewater for irrigation, the irrigation systems and methods and cautions related to harvesting and other details. The Code could be different from one country to another. An example of a Code, which supplements the guidelines, is presented in Appendix III. This code of practice is addressed to both treatment operators (part A and C) and farmers (part B) to demonstrate/guide them how to manage wastewater for irrigation, which crops to select, which irrigation systems to use depending on the crop and the quality of the wastewater. Emphasis is also attached to the precautionary measures, which will ensure to the farmer safe reuse and good economic results. In this way, any farmer will be in the position to protect himself, the nearby population, the consumers and the environment.

2.4 Prerequisites for efficient and effective reuse

Sound program for fertilization and irrigation are the main and most important parameters for long term sustainable irrigation with wastewater. Soil and wastewater analyses are needed in order to decide about the fertilization program. Fertilization with wastewater is different from that with fresh water.

Table 9. Recommended Microbiological Quality Guidelines for Wastewater Use in Agriculture (WHO 1989)[1]

Category Reuse conditions	Exposed Group	Intestinal nematodes[2] (arithmetic mean no. of eggs per litre[3])	Faecal coliforms (geometric mean no. per 100 ml[3])	Wastewater treatment expected to achieve the required microbiological quality
Irrigation of crops likely to be eaten uncooked, sports fields, public parks[4]	Workers, Consumers, Public	≤ 1	≤ 1000[4]	A series of stabilization ponds redesigned to achieve the microbiological quality indicated, or equivalent treatment
Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees[5]	Workers	≤ 1	No standard recommended	Retention in stabilization ponds for 8-10 days or equivalent helminth and faecal coliform removal
. Localized irrigation of crops in category B if exposure of workers and the public does not occur	None	Not applicable	Not applicable	Pre-treatment as required by the irrigation technology, but not less than primary sedimentation

1.In specific cases, local epidemiological, socio-cultural and environmental factors should be taken into account, and the guidelines modified accordingly.
2.Ascaris and Trichuris species and hookworms.
3.During the irrigation period.
4.A more stringent guidelines ($\leq$ 200 faecal coliforms per 100 ml) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact.
5.In the case of fruit trees, irrigation should cease two weeks before fruit is picked, and no fruit should be picked off the ground. Sprinkler irrigation should not be

2.4.1 Code of Practice for fertilization of irrigated crops with treated wastewater: step by step approach

Fertilization could be practised empirically (arbitrarily) or on sound scientific way. The empirical application of fertilizers is associated with severe limitations, which lead to low recovery of fertilizers by the crop. In general, empirical fertilization is based on farmer's experience and on broad recommendations. The scientific approach, takes into consideration crop nutrition, soil fertility, nutrient content of wastewater, expected yield and provides the individual grower dependable information regarding the fertilizer needs of his field.

Crop nutrient and fertilizer requirement

The selection of a sound fertilization programme is influenced by the knowledge of the nutrient requirement of the crop, the nutrient supplying power of both soil and water, the efficiency of nutrient uptake under different irrigation, fertilization methods, and the expected yield. When the soil and irrigation water do not furnish adequate quantities of elements necessary for normal growth of plants, it is essential that the required amounts be applied.

a) Removal of nutrients by crops from soil. The quantities of nutrients removed by a crop from the soil are good information, which can be used to optimise soil fertility level needed for various crops. Part of nutrients removed by crop is used for vegetative growth (canopy) and the other for fruit production. The amount of nutrients removed by crop must be present in soil irrespective of the fact that part of them may remain or return to the soil by the end of the growing season as canopy and roots. An important key is to have enough nutrients in the right proportions in the soil to supply crop needs during the entire growing season. In crops from which just the fruits are removed much lower quantities of nutrients are lost than if the entire above ground portion were harvested. The approximate amounts of N, P, K removed from soil by various crops are given in Table 10. Uptake will vary considerably, depending on a number of factors, including yield level, nutrient supply of the soil, fertilization and irrigation method. The data in (Table 10) indicate the comparative uptake among crops. In addition, they are an indication of the rate at which the reserve or "storehouse" nutrient in the soil is depleted by certain crops.

The amounts of nutrients that are indicated in (Table 10) are needed to be available in soil. However, not all of the nutrients should necessarily come from fertilizer. Part of them is supplied from the soil and part from wastewater. In this respect, estimating the amount of nutrients which may be available to the crop from soil (nutrient supplying power of soil) and wastewater (nutrient supplying capacity of wastewater), are important. These amounts are subtracted from the overall amount, which should be supplied by fertilizer applications.

b) Nutrients coming from soil. A soil test can help for estimating the nutrient-supplying power of a soil for P, K, Ca, Mg and other nutrients. Soluble N leaches readily during the rainy season or with the irrigation water, so there may be little carry-over. Because of this, soil testing is not practised as a tool for soil N fertility. Nevertheless, nitrification may build up the supply of nitrate in soil as the season advances, in case that organic matter is adequate. The soil test measures a part of the total nutrient present in the soil, assumed or experimentally found to be well correlated with the available nutrient. The values of soil analysis are of little use in themselves. To employ such a measurement in predicting nutrient needs of crops should use those chemical methods, which have been tested and calibrated. against nutrient uptake rate experiments. Moreover, no analysis could give good results if soil samples are not representative. The results of the soil test could be reliable only if they are based on representative samples. The problems of representative samples, accurate analyses, correct interpretation, and environmental factors, which influence crop response all, enter in. The soil test helps to reduce guess-work in fertilizer practices.

In order to estimate the nutrient supplying capacity of a soil the following parameters are needed:

- depth of the crop rooting system;
- percent (%) of soil occupied by the root system under different irrigation systems; and
- soil Bulk Density (Bd).

These parameters are needed in order to:

1. Calculate the weight of soil of a certain area to a depth where the active root zone of the crop is developed; and
2. Estimate the reserves or storehouse available nutrients for the crop in a soil.

Table 10. Nutrients required by selected crops for canopy formation and fruit production (Adapted from Papadopoulos)

Crop	N	P	K	P_2O_5	K_2O
Potato					
Canopy (kg/ha)	86	7	120	16	144
Tubers (kg/ton)	3.20	0.54	4.50	1.24	5.40
Tomato					
Canopy (kg/ha)	95	12	108	27	130
Fruits (kg/ton)	1.80	0.17	3.13	0.38	3.75
Eggplant					
Canopy (kg/ha)	105	13	113	30	135
Fruits (kg/ton)	1.96	0.17	3.2	0.40	3.8
Pepper					
Canopy (kg/ha)	90	6	90	14	108
Fruits (kg/ton)	2.0	0.26	1.83	0.6	2.2
Strawberries					
Canopy (kg/ha)	85	5	88	12	106
Fruits (kg/ton)	1.17	0.22	1.53	0.5	1.84
Lettuce (kg/ha)	115	14	160	32	192
Mango					
Canopy (kg/ha)	70	6	108	14	130
Fruits (kg/ton)	1.35	0.19	1.65	0.44	1.98
Banana					
Canopy (kg/ha)	250	26	800	60	1000
Fruits (kg/ton)	2.0	0.22	5.0	0.5	6.0
Citrus					
Canopy (kg/ha)	85	8	90	18	108
Fruits (kg/ton)	1.44	0.19	1.53	0.44	1.84

Rooting system

The amount of available nutrients in soil is estimated up to that depth of soil where roots are active. The appearance, growth and depth to which roots penetrate in soils are in part species properties but prevailing soil conditions usually exert a pronounced influence. If there is a clay pan, hard pan, compacted layer, or other dense formation, the normal depth of roots is not possible. The rooting depths of selected vegetables and fruit trees under good soil conditions and good management are given in (Tables 11 and 12). However, some forest trees and forage crops might have much deeper root depth.

Knowledge of the rooting habits of the crops is helpful for the farmers for determining in a satisfactory way soil exploitation and revealing the depth to which the reserve nutrients in the soil could be available and contribute to the overall nutrition of the crop. In addition the same information helps to give an idea of the most effective placement of fertilizer and irrigation water.

Table 11. Rooting depths of selected vegetables (Adapted from FAO, 1990)

Shallow (20-30 cm)	Moderately deep (30-50 cm)	Deep (>50 cm)
Broccoli	Bean	Artichoke
Brussels sprouts	Beet	Asparagus
Cabbage	Carrot	Pumpkin
Cauliflower	Cucumber	Sweet potato
Celery	Eggplant	Tomato
Chinese cabbage	Muskmelon	Watermelon
Garlic	Pea	
Leek	Pepper	
Lettuce	Squash	
Onion	Turnip	
Potato		
Radish		
Spinach		

Table 12. Rooting depths of selected fruit plant and trees (Adapted from FAO, 1990)

Fruit trees	Rooting depths (cm)
Strawberries	15-25
Avocado	120-150
Citrus	120-150
Mango	130-180

Soil occupied by roots

The mass of soil occupied by roots in m^3 is estimated with the following formula:

Soil weight available in root zone = Area (m2) x Root depth (m) x Bd (tons/m3)

Example

Estimate the weight of one hectare at a rooting depth of 0.4 m and with soil Bd of 1.2 tons/ha.

Soil Weight = 10 000 m^2 x 0.4 m x 1.2 tons/m^3 = 4 800 tons/ha

Soil nutrient supplying capacity

The amount of a nutrient in g/ha is estimated with the following formula:

Amount of nutrient = Soil weight (tons/ha) x Available nutrient (g/ton)

Example

Estimate the amount of available nutrient in the previous soil where soil analysis indicates that the available nutrient is 10 ppm.

Note: 1 ppm = 1 mg/kg = 1 g/ton

Amount of nutrient = (4 800 tons/ha) x 10 g/ton = 48 000 g/ha = 48 kg/ha

To avoid calculations, Table 13 could be used to estimate the amount of a nutrient, which could be provided by soil.

How to use Table 13. The two parameters needed are the value of the available nutrient in g/ton (ppm) and the crop rooting depth.

Example

Given: Soil analysis: P = 50 mg/kg; K = 90 mg/kg; Crop rooting depth 40 cm.

Reading from the table: P = 240 kg/ha

K = 432 kg/ha

Fraction of soil occupied by roots

The values shown in (Table 13) refer to the whole volume of soil up to a certain depth. However, the volume of soil occupied by roots is usually less and depends on the crop, spacing of planting and irrigation system. For drip irrigated vegetables like tomato, pepper, eggplant, the wetted soil volume is usually 30-40% of total soil volume. With wider spacing, which is the case for melon, watermelon, pumpkins the volume of soil occupied by roots could be even less than 20%. For minisprinklers (like minisprinkler irrigated potato) the volume of soil occupied up to a certain depth might be 70-80%. The fraction of soil occupied by roots must be taken into account whenever the amount of available nutrients is calculated; otherwise the available amounts could be overestimated and less fertilizer could be applied and plants could show deficiency symptoms.

Table 13. Available nutrients in soil in kg/ha as determined by chemical analyses at various soil depths. It is assumed that the soil Bulk Density is 1.2

Soil depth (cm)	Soil chemical analysis (mg/kg)										
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**150**
10	12	24	36	48	60	72	84	96	108	120	180
20	24	48	72	96	120	144	168	192	216	240	360
30	36	72	108	144	180	216	252	288	324	360	540
40	48	96	144	192	***240***	288	336	384	***432***	480	720
50	60	120	180	240	300	360	420	480	540	600	900
60	72	144	216	288	360	432	504	576	648	720	1080
70	84	168	252	336	420	504	588	672	756	840	1260
80	96	192	288	384	480	576	672	768	864	960	1440
90	108	216	324	432	540	648	756	864	972	1080	1620
100	120	240	360	480	600	720	840	960	1080	1200	1800

c) Wastewater nutrient supplying capacity. This capacity depends on wastewater applied per ha per year and the content of a certain nutrient in the wastewater as indicated in (Table 8). This amount together with that provided by the soil is subtracted from the overall amount of nutrients required by crop. The amount of nutrients needed by the crop and the amount of nutrients, which should be applied, are not equivalent. Not all of the nutrients applied by fertilizers or by wastewater are used by crop. The actual amount applied by fertilizers is usually higher than the amount required by the crop. The uptake of nutrients depends, among others, on the irrigation system.

d) Irrigation system (method) and efficiency of N, P, K uptake. The potential nutrient uptake efficiency by the same crop is different with various irrigation systems. In general, the higher the irrigation efficiency of a certain irrigation system the higher is the nutrient uptake efficiency. For a well designed irrigation system and with good scheduling of irrigation, the potential N, P and K uptake by the same crop is given in (Table 14).

Table 14. Fertilizer (NPK) uptake in % as influenced by the irrigation system (FAO/RNEA, 1992).

Irrigation system*	Nitrogen	Phosphorus	Potassium
Furrow	40-60	10-20	60-75
Sprinkler	60-70	15-25	70-80
Microirrigation	75-85	25-35	80-90

*The values refer to good designed and operated irrigation systems

With surface irrigation methods, the fertilizer use efficiency is the lowest. In particular, due to leaching, the N use efficiency can be considerably low. Therefore, in order to estimate the overall amount of nutrients, which must be present in soil to meet crop nutrient requirements for certain yield, the efficiency of the fertilizer nutrient uptake by the crop is needed.

Nitrogen, Phosphorus and Potassium requirement of different crops

Taking into account the nutrient requirement for certain yield, the nutrient capacity of soil and wastewater, and the efficiency of nutrient uptake by crop under different irrigation systems, the following formula can be used to estimate the amount of N, P and K required being readily available in soil:

Nutrient Requirement (kg/ha) = NR – (SAN + WN) x 100 / IS

Where: NR = Nutrient Requirement for certain yield (kg/ha)

SAN= Soil Available Nutrients (Soil Supplying Capacity) (kg/ha)

WN= Nutrient capacity of the wastewater (kg/ha)

IS = Nutrient uptake efficiency of irrigation system (%).

Example

Crop, is drip-irrigated tomato with rooting depth of 40 cm. Drippers are wetting 35% of the soil. Soil analyses indicated 20 ppm P and 50 ppm K and wastewater analyses 25, 8 and 35 ppm for N, P and K, respectively. Find the N, P, K required for yield of 100 and 125 tons/ha. Nutrient uptake efficiency of the irrigation system is 80, 30, 85, for N, P, K, respectively.

1. ***Calculate the weight of soil of one hectare to a depth of 40 cm***

   Wt of soil (tons/ha/0.4 m depth) = 10 000 (m^2) x 0.4 (m) x Bd (tons/m^3)

   = 4 000 m^3 x 1.20 tons/m^3 = 4 800 tons

2. ***Calculate available P and K from soil***

   P (kg/ha) = (20 g/ton) x 4 800 tons/ha = 96 000 g/ha = 96 kg/ha

   K (kg/ha) = (50g/ton) x 4 800 tons/ha = 240 000 g/ha = 240 kg/ha

3. ***Actual P and K available in the 35% soil occupied by roots***

   P = 96 x 35/100 = 33.6 kg P/ha

   K = 240 x 35/100 = 84 kg K/ha

4. Amount of N, P, and K from wastewater

In order to estimate the overall supplying nutrient capacity of waters the crop water requirement need to be determined. If crop water requirement data are not available in the region of reuse then the **Fractions of Evaporation from pans** recommended for selected vegetables given in (Table 15) and for fruit trees in (Table 16) could be used. It should be stressed that these values are based on long-term experiments and practical verification at farm level.

Table 15. Crop Water Requirements of selected vegetables expressed as fraction of evaporation from a Class A pan (Papadopoulos)

	Days after planting					
Crop*	**0-15**	**15-30**	**30-45**	**45-60**	**There-after**	**Last month**
Potato	0.4	0.7	0.9	0.8	0.7	
Carrots	0.3	0.5	0.9	0.9	0.8	0.8
Tomato	***0.3***	***0.5***	***0.8***	***0.9***	***1.0***	***0.8***
Cucumber	0.3	0.5	0.7	1.0	1.0	0.8
Lettuce	0.3	0.8	0.9	0.9		
Cabbage	0.3	0.5	0.8	0.9	0.9	
French Beans	0.3	0.4	0.5	0.7	0.8	
Onion	0.3	0.5	0.9	0.9		
Celery	0.3	0.6	0.9	0.9		
Eggplant	0.3	0.5	0.8	0.9	1.0	0.8
Bell Pepper	0.3	0.5	0.7	0.8	0.8	0.7
Watermelon	0.3	0.5	0.9	0.9	0.8	
Melon	0.3	0.5	0.9	0.9	0.8	

*Under less convenient conditions for growth the changes in the amount of water may go every three weeks interval.

Table 16. Crop Water Requirements of selected fruit trees expressed as fraction of Epan evaporation

Citrus	:	**For fully developed trees 0.55**
Avocado	:	**For fully developed trees 0.55**
Olives	:	**At full development 0.33**
Mango	:	**At full development 0.33**
Table grapes	:	**The value increases gradually from 0.2 to 0.5-0.6.**
Banana	:	**Increases gradually from 0.6 to 1.0**

Example

The amount of irrigation water for tomato in an area with the meteorological data is indicated in (Table 17).

Amount of N, P and K from the wastewater (7 000 m^3/ha):

N = 25 g/ m^3 x 7 000 m^3 /ha = 175 kg/ha

P = 8 g/ m^3 x 7 000 m^3 /ha = 56 kg/ha

K = 35 g/ m^3 x 7 000 m^3 /ha = 245 kg/ha

Table 17. Scheduling of irrigation

Month	March		April		May		June		July	
	1-15	**15-31**	**1-15**	**15-30**	**1-15**	**15-31**	**1-15**	**15-30**	**1-15**	**15-31**
Effective Rain (mm)	30	20	15	-	-	-	-	-	-	-
E pan (mm)	63	64	69	68	90	90	93	94	108	128
Epan – Effective Rain (mm)	33	44	54	68	90	90	93	94	108	128
Fraction of Epan	0.3	0.5	0.8	0.9	1.0	1.0	1.0	1.0	0.8	0.8
Irrigation water (mm)	10	22	43	61	81	90	90	93	94	102
m^3/ha	100	220	430	610	810	900	900	930	940	1 020

Total amount of water needed for irrigation is around 7 000 m^3/ha

Table 18. Amount of N, P, K needed to be applied as fertilizer to tomato crop

	Kg/ha for 100 tons/ha			Kg/ha for 125 tons/ha		
	N	**P**	**K**	**N**	**P**	**K**
Drip irrigation						
Required	340	94	367	396	108	459
From soil	-	34	84	-	34	84
From wastewater	175	56	245	175	56	245
Nutrients needed as fertilizer	**165**	**4**	**38**	**221**	**18**	**130**
Furrow irrigation						
Required	497	189	416	579	216	520
From soil	-	34	84	-	34	84
From wastewater	175	56	245	175	56	245
Nutrients needed as fertilizer	**322**	**99**	**87**	**404**	**126**	**191**

From (Table 18) one can see that:

- For drip irrigation no additional P and little K are required for the 100 tons/ha.
- With furrow irrigation more fertilizer is required for the same target yield.
- With fresh water the amount supplied by the wastewater should be added as fertilizer.

- With wastewater, if the fertilization recommended for the fresh water is applied, it will lead to over-fertilization and pollution.

2.5 Monitoring and evaluation

from the microbiological point of view, is not the responsibility of the farmers. Therefore, the precautionary measures which the farmers must take at any time and the additional measures which they should take in case that the wastewater provided to them is not of the anticipated quality should be given to them by the appropriate authorities in each country. No unified measures for all countries could be recommended.

For the farmers it is important to monitor effects on soil and crops from the chemical and particularly crop nutrient point in order to adjust the management accordingly.

3. IRRIGATION WITH TREATED WASTEWATER

Irrigation plays a vital role in increasing crop yields and stabilising production. In arid and semi-arid regions, irrigation is essential for economically viable agriculture, while in semi-humid areas it is often required for certain crops on a supplementary basis.

3.1 Irrigation methods

3.1.1 Surface (traditional) methods

- Flood irrigation (by border or basin), wetting almost all the land surface
- Hose-basin irrigation. The water is delivered by hose
- Furrow irrigation, wetting only part of the ground surface.

These methods account for about 95% of the world's irrigated area and dominate the world's irrigation systems. They are of low cost, simple to understand and implement. They are suitable for many developing countries particularly if water is not the limiting factor for agricultural production.

3.1.2 Pressurised irrigation methods

Sprinklers (Sprinklers of high capacity, ordinary mini-sprinklers, and sprayers). Crops and soil are wetted the same way as rain.

Drip (point or localized irrigation system). The main characteristics of the system are:

- High application efficiency. It is probably, if it is used properly, the best method for irrigation in places where scarcity of water is a problem.
- Appropriate method to cope with problems associated with saline irrigation water and soil alkalinity.
- This method is safe and in general might be the most promising for irrigation with wastewater, particularly if purification is such to prevent extensive clogging.
- Contact of wastewater with both the farmers and the irrigated crops is minimized.
- No aerosols are formed and, therefore, no pollution of the atmosphere and of the area nearby to the irrigated fields occurs.

Subsurface irrigation. This system is not yet used with wastewater, but it might be useful for irrigating with wastewater of lower quality and higher health risk. Subsurface irrigation together with trickle irrigation may provide the best health protection.

Bubbler irrigation. It is a localised irrigation technique with regulated flow. This system performs better than drip and minisprinklers as far as clogging is concerned.

3.1.3 Selection of the irrigation system

Selection of the appropriate irrigation system depends on the quality of wastewater, crop, tradition, background, skill, ability of the farmers to manage the different methods, and the potential risk to the health of farmers, public and the environment. (Table 19) which evaluates suitability of common irrigation methods, namely, border, furrow, sprinkler and drip in relation to brackish water is also valid for treated wastewater, particularly concerning its salinity content.

Clogging problems with the sprinkler, minisprinkler, drip, and subsurface irrigation systems might be a serious problem. Growths (slimes, bacteria, etc.) in the sprinkler head, emitter orifice or supply line, cause plugging. Salts and suspended solids may also create clogging. The most serious clogging occurs with drip irrigation, which is considered ideal as far as health protection and plant contamination but might be difficult to be used for irrigation with wastewater high in suspended solids (SS).

Recommendations

The farmers should be aware that for a treated wastewater of the WHO guideline quality (Table 9), all methods are appropriate to be used from the point of disease transmission control, provided that the agricultural criteria are also met. If the wastewater does not meet the health criteria then:

- Spray irrigation (minisprinklers, sprayers, spitters etc.) is limited to only fodder, fibre, and seed crops.
- Spray irrigation with wastewater when used for irrigating lawns or areas of unlimited access, to be practised during night.
- Sprinkler and particularly spray irrigation is not recommended under windy conditions. There is a potential for the pathogens to be carried away in the spray mist or in the formed aerosols with the wind drift and cause health hazard to the workers, farm population and the nearby residential areas.
- If treated wastewater is not within acceptable health and/or environmental purification level. blending of treated wastewater with normal irrigation water, if available, to achieve prescribed guidelines for a certain use is desirable.

Irrigation methods must also be examined in relation to the extent that they are practised in an area or country, the background of the farmers on certain methods and the extent of contamination that they may induce on the crops, particularly the edible parts.

Table 19. Evaluation of Common Irrigation Methods for their Suitability to Use Brackish Water (Kandiah, 1990)

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

Table 20. Factors affecting the choice of each irrigation method, and the special measures required when wastewater is used, particularly when it does not meet the WHO guidelines (Mara and Cairncross, 1989)

Irrigation method	Factors affecting choice	Special measures for wastewater
Border (flooding) irrigation	Lowest cost, exact levelling not required	Thorough protection for field workers, crop handlers and consumers
Furrow irrigation	low cost, levelling may be needed	Protection for field workers, possibly for crop handlers and consumes
Sprinkler irrigation	Medium water use efficiency, levelling not required	Some Category B* crops, especially tree fruit, should not be grown. Minimum distance 50 - 100 m from houses and roads. Anaerobic wastes should not be used, due to odour nuisance
Subsurface and localised irrigation	High cost, high water use efficiency, higher yields	Filtration to prevent emitters clogging

*Crop categories are presented in following chapters

3.2 Amount of water and scheduling of irrigation

For all practical purposes, water needed by crop plants is equal to their evapotranspiration requirement. This amount might be exceeded due to leaching fraction if required. An extensive review of this subject and guidelines are given in FAO Irrigation and Drainage paper No. 24 (1984). Computer software, called CROPWAT is available at FAO to determine water requirements of crops from climatic data. It could be also used the simple and practical way proposed in this manual which is lonely based on E-pan evaporation.

Table 21. Water requirements of some selected crops (Adapted from FAO, 1992)

Crop	Water requirement (mm/growing period)
Alfalfa	800 – 1600
Banana	1200 – 2200
Bean	300 – 500
Cabbage	380 – 500
Citrus	900 – 1200
Cotton	700 – 1300
Groundnut	500 – 800
Maize	500 – 800
Potato	500 – 700
Rice	350 – 700
Sunflower	800 – 1200
Sorghum	450 – 650
Wheat	450 – 650

(Table 21) presents water requirements of some selected crops. The actual amount has to be adjusted for effective rainfall, leaching requirement, application losses and other factors. The recommended water requirement for a particular crop and place is estimated as indicated in the previous section or based on meteorological data.

3.3 Strategy to protect human health and environment

Human health and environment could be protected through four groups of measures (Mara and Cairncross, 1987):

- Wastewater treatment level
- Restriction of the crops grown
- Irrigation methods and
- Control human exposure to the waste, and hygiene.

Full treatment prevents excreted pathogens from reaching the field. However, the farmers in most of the cases have to cope with wastewater of a certain quality. Because of this, for the farmers crop restriction, irrigation system and human exposure control which act later in the pathway, are more important. A combination of agro-technical measures to be selected, depending on the local socio-cultural, institutional and economic conditions may provide health protection.

Crop selection for health protection

Wastewater which has been treated to the WHO quality guidelines for unrestricted use (<1000 faecal coliforms per 100 ml and < 1 nematode egg per l) can be used to irrigate all crops, without further health protection measures. If the WHO quality guidelines are not fully met, it may still be possible to irrigate selected crops without risk to the consumer (Fig. 1). Crops can be grouped into three broad categories with regard to the degree to which health protection measures are required (Shuval et. al., 1986).

Category A Protection needed only for field workers:

- Crops not for human consumption (cotton, sisal)
- Crops normally processed by heat or drying before human consumption (grains, oilseeds, sugar beet)
- Vegetables and fruits grown exclusively for canning or other processing that effectively destroys pathogens
- Fodder crops sun-dried and harvested before consumption by animals
- Landscape irrigation in fenced areas without public access (nurseries, forests, and greenbelts).

Category B Further measures may be needed:

- Pasturelands, green fodder crops
- Crops for human consumption that do not come into direct contact with wastewater, on condition that none must be picked off the ground and that spray irrigation must not be used (tree crops, vineyards, etc.)
- Crops for human consumption normally eaten only after cooking (potatoes, eggplant, beetroots)
- Crops for human consumption, the peel of which is not eaten (melons, watermelons, citrus, bananas, nuts, groundnuts)
- Any crop if sprinkler irrigation is used.

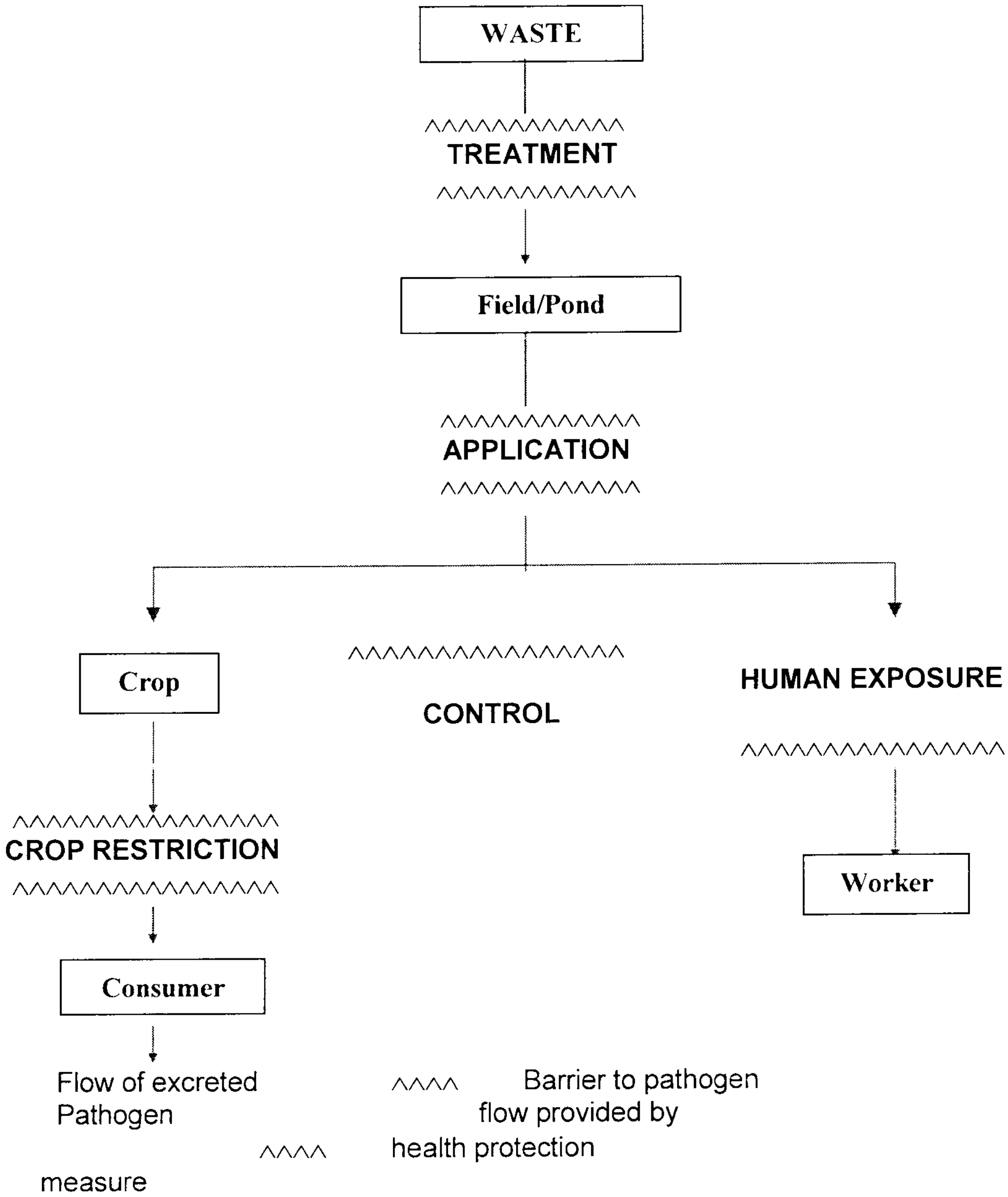

Fig. 1. Flow Diagram to Show the Potential Transmission of Excreted Pathogens and Points at which Different Health Protection Measures Can Interrupt the Pathogen Flow (Blumenthal et. al., 1989).

Category C Treatment to WHO "unrestricted" guidelines is essential:

- Any crops often eaten uncooked and grown in close contact with wastewater effluent (fresh vegetables such as lettuce or carrots, or spray-irrigated fruit)
- Landscape irrigation with public access (parks, lawns, golf courses)

Adopting crop restriction as a mean of health and environment protection requires strong institutional framework and capacity to monitor and control compliance with the regulations. Farmers must be advised why such crop restriction is necessary and be assisted in developing a cropping pattern.

A useful arrangement of crops with declining potential to transmit pathogens if irrigated with treated wastewater, irrespective of the irrigation method and wastewater quality used, is the following:

1) Vegetables eaten raw
2) Vegetables eaten cooked
3) Ornamentals raised for sale in greenhouses
4) Trees producing fruits eaten raw without peeling
5) Lawns in amenity areas of unlimited access to the public
6) Trees producing fruits eaten raw after peeling
7) Table grapes
8) Lawns and other trees in amenity areas of limited access
9) Fodder crops
10) Trees producing nuts and other similar trees
11) Industrial crops

The crop restriction is the strategy to provide protection to the consuming public. However it does not provide protection to farm workers and their families who remain at high risk since they are still exposed to pathogens in the waste on the soil and on the crop. Crop restriction is, therefore, not adequate for the farmers in its own; it should be complemented by other measures including their personal and family hygiene.

Potential crop restrictions bases on wastewater chemical composition

In addition to the wastewater quality criteria related to health it may be necessary for the farmers to select crops according to their tolerance to chemical composition of the treated wastewater.

Control of human exposure to the wastes and hygiene

Controlling the risk of public health from waterborne diseases when treated sewage wastewater is used for irrigation is of high importance. In this respect, the groups of persons running such a risk and the ways such groups are exposed to the risk should be identified and examined. The following groups may be recognised (Kypris, 1989):

- **Farm workers.** The probability for them of wetting their hands, clothes, or other parts of their body from leaks or otherwise is certainly the highest risk of exposure. Therefore, farmers should be aware about the risk and handle wastewater with care.
- Workers **handling or packing** polluted crops. If proper care was not taken at the treatment stage and proper irrigation practise were not followed by the farmers, pathogens may be present on the crops at such concentrations, as to pollute the hands, or clothes of such workers.
- **Consumers.** This group is actually the general public, comprising children, elderly people and others of low resistance to pathogens, being the most

sensitive group. Farmers should feel responsible for this group and manage wastewater in such a way to avoid crop contamination. Crops polluted with pathogens, particularly those consumed raw, allow the chance for consumers to be infected by pathogens, if not properly washed and cleaned. Risks to consumers can be reduced by thorough cooking and by high standards of hygiene. Local residents should be kept fully informed about the location of all fields where wastewater is used. In this way, they may avoid entering them and also prevent their children from doing so.

- The **general public using amenity areas** irrigated with wastewater, particularly if lawn is irrigated, on which children use to play, or other people come in direct contact with. If high concentrations of pathogens remain on such lawn at the time of application, the risks of pathogens being transmitted are high. For this wastewater application farmers are not responsible.
- **People passing by,** or living in the neighbourhood of areas irrigated with treated wastewater.

It is apparent that to control health risk, farmers should know first of all the microbiological quality of wastewater.

4. HEALTH ASPECTS OF WASTEWATER REUSE IN AGRICULTURE

4.1 Background

The reuse of wastewater for irrigation is associated with biological agents (pathogenic viruses, bacteria, protozoa), and eventually reach others whom they enter via the mouth (for example, through the eating of contaminated vegetables as with *Ascaris*) or the skin (in case of the hookworms and schistosornes), WHO, 1988. These kinds of agents are of serious concern in countries, which have diarrhea diseases, and nematode infections, like in several parts of the Near East Region.

It is very important to understand the transmission of vectors and the health risk factors involved in the excreted pathogens. There are 30 known excreted infections of public health importance and these may be conveniently grouped into five categories, which have similar environmental transmission characteristics and pathogen properties.

Factors affecting the transmission of diseases depend on the following:

- survival time of the pathogen in soil, crop, fish, or water.
- infections in the required intermediate host or hosts.
- mode and frequency of excreta or wastewater application.
- type of crop to which the excreta or wastewater is applied.
- nature of exposure of a human host to the contaminated soil, water, crop or fish.

The survival time of excreted pathogens in different environment for a temperature range of (20-30 C) are shown in (Table 22). The data indicate that nearly all excreted pathogens can survive in water, soil, and crops for a sufficient length of time to pose potential risks to farm and pond workers (Mara and Cairncross, 1988).

Table 22. Survival of excreted pathogens (at 20-30C)

Type of Pathogen	Survival time in days			
	In faeces, nightsoil and sludge	**In fresh water and sewage**	**In the soil**	**On crops**
Viruses				
Enteroviruses	< 100 (< 20)	< 120 (< 50)	< 100 (<20)	< 60 (<15)
Bacteria				
Faecal Coliforms	< 90 (<50)	< 60(< 30)	< 70 (< 20)	< 30 (< 15)
Salmonella spp.	< 60 (< 30)	< 60 (< 30)	< 70 (< 20)	< 30 (<15)
Shigella spp.	< 30 (<10)	< 30 (< 10)	-	< 10 (< 5)
Vibrio cholerae	< 30 (< 5)	< 30 (< 10)	< 20 (< 10)	< 5 (< 2)
Protozoa	< 30 (< 15)	< 30 (< 15)	< 20 (< 10)	< 10 (< 2)
Entamoeba histolytica cysts	< 30 (< 15)	< 30 (< 15)	< 20 (< 10)	< 10 (< 2)
Helminths	Many months	Many months	Many months	< 60 (< 30)
Ascaris lumbricoides eggs				

Figures in brackets show the usual survival time

4.2 Microbiological Quality Considerations for Reuse of Wastewater in Agriculture

The recommended Microbiological Quality Guidelines for wastewater reuse in agriculture adapted by WHO were given earlier in Table 9. It should be noted that the high actual risks are associated with intestinal nematodes and bacteria; while viruses have little or no actual risk.

Studies have virtually ignored low level or endemic occurrence of waterborne virus diseases for several reasons (EPA, 1992):

- A significant body of information exists indicating that viruses are reduced or inactivated to low or immeasurable levels via appropriate wastewater treatment, including filtration and disinfection,
- Current virus detection methods are not sufficiently sensitive to accurately detect low concentrations of viruses, even in large volumes of water,
- Enteric virus infections are often not apparent, thus making it difficult to establish the endemicity of such infections,
- There is no consensus among virus experts regarding the health significance of low levels of viruses in reclaimed wastewater;
- The apparently mild nature of most enteric virus infections preclude reporting by the patient or the physician,
- Current epidemiological techniques are not sufficiently sensitive to detect low level transmission of viral diseases through water. The laboratory culturing procedure to determine the presence or absence of viruses in a water sample takes about 14 days, and another 14 days are required to identify the viruses. This adds to the complexity and high cost of laboratory procedures, and the limited number of facilities having the personnel and equipment necessary to perform the analyses,
- Damage due to entero-viral infections may not become obvious for several months or years,
- Once introduced into a population, person-to-person contact becomes a major mode of transmission of an enteric virus, thereby obscuring the role of water in its transmission, and
- There have been no documented cases of viral disease resulting from the reuse of wastewater at any of the water reuse operations in the USA.

4.2.1 Environmental Contamination with Intestinal Parasites

The degree of contamination of the envirnment with the products of intestinal parasites is enormous and depends largely on the method of excreta disposal. About 20 percent of the Eastern Mediterranean Region's population lack safe water, and more than 30 percent lack adequate sanitation.

The contamination of the environment is uneven. In the case of ascariasis, it is concentrated around houses where small children are the most important disseminators of the infection. Hookworm eggs are disseminated by adolescents and adults contamination is heaviest around the edges of cultivated fields.

The reproductive potential of each Ascaris female worm is extremely high - about 240,000 eggs per day, which counterbalances the heavy losses in the viability and infectivity of these eggs in the environment.

From the various ecological factors, (landscape, weather, and type of soil) which are regulating the population of Ascaris eggs outside the human host, the most important factor is the radiation from sunlight. Depending on the action or absence of one or more of these factors,.*A.. lumbricoides* eggs can survive for more than six years in a temperate climate, but only for a few hours under some tropical conditions.

4.2.2. Prevalence and Intensity of Helminthic Infections in the Region

A study by Ali-shrayeh and others (1989) summarizes six years of accumulated data on 22,970 specimens in Nablus, West Bank of Jordan:

Ascaris **177 per 1000 people**

Trichuris **13 per 1000 people**

In the East Bank of Jordan, the only available statistics report on cases of Ascaris found in samples from patients who were visiting the hospital for non-parasitic medical care and whose stool samples were tested for helminth eggs. One percent positive samples were found in the patients whose stools were tested at the Central Laboratories of the Ministry of Health. In Amman city, the concentration of intestinal nematodes I 1988 was 297 eggs per liter, of which 245 eggs per liter were *A. lumbricoides* (Al Salem et. al, 1989). While the *Ascaris eggs* concentration in the Amman Waste Stabilization Ponds influent in 1998 was undetectable.

As study from the Gaza Strip (Chris Smith, 1990) showed that more than 50% of the children under the age of 10 were infected by *Ascaris.*

A study from Riyadh, Saudi Arabia (Abdel-Hafez et. al, 1986) on 5,727 stool specimens from three hospitals during 1986 showed:

Ascaris 30 per 1000 people

Trichuris 25 per 1000 people

Hookworm 4 per 1000 people

In Egypt a village with an improved water supply, latrines and refuse collection had a lower prevalence (50%) and intensity (4200 eggs/gram) of ascariasis than a village without improved sanitation (prevalence of 76% and intensity of 6900 eggs/gram), Chandler, 1954.

In South Batinah Region (Oman) an epidemiological study of intestinal parasitic infestation among schoolchildren showed that 19% of the examined schoolchildren were infected with *H. nana*. The percentage of *Ascaris lumbricoides* was relatively low (0.1%), while for *strongyloides* the infestation was 5 per 1000 of examined schoolchildren (Al Salem, 1998).

4.3 Integration of the Various Measures for Health Protection (WHO 1998)

To the planners and decision-makers concerned with wastewater reuse, wastewater treatment appears as a more straightforward and "visible" measure for health protection, seconded only by crop restriction. Both measures, however, are relatively difficult to implement fully: the first is been limited by costs and problems of operation and maintenance, and the second is constrained by the lack of appropriate markets for specific products or by legal and/or institutional considerations.

It should be noted that the application of isolated measures, may have only partial effects in terms of health protection. Crop restriction for instance if applied may protect the consumers of crops but does not provide protection to farm workers and their families.

In order to analyze the various measures under an integrated fashion aiming at the optimization of the health protection scheme, a generalized model has been proposed. It was conceived to help in decision making, exposing the range of options for protecting agricultural workers and the crop-consuming public, and allowing for flexibility of response to different situations.

Each situation ought to be considered separately and the most appropriate option is to be chosen taking into account economic, cultural and technical factors. The graphical conception of the model is shown in (Figure 2), below.

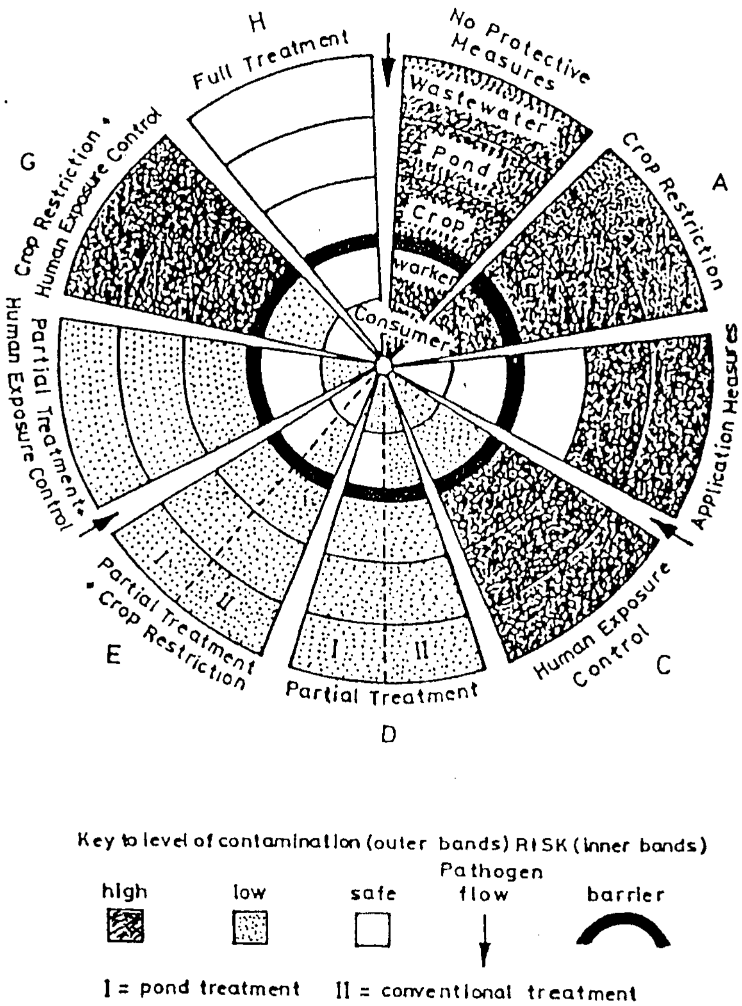

Fig. 2. Generalized model to show the level of risk to human health associated with different combinations of control measures for the use of wastewater or excreta in agriculture or aquaculture (Blumenthal et. al. 1989)

It was assumed that pathogens flow to the center of the circle going through the five concentring bands which represents wastewater of excreta, field or pond, crop, workers and consumers. The thick black circle represents a barrier beyond which pathogens should not pass, if health is to be protected. The level of contamination of wastewater, field, or crop or the level of risk to consumer or worker is shown by the intensity of shading. White areas in the three outer bands means zero of no significant level of contamination and in the inner bands a presumed absence of risk to human health and therefore indicates that the strategy leads to "safe" use of wastewater.

If no protective measures are taken, both workers and consumers will be at the highest risk of contamination. Assuming crop restriction is applied (Regime A, Fig. 2), consumers will be safe but workers will still be at high risk. Regime B assumes that application of wastewater is made through subsurface of localized irrigation avoiding crop contamination and consequently maintaining both workers and consumers virtually free of contamination.

If human exposure control is the only protective measure assumed both consumers and workers will still be submitted to the same level of risk since such measures are rarely fully effective in practice. Regime D assumes partial treatment of wastewater through ponding (D-I) or conventional systems (D-II). Stabilization ponds with an average detention time of 8-13 days provides good helminth egg removal providing protection to the workers. However, reduction of bacteria is not enough to meet the proposed guidelines, so the risk to consumers will remain high. With conventional systems, it does not provide a sufficient helminth egg removal and a small level of risk still remains for both workers and consumers. The following three regimes, E, F and G are examples of the combination of protective measures. Regime E includes partial treatment and crop restriction. In this case, full protection is provided to consumers but only treatment by ponding systems will provide full protection to workers. In Regime F, human exposure control is added to partial treatment. The combination of the two measures may lead to complete protection of the workers but some low level of risk still remains to the consumers.

Associating crop restriction and human exposure control (Regime G) will provide full protection to consumers but still some risks will be remaining to the workers.

Finally, Regime H includes full treatment of wastewater, which will provide complete protection to both workers and consumers. The feasibility and efficacy of any combination of measures will depend on several local factors, which must be carefully considered before a final choice is made.

Some of these factors are the following:

- availability of resources (institution, staff, funds);
- existing social and agricultural practice, and; and
- existing patterns of excreta-related diseases.

4.4 Special Health Issues

The 1989, WHO published new guidelines for wastewater use in agriculture and aquaculture (Table 9). The guidelines included a new dimension, which was not considered in the previous WHO report on reuse (WHO 1973). The new guidelines set microbiological quality criteria for wastewater use in irrigation of: crops to be eaten cooked or eaten raw; sport fields; public parks; cereal crops; industrial crops; fodder, and trees. The new dimension in the guidelines required that wastewater should contain less than 1 nematode egg per liter. In addition to nematode eggs the fecal coliform criteria has been revised and required that wastewater should contain less than 1000 fecal coliforms per 100 ml for vegetables eaten raw.

The WHO Guidelines (WHO, 1989) stated that:

- The presence of free-living nematode, larvae stages, sometimes in large numbers, in stabilization pond effluents *is of no public health significance* because they are not pathogenic to human beings.
- This statement is valid for all helminthic pathogens excreted in faeces except for *Strongyloides Stercoralis* (threadworm) and *Enterobius Vermicularis* (pinworm), since their eggs are NOT normally excreted in the faeces. The pinworm is of minor public health importance because it is an infection that does not commonly cause serious illness.
- *Strongyloides* is potentially serious particularly in malnourished of immune-suppressed individuals. When the body's immune responses are deficient, disseminated strongyloidiasis may occur, with larvae attaching most organs of the body; such cases are usually fatal (Feachem 1983).
- The mode of transmission of Strongyloidiasis infective filariform larvae, which develop in most soils, contaminated with faeces is: penetrate the skin (usually of the foot), enter the venous circulation, and are carried to the lungs. They hatch and liberate non-infective, rhabditiform larvae which migrate into the lumen of the intestine, leave the host in the faeces and develop either into infective filariform larvae, which may infect the same or a new host, or into free-living adults after reaching the soil (Benenson 1985).

In addition, Feachem et. al., (1983) stated that "*Strongyloides stercoralis* is a minute nematode parasitizing man. The adult females, only 2-2.5 millimeters long, live embedded in the mucosa of the small intestine."

The eggs are ovoid and measure 50-60 by 30-35 micrometers but are seldom seen because larvae hatch out and are passed in the faeces. *S. Stercoralis* exists in night soil and sludge as a delicate larva, not as a robust egg. A new infection can be initiated by the penetration of a single larvae. Since *Strongyloides* represent a high actual risk, it is recommended to eliminate or remove 100% of its concentration. This would mean to have zero S. *Stercoralis* larva/liter, because infection can only be initiated by skin penetration of a single *S. Stercoralis* larva. The period of communicability is as long as there are living worms in the intestine which may extend up to 35 years (Benenson, 1985). Concerning inactivation of strongyloides in sewage treatment processes, there are no studies reported (Feachem, 1983).

However, it is suggested that sludge pasteurization as currently applied in Switzerland and Germany at 70 C for 30 minutes may offer a considerable safety. "Pathogens may be reduced in rapid sand filtration but not substantially, and probably insufficiently to justify investment in this filtration method by the health benefits it yields and most helminth eggs will be totally unharmed by effluent chlorination" (Feachem 1983).

This was confirmed by a study carried out in Jordan and by the performance of the Bahrain tertiary treatment plant operating on dual media filtration, chlorination, and ozonation. (Al Salem, 1992).

So far, there is no guaranteed feasible method of inactivation neither for sewage or sludge treatment processes. It is recommended to take protection measures by; wearing shoes and gloves, burying the sludge at least 0.5 m below ground surface, and stopping irrigation of crops at least 3 weeks before harvesting.

5. ENVIRONMENTAL ASPECTS ASSOCIATED WITH WASTEWATER USE FOR IRRIGATION

Environmental benefits

When wastewater is used properly for agricultural purposes, than being disposed in any other way, improvement of the environment could be achieved. The following are some of the environmental benefits:

- Avoidance of discharge to surface waters, preventing occurrence of unpleasant esthetic situations, anaerobic conditions in rivers and eutrophication of lakes and reservoirs. Conservation of water resources will provide benefits to uses such as water supply and recreation.
- Saving groundwater resources in areas where over-utilization of these resources in agriculture is causing problems of water level depletion and salt intrusion.
- Possibility of soil conservation and its improvement by humus build-up on agricultural land and the prevention of land erosion.

Potential negative environmental effects

Wastewater use for irrigation may have also negative effects on the environment and human health. The principal environmental hazards associated with wastewater are:

- The introduction of chemicals into susceptible ecosystems (mainly soil, water and plants) and
- The spread of pathogens.

5.1 Effects on soil

These effects are of particular importance for the farmers since they may reduce soil productivity, fertility and yield. Soil should remain at a good level of chemical and physical characteristics in order to enable long term sustainable use and profitable agriculture. The expected soil problems are:

- Salinization
- Alkalinity and reduced soil permeability
- Accumulation of potentially toxic elements
- Accumulation of nutrients.

5.2 Effects on groundwater

The effects on groundwater under certain conditions are more important than effects on soil. Pollution of groundwater with constituents present in wastewater is possible.

The following management aspects to reduce and/or overcome the problem are recommended:

- Irrigation (amount of water) based on crop water requirement with minimum leaching if needed.

- Scheduling of irrigation based on crop water requirement. soil water holding capacity and wastewater quality.
- Select crops, which may absorb potentially hazardous constituents present in wastewater.
- In case of saline waters introduce in the cropping pattern salt harvesting crops.
- To avoid contamination by NO3-N the amount of water could be restricted to that amount which supplies the N required by the crop and if N exceeds crop requirement then:
  - Select crop with higher N requirement.
  - Select the irrigation system that provides the highest possible application uniformity.
  - Blending of water with fresh water
  - Keep operation and maintenance of irrigation systems at acceptable level.

5.3 Effects on surface water bodies

Eutrophication, growth of algae

The high N concentration in wastewater together with P are of particular interest when wastewater is collected in dams before irrigation since they may create favourable conditions for eutrophication. Under such conditions, blooming of green algae is very common and the problems associated with it, particularly clogging of pressurized irrigation systems, is difficult to overcome. The latter is one of the main concerns for the farmers.

The problem of eutrophication and oxygen depletion due to the nutrients in the wastewater is particularly important when the effluent is discharged in water bodies (rivers, lakes, and sea). The N is the limiting factor for algae growth in the sea, while N and P are the limiting factors in the lakes, salty water depression and in dams where the wastewater is collected before irrigation.

5.4 Effects on crops. Phytotoxicity problem and management

Besides the overall effect of certain constituents of wastewater on the irrigated crops like salinity, the wastewater potentially may create plant toxicity due to high concentration of certain elements like Boron and some heavy metals. Necrotic spots on the leaves recognize the symptoms of Boron toxicity in boron sensitive crops. Toxicity aspects are discussed in more details in relation with sludge use in agriculture.

5.5 Animal heath problems

Reclaimed wastewater can be used for animal watering if it is within the suggested guidelines in (Table 23) where maximum values permitted for certain elements are given. This is important since in most cases it is difficult to control domestic animals from drinking wastewater. Farmers aware of these guidelines could ,therefore, protect the health of their domestic animals.

Table 23. Guidelines for levels of toxic substances in livestock drinking water[1]

Constituent (Symbol)	Upper Limit (mg/l)
Aluminium (Al)	5.0
Arsenic (As)	0.2
Beryllium (Be)[2]	0.1
Boron (B)	5.0
Cadmium (Cd)	0.05
Chromium (Cr)	1.0
Cobalt (Co)	1.0
Copper (Cu)	0.5
Fluoride (F)	2.0
Iron (Fe)	not needed
Lead (Pb)[3]	0.1
Manganese (Mn)[4]	0.05
Mercury (Hg)	0.01
Nitrate + Nitrite (NO_3-N+NO_2-N)	100.0
Nitrite (NO_2-N)	10.0
Selenium (Se)	0.05
Vanadium (V)	0.10
Zinc (Zn)	24.0

[1] Adapted from National Academy of Sciences (1972).
[2] insufficient data for livestock. Value for marine aquatic life is used here.
[3] Lead is accumulative and problems may begin at a threshold value of 0.05 mg/l
[4] Insufficient data for livestock. Value for human drinking water used.

6. CONTROL MEASURES

6.1 General considerations

To the planners concerned with wastewater reuse, wastewater treatment appears as a more straightforward and "visible" measure for health protection, seconded only by crop restriction. Both measures, however, are relatively difficult to implement fully: the first being limited by cost and problems of operation and maintenance, and the second by lack of appropriate markets for specific products, or by legal and/or institutional constraints.

The application of isolated measures, while not economical, may have only partial effects in terms of health protection. Crop restriction for instance, if applied, may protect the consumers but does not provide protection to farm workers and their families.

6.2 Wastewater reuse guidelines

Reuse guidelines may help protect public health and the environment. Currently, there are two situations in the countries of the Near East Region:

- National guidelines are available and thereby farmers should follow and respect them.
- No National guidelines are available. In this case the WHO guidelines are proposed as a solution (Table 9).

6.3 Monitoring and control of wastewater quality

As mentioned already, the general monitoring and wastewater quality control are not the responsibility of farmers but of other authorities. The quality depends on how well the treatment is, on the maintenance and operation of the treatment system and on the background of the people operating the wastewater treatment plant.

However, training the farmers to follow, at least visually or with simple tests, the quality of wastewater could be very helpful. The farmers should be in position to judge whether the wastewater has been appropriately treated. Changes in the color of wastewater or extensive growth of algae are indicators of chemicals and nutrients in the wastewater at higher levels. Odor indicates insufficient treatment. The farmers should be provided training on these aspects prior to the allocation of wastewater for irrigation. Also, farmers must granted free access for the information related to the water quality and type of the treated reclaimed water, which they were provided with.

6.4 Control of storage, transport and distribution facilities

These aspects do not reflect responsibility of the farmers but the farmers should be informed and aware as far as it concerns storage and distribution of wastewater in their farms. This may avoid accidental use of wastewater or accidental damage of the system.

Problems associated with monitoring and evaluation

Monitoring and evaluation is an essential requirement of any project that uses treated wastewater. It should be a continual activity, and constitute an integral part of the operation and management of any such project. Without regular and effective monitoring and evaluation system, unfavourable conditions could appear such as:

- The benefits anticipated from the reuse project would not continue to accrue on a long-term and sustainable basis, leading to the possibility that the project may, in the future, create serious health and environmental hazards.

Thus, a carefully planned and effective monitoring and evaluation system is an essential pre-requisite for the success of any wastewater reuse project.

Integrated quality monitoring of treated effluent reuse for irrigation (FAO, 1995)

In crop irrigation with treated wastewater, a critical issue is the impact of its constituents on the soil and/or crops and furthermore to animals and humans fed with such crops.

Proposed **chemical** quality parameters, which might be regularly or periodically monitored by farmers or for the farmers through official authorities are:

- **EC_w = Electrical conductivity** expressed in units of dS/m referenced at 25°C. It is one of the most commonly measured parameters, particularly in arid and semi-arid regions to estimate the total amount of soluble salts in water. Salinity is probably the most important single parameter, which determines cropping pattern and management of fields irrigated with wastewater.

- **Cations and anions**

  Ca, Mg, Na, CO_3, HCO_3, SO_4, Cl. Some of these ions may be monitored only at the beginning and thereafter periodically since they don't change too much. Some other ions like Boron must be monitored regularly since in cases where detergents with B are widely used, B in wastewater might be the main limiting factor for its reuse for irrigation.

- **Sodium Adsorption Ratio**, the most widely used index to measure physico-chemical changes in the soil:

$$\mathbf{SAR = NA/[(Ca+Mg)/2]^{1/2}}$$

where ionic concentrations are expressed in meq/l.

- **Heavy metals and trace elements**

  Although heavy metals and trace elements (Al, As, Ba, Cd, Cr, Cu, Fe, Pb, Li, Mn, Hg, Ni, Se) may not be a problem for wastewater reuse, it is recommended that these elements be determined at least once before initial irrigation. Periodic monitoring of those (if any) found in concentrations that may affect the soil-plant system, is recommended.

- **Plant nutrients**

  It is advisable to monitor : NO_3-N, NH_4-N, P and K, for three main reasons:

  - To estimate additional fertilizers needed to be supplied for optimizing yield and quality of the crops.
  - To help deciding the appropriate cropping pattern for the best possible water and nutrient use efficiency.
  - To protect surface and underground water pollution by NO3-N.

7. SOCIO-CULTURAL, LEGAL, INSTITUTIONAL AND ECONOMIC ASPECTS

This chapter is concise and up to the point of direct interest to the farmers. It is more relevant to the extension agronomist. The extension agronomists should be aware particularly of legal and institutional aspects existing in their countries in order to control and also give the best possible advice to the farmers to overcome problems that are common with treated wastewater use.

7.1 Social acceptability and public information

Reuse of treated wastewater in some countries presents a new concept. Therefore, an important requirement of the safe and cost effective use of municipal wastewater is the education of all participants in the process of reuse. Training is necessary for the personnel managing and maintaining treatment facilities, and the farmers using the treated wastewater.

Wastewater, as a resource, is under utilized, and even in certain cases not considered for reuse, due to the following main reasons:

- Lack of information about its benefits;
- Fear of health risk involved;
- Cultural bias, religion belief, public perception;
- Lack of a method for comprehensive economic analysis of reuse projects; and
- Poor experience with wastewater reuse where it has been practised under uncontrolled conditions.

Therefore, special care should be taken to provide information and education programmes that will involve people from all community levels and not only farmers. The second step should be a training programme for the users (farmers), because mis-use of wastewater can lead to repugnance.

A well - organized public information campaign should be planned as a mean of making the public informed of the issue. Its primary objective will be to raise collective consciousness and to present wastewater reuse as a reliable substitution technique. It should also make the potential users aware of the facts related to wastewater reuse. Farmers and the public in general should be aware not only of benefits, which will result from reuse but also of environmental and health hazards connected with wastewater use. The awareness campaign should result in minimizing of the cultural and psychological bias linked with wastewater.

7.2 Training and human resource development

Lack of skills and knowledge can cause failure in project implementation and, in the case of wastewater reuse projects, can potentially increase environmental and public health risks. Because of this, training programmes should be an integral part of projects. Programmes of training should include technical, environmental, health and socio-economic aspects. The educational input must provide the farmers with an understanding of the details of techniques and their associated hazards as well as of the precautions to be taken so that the operations take place within acceptable safety levels and at a reasonable cost.

Timing and duration of a training programme are of crucial importance since persons should be sufficiently trained to be able to work properly when it is required. Thus, farmers should already have undergone the necessary training before starting the use of wastewater. Farmers should request for training. The aspects of training could be more or less those covered in this manual.

The provision for training is required not only before use of wastewater but from time to time thereafter, since refreshing and/or upgrading of skills and training of new farmers should be a continual process.

7.3 Institutional aspects, monitoring and control measures

Wastewater reclamation and reuse is viewed increasingly as a mean to augment existing and future water resources against the growing demand for water. Reclaimed water is a reliable source even in drought years, especially in urban environment, that is capable of replacing potable water use for non-potable water use. However, care should be taken to avoid environmental and health risks.

Considering the risks associated with treated wastewater reuse, an adequate institutional framework should always be created to control, supervise and advise on the management of reuse schemes, in order to ensure safe reuse. At a national level, the use of treated wastewater is an activity involving the responsibilities of several ministries or agencies. The institutional framework should be well defined and the distribution of responsibilities clearly specified. Considering that usually a great number of institutions is involved, smooth operation of individual interactions is not always easy to achieve. The form and operational characteristics of the institutional framework vary in different countries and should be designed to suit local conditions. The farmers should be aware of the responsibilities of each institution in order to address their questions and/or problems faced. Without this background a general confusion will be developed.

7.4 Regulatory considerations and legal issues

Public health and the environment are the main concerns in water reuse projects. In this respect, quality guidelines as well as requirements for treatment, sampling and monitoring are essential in each country. In a number of countries, strict control measures are imposed on reuse. In this way farmers are obliged to act within the framework of these regulations in order to safeguard public health and the environment. However, how well the farmers respect the regulations is questionable, which makes strong monitoring essential. Moreover, legislative acts to enforce compliance with the regulations might be needed.

Most countries where wastewater reuse is practised have public health and environmental regulations, which govern treatment and reuse practices. These regulations as guidelines or code of practices are intended to protect the health of both the consumers and the workers. They may prohibit irrigation with wastewater within specified periods prior to harvesting, require appropriate clothing and provide for preventive health care of workers. The guidelines for wastewater reuse, although variable in different countries are usually very stringent because of water pollution control requirements. The technology involved in the treatment process together with appropriate operation of the available system should achieve the guideline objectives. The regulatory agencies must be always ready to monitor treated wastewater quality and enforce appropriate regulations, in order to safeguard the health of the farmers and the consumers.

In several countries of the Near East, the technology to produce an intended effluent quality is often not available or if available not properly maintained. Regulatory agencies are seldom able to enforce the guidelines. Wastewater reuse is, therefore, often uncontrolled and workers and consumers are usually at risk. To resolve the legal problem of unenforceable guidelines, the first step is to set realistic criteria reflecting prevalent risks. It is important that the quality criteria be such as to promote rather than to restrict effluent reuse.

7.5 Economic aspects

For the farmers the main incentive is the profit expected from the use of wastewater for irrigation. The user is not interested on the cost of collection, treatment, distribution and other aspects. His interest is whether with certain amount and quality of wastewater, given to him with some price or free, and with restriction for certain crops, could practice profitable irrigated agriculture.

Benefits

The benefits could be briefly summarized as follows:

- Saving in fresh water
- Saving in fertilizers
- Increasing yield
- Creating job opportunities

In summary, for the farmers the main benefits are resulted from the point that wastewater is a reliable water source even in very drought years and that the nutritional value of wastewater may lead to high yield of good quality without or with limited amount of fertilizer.

8. SLUDGE

Efforts to reduce the pollution of rivers, lakes, and oceans by treating sewage are generating a rapidly growing amount of sludge, solid material, that is removed from a wastewater to produce a reclaimed wastewater.

8.1 Sludge composition

The composition and the pathogens that are the key issues for the suitability of sewage sludge for agricultural use (USDA, 1980) depend on the:

- Sludge source (industrial or domestic);
- Type of wastewater treatment (preliminary, primary, secondary, tertiary or advanced wastewater treatment);
- Chemical used for flocculation; and
- Type of sludge treatment.

The following are the main four aspects concerning sludge reuse:

- **Heavy metals** content of sludge varies with the level of industrial contribution. Under certain conditions concentration of heavy metals (zinc, copper, and nickel) can kill plants. Cadmium can be absorbed by plants in concentrations, which may be harmful for humans. Even domestic wastewater may yield sludge containing enough metals to limit its continuous use. Therefore, heavy metal analyses are needed to assess the suitability of sludge as a fertilizer source or as a soil conditioner.
- **Pathogens.** Viruses, helminths, protozoa and bacteria. In most Near East Countries pathogens are the main factor of concern. In particular, eggs of some parasites with long life and very resistant to high temperatures may be present even after drying sludge in thin layers or processing it to compost. Farmers should be aware of the risk and manage sludge use with care. Precautionary measures such as wearing cloves and boots should be considered as obligatory measure.
- **Salinity.** In certain cases salinity may be high and the overall loading of agricultural land with sludge per application is calculated based on salinity levels and not the N content of sludge.
- **Nutrients.** Sludge may contain high levels of certain nutrients which may damage crops (B and other metals) and the environment (N). These constituents should be taken into account, particularly in sensitive areas such as the water resources, when the overall amount of sludge is calculated per unit area per year.

8.2 Sludge as a fertilizer and soil conditioner

Sludge applied at a rate to supply the nitrogen requirement of the crop will provide most of the plant nutrients except potassium. However, it is unlikely that sewage sludge will be used to supply the total nutrient requirements of crops because of the large amounts that would have to be applied. Other factors may restrict the amount of sludge per application per year.

The maximum value of sludge is realized when it is applied in combination with inorganic fertilizers; in this way, sludge partly meets the crop's nutrient requirements and also serves as a valuable organic soil conditioner for maintaining soil productivity. Sludge and sludge compost are known to improve soil physical properties, as evidenced by enhanced aggregation, increased soil aeration, lower bulk density, less surface crusting, and increased water infiltration, water content, and water retention.

Sludge added to sandy soils will increase the moisture available to plants and reduce the need for irrigation due to increased soil moisture retention capacity. In heavy textured clay soils, the added organic matter will increase soil permeability to water and air, increase water infiltration into the soil profile, thereby minimizing surface runoff, and increases root development and root depth.

The fertilizer benefit to the crop from nitrogen and other nutrients contained in the sludge may be approximated by appropriate calculations. Nitrogen is usually the limiting factor and the most common used for calculations. Several facts must be established to make such calculations.

N-crop requirement

The crop requirement for nitrogen is estimated taking into account the following points:

- Soil fertility. The amount of nitrogen supplied from the soil (including previously applied compost, crop residues, manure, and chemical fertilizers) should be estimated and
- Predicted yield levels (Appendix IV)

The amount of nitrogen available to the crops during the initial growing season from the applied sludge can be estimated as follows:

% Available N = 0.1 x % Organic N

The inorganic N in the sludge immediately available to the plant is accounted for in the 10% mineralization rate prediction. Alternatively, the percent mineralizable nitrogen may be determined more accurately by an incubation technique, using the specific soil to which the sludge will be added.

Mineralization of organic N from earlier sludge or compost applications will supply a considerable portion of the N requirement along with that which is available from the current application (USDA, 1980). The second year mineralization of sludge compost is about 5% of the remaining organic N and it is estimated that 2% of the remaining organic N will mineralize per year after the second year. Available N levels for a designated application of sludge containing 1.0% organic N is given in (Table 24). If farmer uses sludge as the only N source and the crop requires 100 kg N/ha, he would apply 100 metric tons/ha the first year, about 60 metric tons/ha the second, third and fourth years, and 30 metric tons/ha thereafter. This will allow the mineralization equilibrium to be established, and at that time, the amount of available N would equal the total N applied. The user might also consider supplementing nitrogen needs with fertlizer, depending on availability and cost. The user should be aware that, in addition to N availability, heavy metal and salt accumulation should be considered in the determination of a beneficial cumulative loading rate for sludge or sludge compost.

Sludge can supply besides the organic matter and N, other macro-nutrients P, K, Ca, Mg and micro-nutrients Fe, Cu, Zn, Mn, Mo, and B.

Uses of high rates (>50% by volume) is wasteful of the nutrients in the sludge and can cause salt toxicity. If such a situation happen then leaching is recommended.

Table 24. Available N from a single application of sludge at indicated rates*.

Sludge application (dry metric Tons/ha)	Total N applied (kg)	Available N (kg) First year	Second year	Subsequent years
20	200	20	9	3
40	400	40	18	7
100	1000	100	45	17
200	2000	200	89	34

* Mineralization rates are 10%, 5% and 2% for the first, second, and subsequent years, respectively.

8.3 Constraints on uses

8.3.1 Pathogens.

Because of its origin, sewage sludge may not be acceptable by the farmers and the public from the standpoint of aesthetic or health aspects. Aesthetic reservations are generally offensive odours and appearance of sludge. This is one of the reasons why composting of sludge is favoured. In addition, If composting is properly done it destroys or reduces to insignificant levels all primary pathogens present in sewage sludge. Once destroyed, viruses, helminths, protozoa, and most bacteria will not repopulate in the compost, since they cannot grow external to their hosts. Salmonella, one of the most common organisms causing food poisoning, can re-grow to a limited extent in the finished compost. but it does not compete well with other micro-organisms present.

8.3.2 Heavy metals.

Sewage sludge may contain, depending on the source, large amounts of heavy metals, which may reduce the value of sludge as a fertilizer for either direct application to land or for composting. Excessive amounts of these metals are often found in sludge where industrial effluent is discharged into the sanitary sewers without pre-treatment. Application of high metal sludge on land results in soil enrichment in heavy metals. Soil enrichment by zinc, copper, and nickel can cause direct phytotoxic effects manifested as decreased growth and yield, especially where soil pH is low (pH 5.5) and rates of application are high. Heavy metals may also accumulate in plant tissues and enter the food chain through direct ingestion by humans or indirectly through animals.

The element of greatest concern to human health where sewage sludge and sludge compost are applied to land is cadmium (Cd), since it is readily absorbed by most crops and is not generally phytotoxic at the concentrations normally encountered. Therefore, Cd can accumulate in plants and enter the food chain more readily than other metals such as lead (Pb) or mercury (Hg), which are not readily absorbed and translocated to the edible portion of crops.

Plant species, as well as varieties, have been found to differ in their ability to absorb and translocate heavy metals, to accumulate them within edible organs of the plant, and to resist their phytotoxic effects. In this respect, the farmers should remember the following:

- **Leafy vegetables are usually sensitive to the toxic effects of metals and accumulate them, mostly in the leafy part;**
- **Cereal grains, corn, and soybeans are less sensitive; and**
- **Grasses are relatively tolerant.**

Uptake studies with corn, soybean, and cereal grains have shown that heavy metals accumulate less in the edible grain than in the leaves; similar results are found for edible roots, as radish, turnip, carrot, and potato, and fruits, as tomato, squash etc.

The availability of heavy metals in soils be uptaken by plants are influenced by certain chemical and physical properties of soil, especially pH, organic matter content, cation exchange capacity (CEC), and texture (i.e., the proportions of sand, silt, and clay). Phytotoxicity in sludge - borne metals are higher in acid soils than in those with neutral or alkaline pH. Maintaining soil pH in the range of 6.5 or above by liming reduces the availability of heavy metals to plants. Evidently, under calcareous conditions heavy metals are rendered unavailable and the problem is becoming insignificant. Application of organic amendments such as manure and crop residues can also decrease the availability of heavy metals to plants. The CEC is a measure of the soil's capacity to retain cations; higher CEC is usually associated with higher clay and organic matter contents. Heavy metals are generally less available to plants in soils of high CEC (e.g., organic matter rich soils or clay loams) compared with soils of low CEC (e.g., loamy sands).

(Table 25) shows the recommended maximum cumulative sludge metal loading for privately owned agricultural land according to the soil cation exchange capacity (USDA recommendations). Soils in the 0 to 5 of CEC range are sandy through sandy loam; the 5 to 15 range includes sandy loam, loam, silt loam; and > 15 includes silty clay loam and clays. Higher metal loading would be considered reasonably allowable on heavier textured soils. Cadmium loading on land should not exceed 2 kg/ha/year for de-watered sludge or sludge compost and should not exceed the total cumulative loading shown in the Table. Sludge and sludge compost should not be applied to land used to grow tobacco as this crop allows high transfer of Cd to humans; sludge and compost used on land to grow leafy vegetables should be low in Cd and Cd/Zn ratio to minimize any effects on humans.

Table 25. Recommended maximum cumulative metal loading from sludge or sludge compost applications to privately owned land (USDA, 1980).

	Soil cation exchange capacity (meq/100g)[1]		
Metal	**0 - 5**	**5 – 15**	**> 15**
	(Maximum metal addition, kg/ha)		
Pb	500	1000	2000
Zn	250	500	1000
Cu	125	250	500
Ni	50	100	200
Cd	5	10	20

[1]CEC determined prior to sludge application using I N neutral ammonium acetate and is expressed here as a weighted average for a depth of 50cm.

GLOSSARY

Aerated lagoon	This is an adaptation of the waste stabilization pond in which oxygen is added by mechanical aerators.
Alkalinity	The capacity of water to neutralise acids; a property imparted by carbonates, bicarbonates, hydroxides, and occasionally borates, silicates, and phosphates. It is expressed in milligrams of equivalent calcium carbonate per litre
Available water	The portion of water in a soil that can be readily absorbed by plant roots. Difference between field capacity (FC) and wilting point (WP).
Biochemical oxygen demand BOD_5	(1). The quantity of oxygen used in the biochemical oxidation of organic matter after 5 days, at a specified temperature, and under specified conditions. (2) A standard test used in assessing wastewater biological quality. The lowest the BOD value, the better the quality is.
Cation exchange capacity (CEC)	The sum of exchangeable cations that a soil can adsorb expressed in milliequivalents per 100 grams of soil or in millimoles of positive charge per kilogram of soil. CEC is directly related to a soil's ability to retain cations against normal water leaching. CEC is also used in calculating exchangeable sodium percentage (ESP) - a measure of excessive sodium hazard in the soil.
Chemical oxygen demand (COD)	A quantitative measure of the amount of oxygen required for the chemical oxidation of carbonaceous (organic) material in wastewater using dichromate or permanganate salts as oxidants in a two–hour test.
Coliform bacteria	Group of bacteria of the enteric tract of mammals used as an indicator of faecal pollution
Denitrification	The biological conversion of nitrate or nitrite to gaseous N_2 or N_2O.
Effluent	Partially or completely treated wastewater flowing out of a treatment plant, reservoir, or basin.
Electrical conductivity **EC_w for water** **EC_e for soil**	A measure of salinity expressed in millimhos per centimeter (mmho/cm) or decisiemens per meter (dS/m) at 25°C. Empirically related to total dissolved solids (in mg/l). TDS (mg/l) = EC (dS/m) x 640.

Evapotranspiration (ET)	The combined loss of water from a given area and during a specified period of time by evaporation from the soil surface and by transpiration from plants. Et_o is the reference devised as the ET from an extended surface of 8 to 15 cm tall green grass cover of uniform height, actively growing, completely shading the ground and not short of water. E_p or E_{pan} is evaporation from a standard evaporation pan.
Exchangeable sodium percentage (ESP)	The ratio (as percent) of exchangeable sodium to the remaining exchangeable cations in the soil.
Field capacity (FC)	The percentage of water (either weight or volume) remaining in a soil 2-3 days after having been saturated and after free drainage has practically ceased. For many soils, FC is in the range of 1/10 to 1/3 bar water potential.
Hydraulic conductivity	The rate of water flow through the soil per unit gradient of hydraulic head or potential.
Immobilization	The conversion of an element from the inorganic to the organic form in microbial or plant tissues. Often used to describe the conversion of nitrate or ammonium into organic forms in soil microorganism bodies.
Infiltration	(1) The downward entry of water into soil. (2) The flow or movement of water through the pores of a soil or other porous medium. (3) The quantity of groundwater that leaks into a pipe through joints, porous walls, or breaks (4) The entrance of water from the ground into a gallery.
Infiltration rate	(1) A soil characteristic describing the maximum at which water can enter the soil under specified conditions, including the presence of excess water. It has the dimensions of velocity, i.e., cm/hour or cm/sec. Formerly, the infiltration capacity. (2) The rate, usually expressed in cubic feet per second or million gallons per day per mile of waterway, at which groundwater enters an infiltration ditch or gallery, drain, sewer, or other underground conduit.
Land application	The recycling, treatment, or disposal of wastewater or wastewater solids to the land under controlled conditions.
Land disposal	Application of raw or treated wastewater, sludge, or solid waste to soils and/or substrata without production of usable agricultural products.

Leaching fraction (LF)	The fraction of water applied to soil that leaches salts below a depth of interest such as the rooting depth.
Leaching requirements (LR)	Amount of water to maintain average root zone salinity below a phytotoxic threshold value for a specific crop.
Mineralization	The conversion of an element from an organic to an inorganic form (e.g., the conversion of organic nitrogen in wastewater to ammonium nitrogen by microbial decomposition).
Permeability	The ease with which gas, liquids or plant roots penetrate or pass through a soil horizon
pH	The degree of acidity or alkalinity in water.
Primary treatment	(1) The first major treatment in a wastewater treatment facility, usually sedimentation but not biological oxidation, (2) The removal of a substantial amount of suspended matter but little or no colloidal and dissolved matter. (3) Wastewater treatment processes usually consisting of clarification with or without chemical treatment to accomplish solid-liquid separation. See also secondary treatment, tertiary treatment.
Rapid infiltration	A type of land treatment in which water is applied to relatively porous soil at rates far in excess of normal crop irrigation.
Secondary treatment	(1) Generally, a level of treatment that produces removal efficiencies for BOD and suspended solids of 85%. (2) Sometimes used interchangeably with concept of biological wastewater treatment, particularly the activated sludge process. Commonly applied to treatment that consists chiefly of a biological process followed by clarification with separate sludge collection and handling.
Sludge	The solid matter (often having a high water content) that is formed both when sewage is allowed to stand so that the denser solids settle out, and as a product of various treatments processes.
Sodium adsorption ratio SAR	A measure of the amount of sodium relative to the amount of calcium and magnesium in water or in soil saturation extract. It is defined as follows: $SAR = NA/[(Ca+Mg)/2]^{1/2}$ Where the quantities Na, Ca and Mg are expressed in milliequivalent/litter. The SAR can be used to predict the exchangeable sodium percentage of a soil equilibrated with a given solution.

Soil structure	The combination or arrangement of primary soil particles into secondary particles, aggregates, or pees. These secondary units are classified by soil morphologists on the basis of size, shape, and degree of distinctness.
Treated wastewater	Wastewater that, as a result of treatment, is suitable for a beneficial use.
Soil texture	The relative proportion in a soil of sand, silt, and clay - sized mineral particles
Soil water content	The amount of water lost from the soil upon drying to constant weight at 105°C, expressed as g water per g dry soil or cm^3 water per cm^3 bulk soil. In the field, water content is often expressed on a percent dry weight basis. This can lead to ambiguity when it is not stated whether a weight or volume basis is being used.
Total dissolved solids (TDS)	The sum of all dissolved solids in water or wastewater and an expression of water salinity in mg/l. Empirically related to electrical conductivity (EC) multiplied by 640.
Wastewater irrigation	Land application of wastewater with the primary purpose of maximizing crop production per unit of water applied. Often used in a broader sense to mean land treatment and disposal of wastewater where maximum crop production is a secondary objective
Wastewater reclamation	The process of treating wastewater to produce water for beneficial uses, its transportation to the place of used, and its actual use.
Wastewater reuse	The additional use of once-used water.

REFERENCES

- Abdel-Hafez et. al, 1986. Prevalence of Intestinal Parasitic Infections in Riyadh District, Saudi Arabia. Annals of Tropical Medicine and Parasitology, 80, 630-634.

- Al Salem, Saqer 1998. Report of Mission to Oman, December 1998, CEHA/Amman.

- Ali-Shrayeh et. al, 1989. Prevalence and Seasonal Fluctuations of Intestinal Parasitic Infections in the Nablus Area, West Bank of Jordan. Annals of Tropical Medicine and Parasitology, 83, 67-72.

- Ayers, R.S. 1977. Quality water for irrigation. J. Irrig. Drain. Div., ASCE: 135-154.

- Biswas A.K. 1987. Role of wastewater reuse in planning and management. In A.K. Biswas and A. Arar (Eds) Treatment and reuse of sewage effluent for irrigation. Butterrsworth Scientific Guildford, U.K.

- Blumenthal, U.J., M. Strauss, D.D. Mara and S. Cairncross. 1989. Generalized model of the effect of different control measures in reducing health risks from waste reuse. Wat. Sci. Tech. 21:567-577.

- Chandler, A.C., 1954. A Comparison of Helminth and Protozoan Infections in two Egyptian Villages Two Years after the Installation of Sanitary Improvements in one of them. American Journal of Tropical Medicine and Hygiene, 3, 59-73.

- Chris Smith, 1990.. "Geohelminth Infection in the Gaza Strip." Proceedings of Water and Sanitation Study Day, 22 March 1990, Save the Children Federation. Birzeit University

- EPA. 1992 Guidelines for wastewater reuse; WASH Technical Report No. 81, September 1992.

- FAO, 1984. Crop water requirements. FAO Irrigation and Drainage paper 24, FAO, Rome.

- FAO, 1985. Water quality for agriculture. FAO Irrigation and Drainage paper 29, Rev. 1., FAO, Rome.

- FAO, 1990. Protected cultivation in the Mediterranean climate. FAO Pant Production and Protection paper 90, FAO, Rome.

- FAO, 1992. CROPWAT: A computer program for irrigation planning and management. Irrigation and Drainage paper 46. Rome.

- FAO, 1992. Wastewater treatment and use in agriculture. FAO Irrigation and Drainage paper 47, FAO, Rome.

- FAO, 1998. Irrigation in the Near East Region in Figures. Water Report 9 / (AQUASTAT).

- FAO/RNEA, 1991. Wastewater management for irrigation. Tech. Bul. No. 1., p.15.

- FAO/RNEA, 1991. Wastewater use and human health. Tech. Bul. No. 3., p.22.

- FAO/RNEA, 1992. Irrigation methods, crops and practices using wastewater. Tech. Bul. No. 4., p.20.

- FAO/RNEA, 1992. Treatment of wastewater used for irrigation. Tech. Bul. No. 2., p.33.

- FAO/RNEA, 1992. Wastewater as a crop nutrient source. Tech. Bul. No. 5., p.15.

- FAO/RNEA, 1993. Considerations of wastewater reuse system for irrigation. Tech. Bul. No. 7., p.18.

- FAO/RNEA, 1993. Monitoring wastewater quality for irrigation. Tech. Bul. No. 6., p.23.

- FAO/RNEA, 1995. Wastewater management for agricultural production and environmental protection in the Near East Region. FAO Regional office, Cairo, Egypt.

- Feachem, R. G. 1983. Bradley, D.J., Garelick, H., and Mara, D.D. Sanitation and Diseases: Health Aspects of Excreta and Wastewater Management. Chichester, John Wiley.

- Goldberg D., Bornat, B and Bar-Yosef, 1971. Distribution of roots, water and minerals as a result of trickle irrigation. J. Am. Soc. Hort. Sci., 96:645-648.

- Kypris, D., 1989. Considerations of the quality standards for the reuse of treated effluents. In Proceedings of Wastewater Reclamation and Reuse. Cairo, Egypt 11-16 Dec. 1988.

- Maas, E.V., 1984. Salt tolerance of plants. The handbook of land science in agriculture. B.R. Cristie (Ed). CRC Press, Boca Raton, Florida.

- Mara, D. and S. Cairncross, 1989. Guidelines for the safe use of wastewater and excreta in agriculture and aquaculture: Measures for public health protection.

- Mara, D. and S. Cairncross. 1988. Guidelines for the safe use of wastewater and excreta in agriculture and aquaculture: Methods of public health protection. IRCWD News. 24/25: 4-12.

- National Academy of Science USA-National Academy of Engineering, 1973. Water quality criteria. 232-253.

- Papadopoulos, I. and Y. Stylianou. 1988. Treated effluent as a source of N for trickle irrigated sudax. Plant and Soil 110: 145-148.

- Papadopoulos, I. and Y. Stylianou. 1991. Trickle irrigation of sunflower with municipal wastewater. Agric. Water Manag. 19:67-75.

- Pettygrove, G.S. and T. Asano (Ed). 1984. Irrigation with reclaimed municipal wastewater - A Guidance Manual. Report No. 84 - 1 wr, California State Water Resources Control Board, Sacramento.

- Rhoades, J.D. 1977. Potential of using saline agricultural drainage for irrigation. In Proc. Water management for irrigation and drainage. ASAE, Reno, Nevada, July 1977:85-116.

- Shuval, H.A., A. Adin, B. Fattal, E. Ravitz and P. Yekutiel. 1986. Wastewater irrigation in developing countries. Health effects and technical solutions. Technical Paper No. 51. Washington D.C. : The World Bank.

- UNEP-FAO. 1991. Environmental guidelines for municipal wastewater reuse in the Mediterranean region. Split. pp.127.

- USDA, 1980. Manual for composting sewage sludge by the Beltsville aerated-pile method. P. 65.

- WHO, 1973. Group of Experts. "Reuse of Effluents: Methods of Wastewater Treatment and Health Safeguards: World Health Organization, Technical Report Series No. 517, Geneva, 1973.

- World Health Organization, (WHO). 1989. Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture. Technical Report Series No. 778. WHO, Geneva.

Appendix I: Constituents of concern in wastewater treatment and irrigation with reclaimed wastewater

Constituent	Measured Parameters	Reason for concern
Suspended solids	Suspended solids, including volatile and fixed solids	Suspended solids can lead to the development of sludge deposits and anaerobic conditions when untreated wastewater is discharged in the aquatic environment. Excessive amounts of suspended solids cause plugging in irrigation systems.
Biodegradable organics	Biochemical oxygen demand, Chemical oxygen demand	Composed principally of proteins, carbohydrates, and fats. If discharged to the environment, their biological decomposition can lead to the depletion of dissolved oxygen in receiving waters and to the development of septic conditions.
Pathogens	Indicator organisms, total and faecal coliform bacteria	Communicable diseases can be transmitted by the pathogens in wastewater: bacteria, virus, parasites.
Nutrients	Nitrogen, Phosphorus, Potassium	Nitrogen, Phosphorus and Potassium are essential nutrients for plant growth, and their presence normally enhances the value of the water for irrigation. When discharged to the aquatic environment, nitrogen and phosphorus can lead to the growth of undesirable aquatic life. When discharged in excessive amounts on land, nitrogen can also lead to the pollution of groundwater.
Stable (refractory) orgnanics	Specific compounds (e.g., phenols, pesticides, chlorinated hydrocarbons)	These organics tend to resist conventional methods of wastewater treatment. Some organic compounds are toxic in the environment, and their presence may limit the suitability of the wastewater for irrigation.
Hydrogen ion activity	pH	The pH of wastewater affects metal solubility as well as alkalinity of soils. Normal range in municipal wastewater is pH=6.5 - 8.5, but industrial waste can alter pH significantly.
Heavy metals	Specific elements (e.g., Cd, Zn, Ni, Hg)	Some heavy metals accumulate in the environment and are toxic to plants and animals. Their presence may limit the suitability of the wastewater for irrigation.
Dissolved inorganics	Total dissolved solids, electrical conductivity, specific elements (e.g., Na, Ca, Mg, Cl, B)	Excessive salinity may damage some crops. Specific ions such as chloride, sodium, boron is toxic to some crops. Sodium may pose soil permeability problems.
Residual chlorine	Free and combined chlorine	Excessive amount of free available chlorine (>5 mg/l Cl_2) may cause leaf–tip burn and damage some sensitive crops. However, most chlorine in reclaimed wastewater is in a combined form, which does not cause crop damage. Some concerns are expressed as to the toxic effects of chlorinated organics in regard to groundwater contamination.

* Pettygrove, G.S. and T. Asano, 1984

Appendix II: Wastewater quality guidelines for irrigation in Cyprus

Irrigation	BOD mg/l	SS mg/l	Fecal coliforms /100ml	Intestinal worms/l	Treatment Required
All crops (1)	A) 10*	10*	5* 15**	Nil	Secondary and tertiary and disinfection
Amenity areas of unlimited access and vegetables eaten cooked (2)	A) 10* 15**	10* 15**	50* 100**	Nil	Secondary and Tertiary and disinfection
Crops for human consumption. Amenity areas of limited access	A) 20* 30**	30* 45**	200* 1000**	Nil	Secondary and storage >1 week and disinfection, or Tertiary and disinfection
	B) -	-	200* 1000*	Nil	Stabilization - maturation ponds total retention time>30 days or Secondary and storage >30 days
Fodder crops	A) 20* 30**	30* 45**	1000* 5000**	Nil	Secondary and storage >1 week or tertiary and disinfection
	B) -	-	5000*	Nil	Stabilization-maturation ponds total retention time >30 days or Secondary and storage >30 days
Industrial crops	A) 50* 70**	- -	3000* 10000**	- -	Secondary and Disinfection, stabilization-maturation ponds retention time 30 days or Secondary and storage >30 days
	B) -	-	3000* 10000**	- -	

A .Mechanized methods of treatment (activated sludge etc.)
B. Stabilization ponds
*These values must not be exceeded in 80% of samples per month. Minimum number of samples is 5.
** Maximum value allowed
1. Irrigation of leafy vegetables, bulbs eaten uncooked is not allowed
2. Potato, beet-roots, colocasia
Note:No substances accumulating in the edible parts of crops and proved to be toxic to humans or animals are allowed in the effluent

Appendix III: Code of practice for treatment and use of domestic sewage effluent for irrigation (Cyprus case)

A. Treatment

1. The sewage treatment and disinfection must be kept and maintained continuously in satisfactory and effective operation so long as treated sewage effluents are intended for irrigation and according to the license issued under the existing legislation.

2. Skilled operators should be employed to operate the treatment and disinfection plant, following formal approval by the appropriate authority that the persons are competent to perform the required duties, necessary to ensure that conditions of (I) are satisfied.

3. The treatment and disinfection plant must be checked every day according to the program issued by the Authority and records to be kept of all operations performed according to the instructions of the appropriate Authority. A copy must be kept for easy access within the treatment facilities.

4. All outlets, taps and valves in the irrigation system must be secured to prevent their use by unauthorized persons. All such outlets must be colored red or purple and clearly labeled so as to warn the public that the water is unsafe for drinking.

5. No cross connections with any pipeline or works conveying potable water, is allowed. All pipelines conveying sewage effluent must be satisfactorily marked with red tape so as to distinguish them from domestic water supply. In unavoidable cases where sewage/effluent and domestic water supply pipelines must be laid close to each other the sewage or effluent pipes should be buried at least 0.5 m below the domestic water pipes.

B. Treated Wastewater Use for Irrigation

Irrigation methods allowed and conditions of application, differ according to different plantations as follows:

1. **Park lawns and ornamental in amenity areas of unlimited access**

- Subsurface irrigation methods
  - Drip irrigation
  - Pop-up, low pressure and high precipitation rate, low angle sprinklers (less than 11 degrees). Sprinkling preferably be practiced at night and when people are not around, avoiding windy hours.

2. **Park lawns and ornamental in amenity areas of limited access, industrial and fodder crops**

- Subsurface irrigation methods
  - Drip irrigation
  - Bubblers
  - Pop-up sprinklers
  - Surface irrigation systems
  - Low capacity sprinklers

Spray and sprinkler irrigation is allowed with a buffer zone of about 300m.

For fodder crops, irrigation is recommended to stop at least one week before harvesting and no milking animals should be allowed to graze on pastures irrigated with sewage. Veterinary Services should be informed.

3. **Vines**
    - Drip irrigation
    - Minisprinklers and sprinklers (in case where crops get wetted, irrigation should stop two weeks before harvesting).
    - Movable irrigation systems are not allowed.
    - No crops should be picked up from the ground.
4. **Fruit trees**
    - Drip irrigation
    - Hose basin irrigation
    - Bubblers irrigation
    - Mini sprinklers

No fruits to be collected from the ground except for nut-trees. In case where crops get wet irrigation should stop one week before harvesting.

5. **Vegetables**

- Subsurface irrigation
- Drip irrigation

Crops must not come in contact with the ground or the wastewater (only vegetables which are supported). Other irrigation methods could also be considered.

6. **Vegetables eaten cooked**

- Sprinklers
    - Subsurface irrigation
    - Drip irrigation

Other irrigation methods may be allowed after the approval of the appropriate Authority. Restrictions may be posed to any method of irrigation by the appropriate authority in order to protect public health and the environment.

C. Tertiary treatment

1. **The following tertiary treatment methods are acceptable:**

- Coagulation plus flocculation followed by Rapid Sand Filtration.
- Slow Sand Filters.
- Any other method which may secure the total removal of helminthes ova and reduce faecal coliforms to acceptable level. The appropriate Authority must approve this.

2. **Appropriate disinfection methods** should be applied when sewage wastewater is to be used for irrigation. In the case of chlorination the total level of free chlorine in the effluent at the outlet of the chlorination tank, after an hour of contact time should be at least 0.5 mg/l and not greater than 2 mg/l.

3. **Suitable facility for monitoring** of the essential quality parameters should be kept on site of treatment.

APPENDIX IV: Nutrient requirements of selected crops

Tomato

Yield (tons/ha)	Irrigation method	Kg/ha				
		N	P	K	P_2O_5	K_2O
50	Drip	227	67	184	153	380
	Furrow	333	133	208	306	435
75	Drip	283	80	275	185	490
	Furrow	415	161	312	370	560
100	Drip	340	94	367	216	600
	Furrow	497	189	416	433	685
125	Drip	396	108	459	248	710
	Furrow	579	216	520	496	810
Each additional 10 tons	Drip	23	5.5	37	13	45
	Furrow	33	11	42	25	50

Potato

Yield (tons/ha)	Irrigation method	kg/ha				
		N	P	K	P_2O_5	K_2O
40	Sprinkler	251	95	353	218	423
	Furrow	256	143	400	327	480
50	Sprinkler	289	113	406	260	487
	Furrow	409	170	460	390	552
60	Sprinkler	327	131	459	301	550
	Furrow	463	197	520	452	624
70	Sprinkler	364	149	512	342	614
	Furrow	516	224	580	513	696
Each additional 10 tons	Sprinkler	38	18	53	41	64
	Furrow	53	29	60	62	72

Eggplant

Yield (tons/ha)	Irrigation method	Kg/ha				
		N	P	K	P_2O_5	K_2O
50	Drip	255	105	326	241	392
	Furrow	367	210	370	482	445
75	Drip	313	136	419	312	503
	Furrow	456	272	476	625	572
100	Drip	349	167	512	383	615
	Furrow	545	334	582	766	699
125	Drip	410	198	605	454	726
	furrow	633	396	688	908	825
Each additional 10 tons	Drip	24	12	38	28	45
	Furrow	35	24	43	56	51

Citrus

Yield (tons/ha)	Irrigation method	kg/ha				
		N	P	K	P_2O_5	K_2O
30	Microirrigation	183	39	160	89	192
	Surface	256	68	194	156	233
40	Microirrigation	203	44	178	101	214
	Surface	285	78	215	178	259
50	Microirrigation	223	50	196	114	235
	Surface	314	87	238	200	286
60	Microirrigation	243	55	214	127	257
	Surface	342	97	260	222	312
70	Microirrigation	263	61	233	139	279
	Surface	372	107	282	244	338
80	Microirrigation	283	66	250	152	300
	Surface	400	116	303	266	364
90	Microirrigation	303	72	268	165	322
	Surface	429	126	326	288	391
Each additional 10 tons	Microirrigation	20	6	18	13	22
	Surface	29	10	22	22	26

Mango

Yield (tons/ha)	Irrigation method	N	P	K	P_2O_5	K_2O
		kg/ha				
20	Microirrigation	139	30	177	68	212
	Surface	194	52	202	119	242
25	Microirrigation	148	32	187	74	224
	Surface	208	57	213	130	256
30	Microirrigation	158	35	197	80	236
	Surface	221	62	225	141	270
35	Microirrigation	168	38	207	86	248
	Surface	235	66	237	152	284
40	Microirrigation	177	40	217	92	260
	Surface	248	71	249	163	298
45	Microirrigation	187	43	227	98	272
	Surface	262	76	260	174	312
50	Microirrigation	197	45	237	104	284
	Surface	275	81	272	185	326
Each additional ton	Microirrigation	2.0	0.5	2.0	1.2	2.4
	Surface	2.5	0.96	2.3	2.2	2.8

Banana

Yield (tons/ha)	Irrigation method	N	P	K	P_2O_5	K_2O
		kg/ha				
40	Microirrigation	388	117	1176	268	1411
	Sprinkler	440	175	1333	401	1600
50	Microirrigation	412	123	1235	282	1482
	Sprinkler	467	185	1400	424	1680
60	Microirrigation	435	130	1294	298	1553
	Sprinkler	493	195	1467	446	1760
70	Microirrigation	459	137	1353	314	1624
	Sprinkler	520	205	1533	469	1840
80	Microirrigation	482	147	1412	337	1694
	Sprinkler	547	220	1600	504	1920
90	Microirrigation	506	157	1470	359	1764
	Sprinkler	573	235	1667	538	2000
100	Microirrigation	529	167	1529	382	1835
	Sprinkler	600	250	1733	572	2080
Each additional 10 tons	Microirrigation	23	7	59	16	71
	Sprinkler	27	11	67	25	80

TC/D/Y5009F/1/10.03/100