CHAPTER 7: Water quality for irrigation

INTRODUCTION

Irrigation waters whether derived from springs, diverted from streams, or pumped from wells, contain appreciable quantities of chemical substances in solution that may reduce crop yield and deteriorate soil fertility. In addition to the dissolve salts, which has been the major problem for centuries, irrigation water always carry substances derived from its natural environment or from the waste products of man's activities (domestic and industrial effluents). These substances may vary in a wide range, but mainly consist of dirt and suspended solids (SS) resulting into the emitters' blockages in micro-irrigation systems and bacteria populations and coliforms harmful to the humans and the animals.

CLASSIFICATION OF WATER QUALITY FOR IRRIGATION

In several studies carried out in the eighties on the various causes for the clogging of the emitters, the engineers, based on the three major interrelated factors contributing to that specific problem, classified the water according to the chemical quality, the physical and the biological. This classification although primary and simple seemed convenient for a more or less broad evaluation to cover the whole spectrum of irrigation waters quality for crop production. With the inclusion of reuse of treated municipal wastewater in agriculture during that period, the water quality considerations were broadened in order to cover all the physicochemical, biological and microbiological properties of water that may cause any impact on soil, plants, environment and the consumers, human or livestock. The water quality evaluation method in this chapter, although in brief, draws on the important parameters and criteria for a more or less practical evaluation of the chemical, the physical and the biological quality of the water for irrigation with pressurized techniques as follows:

a) Chemical, (salinity/toxicity hazards for the soil, the plants and the irrigation system such as it is pipe corrosion and emitter chemical clogging),
b) Physical (emitters blockages problems from suspended solid particles and other impurities content),
c) Biological (problems from bacteria and other contents harmful for human and animal health as well as for the soil the plants and the irrigation systems).

The information on the physical and biological evaluation is given in brief as compared to the chemical evaluation. Yet an in-depth and complete examination should include the soil physical properties and the climatic conditions as well as many other factors with direct or indirect influence on water use in agriculture and landscape.

THE CHEMICAL QUALITY OF IRRIGATION WATER

Composition and concentration of soluble salts

Salinity is a common problem facing farmers who irrigate in arid climates. This is because all irrigation waters contain soluble salts. Whether derived from springs, diverted from streams, or pumped from wells, the waters contain appreciable quantities of chemical substances in solution, dissolved from the geological strata through and over which the waters have flowed. Waters with a high salt content may have moved from a saline water table. In areas with intensive agriculture, fertilization is a major cause of aquifer salinization.

The composition of salts in water varies according to the source and properties of the constituent chemical compounds. These salts include substances such as gypsum (calcium sulphate, $CaSO_4.2H_2O$), table salt (sodium chloride NaCl) and baking soda (sodium bicarbonate $NaHCO_3$). When dissolved in water, salts separate into ions; e.g. sodium chloride breaks down into sodium and chloride ions. Thus, it is customary to refer to ions rather than salts. The principle ions in irrigation water and their characteristics are listed in Table 7.1.

TABLE 7.1 - Principle ions present in irrigation water

Ions	Chemical symbol	Equivalent weight
Anions (acidic ions)		
Chloride	Cl^-	35.5
Sulphate	SO_4^{--}	48
Carbonate	CO_3^{--}	30
Bicarbonate	HCO_3^-	61
Nitrate	NO_3^-	62
Cations (basic ions)		
Sodium	Na+	23
Potassium	K+	39.1
Calcium	Ca++	20
Magnesium	Mg++	12.2

All ions are expressed in the form of milligrams per litre (mg/litre or ppm) and milliequivalents per litre (meq/litre). The latter unit is preferable because water quality criteria involve milliequivalents per litre calculations.

The conversion formula is:

$$meq/litre = \frac{mg/litre}{equivalentweight}$$

Boron is also present in irrigation waters as un-ionized boric acid expressed as boron element (B) in milligrams per litre. The salt concentration in most irrigation waters ranges from 200 to 4 000 mg/litre total dissolved solids (TDS). The pH of the water is also an indicator of its quality and it normally ranges from 6.5 to 8.4.

The common method for evaluating the total salts content in water is by measuring the electrical conductivity of water (ECw) at 25°C. Electrical conductivity is expressed in deciSiemens per metre. There is a relation between the electrical conductivity and the concentration of salts in milliequivalents per litre and in milligrams per litre when the ECw is in the range of 1–5 dS/m. Thus, every 10 meq/litre of salts (cation concentration) create 1 dS/m ECw. The relationship between electrical conductivity and total dissolved salts (TDS) is:

$$ECw\ (dS/m) \times 640 = TDS\ (mg/litre)$$

The sum of cations should equal the sum of anions. The accuracy of the chemical water analyses should be checked on the basis of the above relationships.

Effect of soluble salts on plants

The application of irrigation water to the soil introduces salts into the root zone. Plant roots take in water but absorb very little salt from the soil solution. Similarly, water evaporates from the soil surface but salts remain behind. Both processes result in the gradual accumulation of salts in the root zone, even with low salinity water. This situation may affect the plants in two ways: a) by creating salinity hazards and water deficiency; and b) by causing toxicity and other problems.

Salinity hazards and water deficiency

The build-up of salinity in the root zone increases the osmotic pressure of the soil solution and causes a reduction in both the rate of water absorption by the plants and the soil water availability. Thus, a continuous water deficiency may exist even though the field is heavily irrigated. Plant wilting symptoms may not become apparent, but growth and yield are depressed. Under such circumstances it is not possible to maintain good crop development conditions and obtain high yields. Instead, plant growth is delayed and there is a considerable reduction in yield. Seed germination is also affected by the presence of salts. It is usually delayed and in some cases does not occur.

The level of salinity build-up depends on both the concentration and the composition of salts in the water. Chloride is highly soluble and remains in the soil solution, while sulphate and bicarbonate combine with calcium and magnesium, where present, to form calcium sulphate and calcium carbonate, which are sparingly soluble compounds.

Toxicity hazards

Many fruit trees and other cultivations are susceptible to injury from salt toxicity. Chloride, sodium and boron are absorbed by the roots and transported to the leaves where they accumulate. In harmful amounts, they result in leaf burn and leaf necrosis. Moreover, direct contact during sprinkling of water drops with a high chloride content may cause leaf burn in high evaporation conditions. To some extent, bicarbonate is also toxic. Other symptoms of toxicity include premature leaf drop, reduced growth and reduced yield. In most cases, plants do not show clear toxicity problems until it is too late to remedy the situation.

Chloride and sodium ions are both present in the solution. Thus, it is difficult to determine whether the damage caused is due to the one or to the other. Chloride ions in high concentrations are known to be harmful to citrus and many woody and leafy field crops. A chloride content exceeding 10 meq/litre may cause severe problems to crops. The effect of sodium toxicity is not very clear. However, it has been found that it may cause some direct or indirect damage to many plants.

Boron is an essential element to the plants. However, where present in excessive amounts, it is extremely toxic, even at relatively very low concentrations of 0.6 mg/litre. Toxicity occurs with the uptake of boron from the soil solution. The boron tends to accumulate in the leaves until it becomes toxic to the leaf tissue and results in the death of the plant. In arid regions, boron is considered the most harmful element in irrigation water.

Other problems

In addition to the moisture availability effect and the toxicity problems to which the soluble salts contribute, certain salt constituents may interfere with the normal nutrition of various crops. Bicarbonate ions in high concentrations may affect the uptake of mineral nutrients and their metabolism in the plant. Chlorotic symptoms in sensitive plants may be due to the direct or indirect effects of bicarbonate, e.g. an increase in soil pH.

Excessive nitrate contents, higher than 100 mg/litre, may affect transplants and sensitive crops at the initial growth stage. However, no negative effects have been reported in the last three decades from fertigation with pure nitrogen concentrations in irrigation water of about 200 ppm. Although there is no doubt about the problem's existence, it seems that the main concern should be the nitrate content in the irrigation water, when calculating the total nitrogen application, NO_3 equals 0.226 N (pure nitrogen).

Effects of soluble salts on soil

Sodium hazard

A soil permeability problem occurs with a high sodium content in the irrigation water. Sodium has a larger concentration than any other cation in saline water, its salts being very soluble. Positively charged, it is attracted by negatively charged soil particles, replacing the dominant calcium and magnesium cations. The replacement of the calcium ions with sodium ions causes the dispersion of the soil aggregates and the deterioration of its structure, thus rendering the soil impermeable to water and air. The increase in the concentration of exchangeable sodium may cause an increase in the soil pH to above 8.5 and reduce the availability of some micronutrients, e.g. iron and phosphorus.

The degree of absorption to the clay particles of the sodium depends on its concentration in the water and the concentration of the calcium and magnesium ions. This reaction is called cation exchange and it is a reversible process. The capacity of soil to adsorb and exchange cations is limited. The percentage of the capacity that sodium takes up is known as the exchangeable sodium percentage (ESP). Soils with ESP > 15 are seriously affected by adsorbed sodium.

The sodium problem is reduced if the amount of calcium plus magnesium is high compared with the amount of sodium. This relation is called the sodium adsorption ratio (SAR) and it is a calculated value from the formula:

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$$

(ions units meq/litre)

The use of water with a high SAR value and low to moderate salinity may be hazardous and reduce the soil infiltration rate. The SAR of irrigation water indicates the approximate ESP of a soil with water.

Residual sodium carbonate (RSC)

This is defined as the difference in milliequivalents per litre between the bicarbonate ions and those of calcium and magnesium. Calcium and magnesium may react with bicarbonate and precipitate as carbonates. The relative sodium concentration in the exchangeable complex increases resulting in the dispersion of soil. When the RSC value is lower than 1.25 meq/litre, the water is considered good quality, while if the RSC value exceeds 2.5 meq/litre, the water is considered harmful.

Crop tolerance to salinity

Crop tolerance is the degree to which a crop can grow and yield satisfactorily in saline soil. Different crops vary widely in their response to salinity. Some can tolerate less than 2 dS/m and others up to and above 8 dS/m. Salt tolerance also depends considerably upon cultural conditions and irrigation management practices. Many other factors such as plant, soil, water and climate interact to influence the salt tolerance of a crop.

Relative salt tolerance data have been developed for many crops and are used as general guidelines. The following data are related to the expected decline in yield. The ECe is the soil salinity in terms of electrical conductivity (EC) measured from the soil saturation extract, with a value of 1.5 EC for irrigation water (ECiw). Tables 13–18 (taken from Maas, 1990) give two important parameters for expressing a plant's salt tolerance:

- Threshold - the maximum allowable salinity of soil saturation extract (ECe).
- Slope - the percent yield decrease per unit increase in salinity.

The rating of plants according to their sensitivity/tolerance to salts (Tables 7.2, 7.3, 7.4, 7.5, 7.6 and 7.7) is even more important as it provides vital information at first sight for the evaluation of and diagnosis for potential salinity problems.

TABLE 7.2 - Relative salt tolerance of herbaceous crops - vegetables and fruit crops (Maas, 1990)

Common name	Botanical name	Threshold dS/m	Slope % per dS/m	Rating
Artichoke	*cynara scolymus*	--	--	MT*
Asparagus	*asparagus officinalis*	4.1	2.0	T
Bean	*phaseolus vulgaris*	1.0	19.0	S
Bean, mung	*vigna radiata*	1.8	20.7	S
Beet, red	*beta vulgaris*	4.0	9.0	MT
Broccoli	*brassica oleracea botrytis*	2.8	9.2	MS
Brussels sprouts	*b. oleracea gemmifera*	--	--	MS*
Cabbage	*b. oleracea capitata*	1.8	9.7	MS
Carrot	*daucus carota*	1.0	14.0	S
Cauliflower	*brassica oleraca botrytis*	--	--	MS*
Celery	*apium graveolens*	1.8	6.2	MS
Corn, sweet	*zea mays*	1.7	12.0	MS
Cucumber	*cucumis sativa*	2.5	13.0	MS
Eggplant	*solanum melongena esculentum*	1.1	6.9	MS
Kale	*brassica oleracea acephala*	--	--	MS*
Kohlrabi	*b. oleracea gongylode*	--	--	MS*
Lettuce	*lactuca sativa*	1.3	13.0	MS
Muskmelon	*cucumis melo*	--	--	MS
Okra	*abelmoschus esculentus*	--	--	S
Onion	*akkium cepa*	1.2	16.0	S
Parsnip	*pastinaca sativa*	--	--	S*
Pea	*pisum sativa*	--	--	S*
Pepper	*capsicum annuum*	1.5	14.0	MS
Potato	*solanum tuberosum*	1.7	12.0	MS
Pumpkin	*cucurbita pepo pepo*	--	--	MS*
Radish	*raphanus sativus*	1.2	13.0	MS
Spinach	*spinacia oleracea*	2.0	7.6	MS
Squash scallop	*curcubita melo melopepo*	3.2	16.0	MS
Squash zucchini	*curcubita melo melopepo*	4.7	9.4	MT
Strawberry	*fragaria sp.*	1.0	33.0	S
Sweet potato	*ipomoea batatas*	1.5	11.0	MS
Tomato	*lycopersicon lycopersicum*	2.5	9.9	MS
Tomato cherry	*l.esculentum var cerasiforme*	1.7	9.1	MS
Turnip	*brassica rapa*	0.9	9.0	MS
Watermelon	*citrullus lanatus*	-	--	MS*

Note:

S sensitive, MS moderately sensitive, MT moderately tolerant,
T tolerant. The above data serve only as a guideline to relative tolerance among crops. Absolute tolerance varies, depending upon climate, soil conditions, and cultural practices.

In gypsipherus soils, plants will tolerate an ECe about 2 dS/m higher than indicated.

***:** *Ratings are estimates.*

TABLE 7.3 - Relative salt tolerance of herbaceous crops - woody crops (Maas, 1990)

Common name	Botanical name	Threshold dS/m	Slope % per dS/m	Rating
Almond**	*prunus duclis*	1.5	19.0	S
Apple	*malus sylvestris*	--	--	S
Apricot**	*prunus americana*	1.6	24.0	S
Avocado**	*persea americana*	--	--	S
Blackberry	*rubus sp*	1.5	22.0	S
Boysenberry	*rubus ursinus*	1.2	22.0	S
Castor seed	*ricinus communus*	--	--	MS*
Cherimoya	*annona cherimola*	--	--	S*
Cherry, sweet	*prunus avium*	--	--	S*
Cherry, sand	*prunus besseyi*	--	--	S*
Currant	*ribes sp.*	--	--	S*
Date palm	*phoenix dactylifera*	4.0	3.6	T
Fig	*ficus carica*	--	--	MT*
Gooseberry	*ribes sp.*	--	--	S*
Grape**	*vitis sp.*	1.5	9.6	MS
Grapefruit**	*citrus paradisi*	1.8	16.0	S
Guayule	*parthenium argentantum*	15.0	13.0	T
Jojoba**	*simmondsia chinensis*	--	--	T
Jujube	*ziziphus jujuba*	--	--	MT*
Lemon**	*citrus limon*	--	--	S
Lime	*citrus aurantiifolia*	--	--	S*
Loquat	*eriobotrya japonica*	--	--	S*
Mango	*mangifera indica*	--	--	S*
Olive	*olea europea*	--	--	MT
Orange	*citrus sinensis*	1.7	16.0	S
Papaya**	*carica papaya*	--	--	MT
Passion fruit	*passiflora edulis*	--	--	S*
Peach	*prunus persica*	1.7	21.0	S
Pear	*pyrus communis*	--	--	S*
Persimmon	*diospyros virginiana*	--	--	S*
Pineapple	*ananas comosus*	--	--	MT*
Plum, prune**	*prunus domestica*	1.5	18.0	S
Pomegranate	*punica granatum*	--	--	MT*
Pummelo	*citrus maxima*	--	--	S*
Raspberry	*rubus idaeus*	--	--	S
Rose apple	*syzygium jambos*	--	--	S*
Sapote, white	*casimiroa edulis*	--	--	S*
Tangerine	*citrus reticulata*	--	--	S*

Note:

Data applicable when rootstocks are used that do not accumulate Na or Cl rapidly, or when these ions do not predominate in the soil.

In gypsipherus soils, plants will tolerate an ECe about 2 dS/m higher than indicated.

***:** *Ratings are estimates.*
****:** *Tolerance is based on growth rather than yield*

TABLE 7.4 - Relative salt tolerance of herbaceous crops - grasses and forage crops (Maas, 1990)

Common name	Botanical name	Threshold dS/m	Slope % per dS/m	Rating
Alfalfa	*medicago sativa*	2.0	7.3	MS
Alkali sacaton	*sporobolus airoides*	--	--	T*
Alkaligrass, Nuttal	*puccinellia airoides*	--	--	T*
Barley (forage)	*hordeum vulgare*	6.0	7.1	MT
Barnet	*poterium sanguisorba*	--	--	MS*
Bentgrass	*agrostis stolonifera palustris*	--	--	MS
Bermudagrass	*cynodon dactylon*	6.9	6.4	T
Bluestem, Angleton	*dichanthium aristatum*	--	--	MS*
Brome, mountain	*bromus marginatus*	--	--	MT*
Brome, smooth	*b. inermis*	--	--	MS
Buffelgrass	*cenchrus ciliaris*	--	--	MS*
Canarygrass, reed	*phalaris arundinacea*	--	--	MT
Clover, alsike	*trifolium hybridum*	1.5	12.0	MS
Clover, Berseem	*trifolium alexandrinum*	1.5	5.7	MS
Clover, Hubam	*melitotus alba*	--	--	MT*
Clover, ladino	*trifolium repens*	1.5	12.0	MS
Clover, red	*trifolium pratense*	1.5	12.0	MS
Clover, strawberry	*melitotus*	--	--	MT*
Clover, white Dutch	*trifolium repens*	--	--	MS*
Corn (forage)	*zea mays*	1.8	7.4	MS
Cowpea (forage)	*vigna unguiculata*	2.5	11.0	MS
Dallisgrass	*paspalum dilatatum*	--	--	MS*
Fescue, meadow	*f. pratensis*	--	--	MT*
Fescue, tall	*festuca elatior*	3.9	5.3	MT
Foxtail, meadow	*alopecurus pratensis*	1.5	9.6	MS
Grama, blue	*bouteloua gracilis*	--	--	MS*
Hardinggrass	*phalaris tuberosa*	4.6	7.6	MT
Kallargrass	*diplachne fusca*	--	--	T*
Lovergrass	*eragrostis sp.*	2.0	8.4	MS
Milkvetch, Cicer	*astragalus cicer*	--	--	MS*
Oatgrass, tall	*arrhenatherum danthonia*	--	--	MS*
Oats (forage)	*avena sativa*	--	--	MS*
Orchardgrass	*dactylis glomerata*	1.5	6.2	MS
Panicgrass, blue	*panicum antidotale*	--	--	MT*
Rape	*brassica napus*	--	--	MT*
Rescuegrass	*bromus unioloides*	--	--	MT*
Rhodesgrass	*chloris gayana*	--	--	MT
Rye (forage)	*secale sereale*	--	--	MS*
Ryegrass, Italian	*lolium italicum multiflorum*	--	--	MT*
Ryegrass, perennial	*l. perenne*	5.6	7.6	MT
Saltgrass, desert	*distichlis stricta*	--	--	T*
Sesbania	*sesbania exaltata*	2.3	7.0	MS
Sirato	*macroptilium atropurpureum*	--	--	MS
Sphaerophysa	*sphaerophysa salsula*	2.2	7.0	MS
Sudangrass	*sorghum sudanense*	2.8	4.3	MT
Timothy	*phleum pratense*	--	--	MS*
Trefoil, big	*lotus uliginosus*	2.3	19.0	MS
Trefoil, broadleaf	*l. corniculatus arvenis*	--	--	MT
Trefoil, narrowleaf	*l. corniculatus tenuifolium*	5.0	10.0	MT
Vetch, common	*vicia angustifolia*	3.0	11.0	MS
Wheat (forage)	*triticum aestivum*	4.5	2.6	MT
Wheat, durum (forage)	*t. turgidum*	2.1	2.5	MT

TABLE 7.4 - Relative salt tolerance of herbaceous crops - grasses and forage crops (cont'd)

Common name	Botanical name	Threshold dS/m	Slope % per dS/m	Rating
Wheatgrass, fairway	*a. cristatum*	7.5	6.9	T
Wheatgrass, intermediate	*a. intermedium*	--	--	MT*
Wheatgrass, slender	*a. trachycaulum*	--	--	MT
Wheatgrass, standard	*agropyron sibiricum*	3.5	4.0	MT
Wheatgrass, tall	*a. elongatum*	7.5	4.2	T
Wheatgrass, western	*a.smithii*	--	--	MT*
Wildrye, Altai	*elymus angustus*	--	--	T
Wildrye, beardless	*e. triticoides*	2.7	6.0	MT
Wildrye, Canadian	*e. canadensis*	--	--	MT*
Wildrye, Russian	*e. junceus*	--	--	T

Note:

The above data serve only as a guideline to relative tolerance among crops. Absolute tolerance varies, depending upon climate, soil conditions, and cultural practices.

In gypsipherus soils, plants will tolerate an ECe about 2 dS/m higher than indicated.

TABLE 7.5 - Boron tolerance limits for agricultural crops (Maas, 1990)

Common name	Botanical name	Threshold ** mg/litre	Slope % per mg/litre
Very sensitive			
Lemon*	*Citrus limon*	--	--
Blackberry	*Rubus sp.*	--	--
Sensitive			
Avocado	*persea american*	0.5–0.75	--
Grapefruit*	*citrus paradisi*	0.5–0.75	--
Orange*	*c. sinensis*	0.5–0.75	--
Apricot*	*prunus americana*	0.5–0.75	--
Peach*	*p. persica*	0.5–0.75	--
Cherry*	*p. avium*	0.5–0.75	--
Plum*	*p. domestica*	0.5–0.75	--
Persimmon*	*diospyros kaki*	0.5–0.75	--
Fig, kadota*	*ficus carica*	0.5–0.75	--
Grape*	*vitis vinifera*	0.5–0.75	--
Walnut*	*juglans regia*	0.5–0.75	--
Pecan*	*carya illinoienis*	0.5–0.75	--
Onion	*allium cepa*	0.5–0.75	--
Garlic	*allium sativum*	0.75–1.0	--
Sweet potato	*ipomea batatas*	0.75–1.0	--
Wheat	*triticum aestivum*	0.75–1.0	0.33
Sunflower	*helianthus annuus*	0.75–1.0	--
Bean, mung*	*vigna radiata*	0.75–1.0	--
Sesame*	*sesamum indicum*	0.75–1.0	--
Lupine*	*lipinus hartwegii*	0.75–1.0	--
Strawberry*	*fragaria ap.*	0.75–1.0	--
Artichoke, Jerusalem*	*helianthus tuberosus*	0.75–1.0	--
Bean, kidney*	*phaseolus vulgaris*	0.75–1.0	--
Bean, limab	*p. lunatus*	0.75–1.0	--
Peanut	*arachis hypogaea*	0.75–1.0	--

***:** *Ratings are estimates.*

TABLE 7.5 - Boron tolerance limits for agricultural crops (cont'd)

Common name	Botanical name	Threshold ** mg/litre	Slope % per mg/litre
Moderately sensitive			
Broccoli	*brassica oleracea botrytis*	1.0	1.8
Pepper, red	*capsicum annuum*	1.0–2.0	--
Pea*	*pisum sativa*	1.0–2.0	--
Carrot	*daucus carota*	1.0–2.0	--
Radish	*raphsnus sativus*	1.0–2.0	1.4
Potato	*solanum tuberosum*	1.0–2.0	--
Cucumber	*cucumis sativus*	1.0–2.0	--
Moderately tolerant			
Cabbage*	*brassica oleracea capitata*	2.0–4.0	--
Turnip	*b. rapa*	2.0–4.0	--
Bluegrass, Kentucky*	*poa pratensis*	2.0–4.0	--
Barley	*hordeum vulgare*	3.4	4.4
Cowpea	*vigna unguigulata*	2.5	12
Oats	*avena sativa*	2.0–4.0	--
Corn	*zea mays*	2.0–4.0	--
Artichoke*	*cynara scolymus*	2.0–4.0	--
Tobacco*	*nicotiana tabacum*	2.0–4.0	--
Mustard*	*brassica juncea*	2.0–4.0	--
Clover, sweet*	*melitotus indica*	2.0–4.0	--
Squash	*cucurbita pepo*	2.0–4.0	--
Muskmelon*	*cucmis melo*	2.0–4.0	--
Cauliflower	*b. oleracea botrytis*	2.0–4.0	1.9
Tolerant			
Alfalfa*	*medicago sativa*	4.6–6.0	--
Vetch, purple*	*vicia bengalensis*	4.6–6.0	--
Parsley*	*petroselinum crispum*	4.6–6.0	--
Beet, red	*beta vulgaris*	4.6–6.0	--
Sugar beet	*b. vulgaris*	4.9	4.1
Tomato	*lycopersicum*	5.7	3.4
Very tolerant			
Sorghum	*sorhgum bicolor*	7.4	4.7
Cotton	*gossypium hirsutum*	6.0–10.0	--
Celery*	*apium graveolens*	9.8	3.2
Asparagus*	*asparagus officinalis*	10.0–15.0	--

***:** *Tolerance based on reduction in vegetative growth*
****:** *Maximum permissible concentration in soil water without reduction in yield. Boron tolerances may vary, depending upon climate, soil conditions, and crop varieties.*

TABLE 7.6 - Salt tolerance of ornamental shrubs, trees and ground cover (Maas, 1990)

Common name	Botanical name	Max. permissible ECe dS/m
Very sensitive		
Star jasmine	*Trachelospermum jasminoides*	1–2
Pyrenees cotoneaster	*Cotoneaster congestus*	1–2
Oregon grape	*Mahonia aquifolium*	1–2
Photinia	*Photinia fraseri*	1–2
Sensitive		
Pineapple guava	*feijoa sellowiana*	2–3
Chinese holly, cv. Burford	*Ilex cornuta*	2–3
Rose cv. Grenoble	*Rosa sp.*	2–3
Glossy abelia	*Abelia grandiflora*	2–3
Southern yew	*Podocarpus macrophyllus*	2–3
Tulip tree	*Liriodendron tulipifera*	2–3
Algerian ivy	*Hedera canariensis*	3–4
Japanese pittosporum	*Pittosporum tobira*	3–4
Heavenly bamboo	*Nandina domestica*	3–4
Chinese hibiscus	*Hibiscus rosa sinensis*	3–4
Laurustinus cv. Robustum	*Viburnum tinusm*	3–4
Strawberry tree, cv compact	*Arbutus unedo*	3–4
Grape myrtle	*Lagerstroemia indica*	3–4
Moderately sensitive		
Glossy privet	*Ligustrum lugidum*	4–6
Yellow sage	*Lantana camara*	4–6
Orchid tree	*Bauhinia purpurea*	4–6
Southern magnolia	*Magnolia grandiflora*	4–6
Japanese boxwood	*Buxus microphylla var. japonica*	4–6
Xylosma	*Xylosma congestum*	4–6
Japanese black pine	*Pinus thunbergiana*	4–6
Indian hawthorn	*Raphiolepis indica*	4–6
Dodonaea, cv. atropurpurea	*Dodonaea viscosa*	4–6
Oriental arborvitae	*Platycladus orientalis*	4–6
Thorny elaeagnus	*Elaeagnus pungens*	4–6
Spreading juniper	*Uniperus chinensis*	4–6
Pyracantha, cv. Graberi	*Pyracantha fortuneana*	4–6
Cherry plum	*Prunus cerasifera*	4–6
Moderately tolerant		
Weeping bottlebrush	*Callistemon viminalis*	6–8
Oleander	*Nerium oleander*	6–8
European fan palm	*Chamerops humilis*	6–8
Blue dracaena	*Cordiline indivisa*	6–8
Rosemary	*Rosmarinus officinalis*	6–8
Aleppo pine	*Pinus halepensis*	6–8
Sweet gum	*Liquidamabar styraciflua*	6–8
Tolerant		
Brush cherry	*Syzygium paniculatum*	> 8
Ceniza	*Leucophyllum frutescens*	> 8
Natal plum	*Carssa grandiflora*	> 8
Evergreen pear	*Pyrus Kawakamii*	> 8
Bougainvillaea	*Bougainvillaea spectabilis*	> 8
Italian stone pine	*Pinus pinea*	> 8
Very tolerant		> 10
White iceplant	*Delosperma alba*	> 10
Rosea iceplant	*Drosanthemum hispidum*	> 10
Purple iceplant	*Labranthus productus*	> 10
Croceum iceplant	*Hymenocyclus croceus*	> 10

Note:
Salinities exceeding the maximum permissible ECe may cause leaf burn, loss of leaves and/or excessive stunting.

TABLE 7.7 - Boron tolerance limits for ornamentals (Maas, 1990)

Common name	Botanical name	Threshold mg/litre
Very sensitive		
Oregon grape	*Mahonia aquifolium*	
Photinia	*Photinia x fraseri*	
Xylosma	*Xylosma congestum*	
Thorny elaeagnus	*Elaeagnus pungens*	
Laurustinus	*Viburnum tinus*	
Wax-leaf privet	*Ligustrum japonicum*	
Pineapple guava	*Feijoa sellowiana*	
Spindle tree	*Euonymu japonica*	
Japanese pittosporum	*Pittosporum tobira*	
Chinese holly	*Ilex cornuta*	
Juniper	*Juniperus chinensis*	
Yellow sage	*Lantana camara*	
American elm	*Ulmus americana*	
Sensitive		
Zinnia	*Zinnia elaeagnus*	0.5–1.0
Pansy	*Viola tricolor*	0.5–1.0
Violet	*Viola odorata*	0.5–1.0
Larkspur	*Delphinum sp.*	0.5–1.0
Glossy abelia	*Abelia x grandiflora*	0.5–1.0
Rosemary	*Rosmarinus officinalis*	0.5–1.0
Oriental arborvitae	*Platycladus orientalis*	0.5–1.0
Geranium	*Pelargoium x hortorum*	0.5–1.0
Moderately sensitive		
Gladiolus	*Gladiolus sp.*	1.0–2.0
Marigold	*Calendula officinalis*	1.0–2.0
Poinsettia	*Euphorbia pulcherrima*	1.0–2.0
China aster	*Callistephus chinensis*	1.0–2.0
Gardenia	*Gardenia sp.*	1.0–2.0
Southern yew	*Podocarpus macrophyllus*	1.0–2.0
Brush cherry	*Syzygium paniculatum*	1.0–2.0
Blue dracaena	*Cordyline indivisa*	1.0–2.0
Ceniza	*Leucophyllus frutenscens*	1.0–2.0
Moderately tolerant		
Bottlebrush	*Callistemon citrinus*	2.0–4.0
California poppy	*Eschscholzia californica*	2.0–4.0
Japanese boxwood	*Buxus microphylla*	2.0–4.0
Oleander	*Nerium oleander*	2.0–4.0
Chinese hibiscus	*Hibiscus rosa-senensis*	2.0–4.0
Sweet pea	*Lathyrus odoratus*	2.0–4.0
Carnation	*Dianthus caryophyllus*	2.0–4.0
Tolerant		
Indian hawthorn	*Raphiolepis indica*	6.0–8.0
Natal plum	*Carissa grandiflora*	6.0–8.0
Oxalis	*Oxalis bowiei*	6.0–8.0

Note:

Species listed in order of increasing tolerance based on appearance as well as growth reductions. Boron concentration exceeding threshold may cause leaf burn and leaf loss.

Water quality criteria

There have been calls to establish standards as a guide for judging the suitability of water for irrigation. Any classification should be based on the total concentration and the composition of salts. However, the suitability of water for irrigation also depends on other associated factors, such as the crop, soil, climate and management practices. The classification adopted by FAO in 1985 (after Maas), and proposed as an initial guide (Table 7.8), has proved most practical and useful in assessing water quality for on-farm water use. The principal parameters for water classification (crop response to salinity, sodium hazard and toxicity) are quite clear and understood by both the extension engineers and the farmers themselves for proper irrigation management and follow-up purposes.

With the FAO assessment method, the parameters taken into consideration are the four presented below.

Total salinity

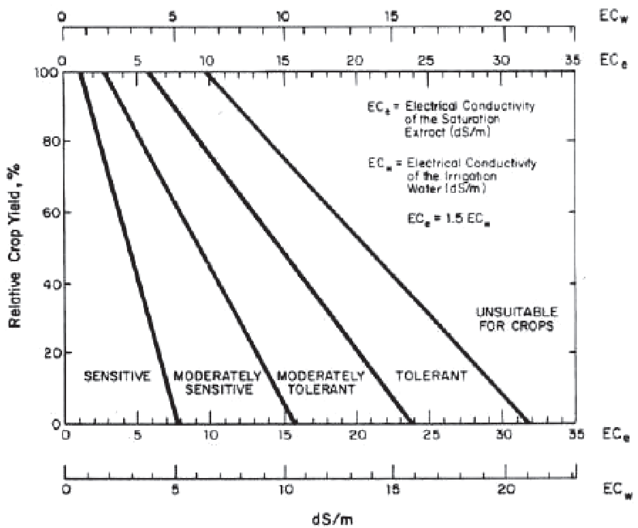
TABLE 7.8 - Water classification by salinity

	EC dS/m	TDS mg/litre
Non-saline water	< 0.7	< 500
Saline water	0.7–42	500–30 000
Slightly saline	0.7–3.0	500–2 000
Medium saline	3.0–6.0	2 000–4 000
Highly saline	> 6.0	> 4 000
Very saline	> 14.0	> 9 000
Brine	> 42	> 30 000

Crop response to salinity

The Figure 7.1 below shows the expected yield reduction for each crop in accordance with its sensibility/tolerance to salt. This graph enables a quick assessment of the two main parameters for the water suitability.

FIGURE 7.1 - Divisions for relative salt tolerance ratings of agricultural crops (Maas, 1984)



Sodium hazard

The sodium adsorption ratio is commonly used as an index of the sodium hazard of soils and waters, and as a substitute soil ESP. The SAR (Sodium Absorption Ratio) of a given water determines, to a certain extent, the relative amount of sodium that may be adsorbed by the soil. The effect of sodium ions in the irrigation water in reducing the infiltration rate and soil permeability is dependent on the total salt concentration, as shown in Table 7.9.

TABLE 7.9 - Potential infiltration problem due to sodium in irrigation water

Salinity levels of irrigation water dS/m	No reduction	Slight reduction	Medium reduction	Severe reduction
	SAR	SAR	SAR	SAR
ECw = 0.7	< 1	1–5	5–11	> 11
ECw = 0.7–3.0	< 10	10–15	15–23	> 23
ECw = 3.0–6.0	< 25	> 25	No effect	No effect
ECw = 6.0–14.0	< 35	> 35	No effect	No effect
ECw = >14.0	No effect	No effect	No effect	No effect

Source: Based on Rhoades, Oster and Schroer.

Toxicity problems

Toxicity problems may be created by excess chloride, sodium, boron, bicarbonate, nitrates and an abnormal pH. The evaluation of the water quality for irrigation should include these and a few other parameters in association with all the other factors involved.

Salinity control

The salts that accumulate in the soil can be effectively removed only by leaching. For this to occur, enough water must enter the surface to produce downward percolation and outflow of drainage water from the root zone. The extra amount of this water in addition to the irrigation dose is called the leaching requirement (LR), and can be estimated exactly with the use of the equation:

$$LR = \frac{ECw}{5(ECe) - ECw}$$

where **LR** is the leaching requirements as a fraction of the irrigation dose, and **ECe** is the permissible level of salinity in the soil solution primarily related to the salt tolerance of the crop grown at a 100 percent yield potential. The average value usually taken for ECe is 1.5 ECw. In this case, LR = 0.15.

Leaching is especially necessary as a soil preparation for crops with high plant density, such as carrots, onions and groundnuts. The salinity over the entire area should be the same with no difference between the wetted and the non-wetted parts of the field during the preceding season. The leaching of the salts in the top layer is particularly important because crops are sensitive to salinity during the first stages of their growth.

For the control of the salinity level in the root zone, frequent observations should be conducted with soil sampling for the laboratory determination of the soil extract EC. The use of soil solutions, extractors and portable metering devices on the spot enables the continuous monitoring, for immediate action, of any significant change in the EC of the soil solution, the chloride and nitrate content, and the soil pH as a result of irrigation and fertilization.

Micro-irrigation and salinity control

In drip irrigation, the distribution of dissolved salts in the soil profile follows the pattern of the water flux with the tendency for accumulation at the periphery of the wetted soil mass. Most of the wetted zone below the emitter, where most of the roots concentrate and function, remains free from salts during the irrigation season with low to medium salinity values. Near the surface, due to evaporation, the salt accumulation is five times greater than in the deeper layers and increases with distance from the emitters. This, in combination with the use of poor quality irrigation water and the application of fertilizers through the system, will cause a salinity build-up, which might become a problem in areas where the annual rainfall does not exceed 250 mm. In these cases, it is essential to flood the total area once a year, at the end of the season, with adequate amounts of water in order to leach the salts beyond the rooting depth.

The salinity level in the root zone is related to the water quality, the amount of fertilizers and the irrigation dose. The salt accumulation in the vicinity of the emitters is less than half that between the emitter lines. The EC value of the saturation extract beyond the emitter is 2–3 times the ECw, and between the lines it is six to ten times higher. This high salt content can be controlled only by leaching or by reducing the amount of fertilizer during the growing season. In no case should the fertilizer concentration in the irrigation water exceed EC 0.5 dS/m that is added to the total salinity of the irrigation water.

In drip irrigation, extra leaching with increased quantities of water every application during the irrigation season is not recommended unless salt accumulation reaches hazardous levels. Leaching should take place after the crop harvest, between irrigation seasons, where the salt content is excessive and the rainfall is not sufficient. It is done either by flooding the area or by low precipitation sprinklers with very fine drops (Tables 7.10, 7.11 and 7.12).

Example analyses

TABLE 7.10 - Case 1: Water chemical analysis data sheet

Submitted by: Andreas Christoforou				**Date:** 11.9.97	
Locality: Potamia				**Laboratory No.:** W-76/97	
Analysis requested: Full ionic plus boron				**Borehole No.:** N332	
Remarks: Planning cropping patterns - fruit trees, vegetables					
LABORATORY RESULTS				**Analyst:** N. Antoniou **Date:** 19.9.97	
Electrical conductivity ECw dS/m: 3.6				**pH:** 7.1	
Anions	**mg/litre**	**meq/litre**	**Cations**	**mg/litre**	**meq/litre**
Chloride (Cl^-)	429	2.09	**Sodium (Na^+)**	480	20.8
Sulphate (SO_4)	552	11.50	**Potassium (K^+)**	19	0.5
Carbonate (CO_3^{--})	Nil	Nil	**Calcium (Ca^{++})**	160	8.0
Bicarbonate (HCO_3^-)	480	7.90	**Magnesium (Mg^{++})**	60	5.0
Nitrate (NO_3^-)	180	2.90	**Boron (B)**	1.5	------
Total	1 641	34.3		719	34.3
TDS:	2 360				

Evaluation and remarks: SAR = 8, RSC = Nil
Medium saline water - High in sodium and boron content at toxic levels for most fruit trees (citrus, deciduous, etc.) grapes, strawberries and some vegetables (onion, garlic, beans) - there is no sodium hazard - under proper management, on light soil with good infiltration and internal drainage and no impermeable layer, it can be used for irrigation of crops tolerant to salinity and boron, such as olives, pomegranates, pistachio, date palms, most of the vegetables, watermelons, potatoes, etc. and forage crops - some delay in crop development and certain yield reduction should be expected - any problems from bicarbonates can be solved easily - due to high nitrate content, which is equal to 40 g of net nitrogen per cubic metre of water, the application of nitrogen fertilizer should be reduced by 66 percent for fruit trees and 20-30 percent for vegetables accordingly - frequent irrigation is recommended - LR 0.15.

Signature: A. Phocaides

TABLE 7.11 - Case 2: Water chemical analysis data sheet

Submitted by: N. Papas				**Date:** 2.10.1997	
Locality: Orini				**Laboratory No.:** W/400/97	
Analysis requested: Full ionic plus boron				**Borehole No.:** N335	
Remarks: Irrigation use					
LABORATORY RESULTS				**Analyst:** A.Magnetis **Date:** 9.10.1997	
Electrical conductivity ECw dS/m: 2.1				**pH:** 8.35	
Anions	**mg/litre**	**meq/litre**	**Cations**	**mg/litre**	**meq/litre**
Chloride (Cl^-)	215	6.05	**Sodium (Na^+)**	320	13.9
Sulphate (SO_4)	244	5.10	**Potassium (K^+)**	2	--
Carbonate (CO_3^{--})	Nil	Nil	**Calcium (Ca^{++})**	48	2.4
Bicarbonate (HCO_3^-)	432	7.11	**Magnesium (Mg^{++})**	31	2.6
Nitrate (NO_3^-)	41	0.66	**Boron (B)**	0.56	
Total	932	18.9		401	18.9
TDS:	1 333				

Evaluation and remarks: SAR = 9, RSC = 2.11
Slightly saline water - no sodium hazard or any severe toxicity problem - under proper management and on light soils with good structure and internal drainage it is suitable for use in the majority of the crops - bicarbonate may cause some micronutrient deficiency problems that can be overcome.

Signature: A. Phocaides

TABLE 7.12 - Case 3: Water chemical analysis data sheet

Submitted by: G. Demosthenous				**Date:** 3.11.97	
Locality: Limassol				**Laboratory No.:**	
Analysis requested: Full ionic plus boron				**Borehole No.:**	
Remarks: Irrigation of olives and other field crops					
LABORATORY RESULTS				**Analyst:** E. Iasonos **Date:** 10.11.97	
Electrical conductivity ECw dS/m: 2.3				**pH:** 8.7	
Anions	**mg/litre**	**meq/litre**	**Cations**	**mg/litre**	**meq/litre**
Chloride (Cl^-)	107	3.02	**Sodium (Na^+)**	410	17.80
Sulphate (SO_4)	278	5.80	**Potassium (K^+)**	6	0.10
Carbonate (CO_3^{--})	14	0.48	**Calcium (Ca^{++})**	8	0.40
Bicarbonate (HCO_3^-)	624	10.27	**Magnesium (Mg^{++})**	14	1.20
Nitrate (NO_3^-)	Nil	Nil	**Boron (B)**	2.88	
Total	1 023	19.5		438	19.5
TDS:	1 461				

Evaluation and remarks: SAR = 20, RSC = 8.67
Slightly saline water, however problematic - boron content at toxic levels for the majority of fruit trees and most herbaceous agricultural crops - danger of severe soil infiltration and permeability problem from the use of this water - excess bicarbonate salts could cause chlorosis to some plants - pH is higher than normal and may result in imbalanced nutrition - usage of this water should be done with caution, very good management, on light soils with high infiltration rate and permeability, and selected crops tolerant to boron toxicity, such as date palms, cabbage, cauliflower, squash, parsley, tomato, celery, asparagus, corn, alfalfa, sugar beet - the existing olive trees may be irrigated reservedly - soil improvement additives (washed manure, gypsum, etc.) should be applied occasionally - frequent irrigation is preferable - a follow-up based on a schedule is essential.

Signature: A. Phocaides

THE PHYSICAL QUALITY OF IRRIGATION WATERS AND TREATMENT (FILTRATION)

Irrigation water usually is not found in its pure state, but mostly with foreign solid particles and other impurities. The solid content in irrigation water mainly consist of dirt and suspended inorganic matter (*silt, sand, leaves, fine clay and rust dust*) and organic substances (*algae, bacteria, protozoa*) from vegetative origin and living organisms and bacteria populations. The introduction of improved irrigation systems with the use of closed pipes networks and small nozzles' passage water emitters, liable to blockages, necessitates the removal of the suspended solids to protect the emitters against clogging hazards.

The suspended solid content in the irrigation water may vary in a wide range and depends on the nature of the source. The four main sources of the irrigation water used with pressurized irrigation techniques and the primary kind of suspended solids (SS) content are:

a) Dams and open reservoirs: Green algae (phytoplankton), bacteria and zooplankton of different kinds and bacterial slime (sulphatic, iron and other), dissolved iron and manganese, and all kinds of other impurities from inorganic origin (debris, silt, clay etc.).
b) Underground water (wells and boreholes): Sand, silt, iron, manganese, sulphates and carbonates and bacteria.
c) Treated wastewater: Suspended solid particles of different sizes and shapes.
d) Water from pipe networks: Zooplankton (grown for years in the pipes in colonies up to 5 mm size and developed in 2–3 days in worms that blocked the filters).

Irrigation water quality cannot be clearly defined in respect of clogging problems, yet it can be primarily classified as Good – Moderate – Bad - Very Bad. The various substances in water, which contribute to the clogging of the micro-irrigation systems can be divided into three main categories of:

- Suspended particles of organic and inorganic matter,
- Precipitate forming elements (iron, manganese, calcium, magnesium),
- Bacterial slimes.

For an in-depth evaluation it is necessary to examine the Total Suspended Solids, the Particle size Distribution, the Total Dissolved Solids, the water pH, the Hardness, the Turbidity, Iron and Manganese, the Hydrogen Sulphide and the Microbial population.

Filtration

The filtration of the irrigation water is essential in order to avoid blockages damage of the small passage emitters, drippers, sprayers and sprinklers. This is a mechanical water treatment and it is achieved by the installation of main filtering devices (filters) at the Control head of the irrigation systems. It is an integral part of the pressurized systems installations. The size of flow (capacity of filtration) may affect the type of the filtration in major water works, but for low rate applications at the farm level the type and the degree of filtration depends on:

- The kind of suspended matter in the irrigation water, and
- The filtration requirement of the system (emitters).

Most of the filters available for irrigation water are:

- the **gravel or granular (sand media) filters**, which operate on the principle of in-depth filtration and effectively withhold the large particles of unbroken organic mutter (algae) and dust,
- the **hydrocyclones (sand separators)** operate on the vortex flow principle and are used to collect large quantities of sand contained in pump underground water,
- the **strainers (screen type or disk/grooved rings type)** effective in filtering the inorganic suspended matter. These are equipped with filtering elements with perforations smaller than the emitters' diode (up to 70 percent).

In cases where water contains all kind of suspended matter it is necessary to install all three types of filters. The Hydrocyclone and the Gravel filter are always placed at the upstream of the Control Head of the System and the Strainer filter at the downstream. The latter is always installed in every micro-irrigation system after the fertilizer apparatus. The degree of filtration is usually given in the old English unit "mesh" (number of perforations per linear inch) or in "microns". The filtration requirements of various water emitters are:

- 16–25 mesh (1000–500 micron) for Slow-rotation impact drive sprinklers medium pressure
- 60–100 mesh (250–120 micron) for mini and micro-sprinklers and sprayers.
- 80–160 mesh (200–100 micron) for dripper emitters.

Operation and maintenance

Proper operation and maintenance (cleaning) of the filters is of paramount importance for effective filtration and to avoid the build up of a "filter cake" generating further clogging problems to the systems. Some filters are made for complete automatic and unattended operation, others are automatic self-cleaning and others are of self-cleaning or manual flushing and cleaning mechanism (a brief description of the filters is given in Chapter 3). The systems hydraulic pressure operates the filters, but automation requires electricity (AC or DC). The frequency of cleaning is planned either at fixed time intervals between two consecutive cleanings or whenever the differential pressure along the filter increases to the initial normal value (0.2–0.3 Bars). The suppliers give detail instructions for back flushing (size and velocity of flow, stream direction etc.) according to the filter mechanism and mode of operation.

Application of chemicals

Application of chemicals into the irrigation water, before the filtration system, may reduce the quantity of suspended matter, control the bacteria growth in the system network, decompose algae and dissolve the solid particles. It also prevents sedimentation. Copper sulphate is used extensively in reservoirs at a maximum concentration of 2 ppm to control growth of algae. Treatment with acid reduces the pH of the water thus prevents precipitation of dissolved solids and dissolves the existing precipitations. It can prevent carbonate precipitation too. The various acids recommended are the Hydrochloric acid (HCl) the Sulphuric acid (H_2SO_4) and Phosphoric acid (H_3PO_4). The phosphoric acid is a fertilizer too, however the concentration should be high enough to decrease pH < 6 and prevent phosphorous sediments. The quantity of acid depends on the requested pH of the water.

The safest and less expensive chemical for use with irrigation water, at normal pH and temperatures around 20°C, is chlorine in the form of Sodium Hypochlorite (NaOCl). Contact time also influences the effectiveness of chlorination. It is available everywhere as household liquid at concentrations of 2–15 percent available chlorine. The application is done through continuous or intermittent injection during irrigation at low uniform concentrations of approx. 5 ppm and 10 ppm respectively. Control of effective chlorination is achieved by the measurement of the free residual chlorine concentration in the water. This should be around 1.0–2.0 ppm at the end of the irrigating pipe. Use of ammonia fertilizer should be avoided during chlorination. Over dosage of chlorine into the systems networks may result into the movement of sediments cause severe clogging of the emitters.

QUALITY OF TREATED WASTEWATER FOR IRRIGATION (PHYSICAL, BIOLOGICAL AND CHEMICAL)

The treated wastewaters are a new source of water, which is expected to cover gradually more than 10 percent of the water requirements for agricultural and landscape irrigation. Treated wastewater may possess various chemical contaminants (salts, nutrients and trace elements) and biological undesirable constituents (water born pathogens, i.e. helminths, protozoa, bacteria and viruses shed in the excreta of healthy people and ill persons). Uncontrolled use of this type of water frequently is associated with significant negative impacts on human health and the environment. These impacts can be minimized when good management practices are implemented. So, it introduces a new element regarding the water quality evaluation for irrigation. "Wastewater" refers to domestic sewage and municipal wastewaters that do not contain substantial quantities of industrial effluents.

Evaluation criteria and parameters

The use of reclaimed wastewater is always planned, designed and managed properly. If not it might become hazardous for the people, the livestock and the environment. World Health Organization (WHO) published Guidelines for the Safe Use of Wastewater and Excreta in Agriculture and Aquaculture in 1989. These guidelines are currently under revision with expected publication in 2004. In this context some additional water quality criteria are considered based on water suitability for re-use in agriculture and landscape irrigation, and on ways and methods of improvement and management to satisfy the requirements of the installations, the operators and the yield consumers.

The evaluation of the treated effluents is based on world-wide established criteria, which refer to limiting values of certain physical, chemical and biological parameters in order to avoid possible adverse responses, when used, or disposed. The following parameters, when considered can give a correct picture of the usability of the treated wastewater and the level of its suitability for irrigation purposes:

Chemical Parameters:
- Total Salinity, ECw dS/m, TDS mg/l,
- Acidity/Basicity, pH
- Hardness, $CaCO_3$ mg/l
- Types and concentration of anions and cations, me/l
- Sodium adsorption Ratio, SAR
- Nitrate – Nitrogen, NO_3–N mg/l
- Phosphate Phosphorus, PO_4–P mg/l
- Trace Elements, mg/l
- Heavy Metals, mg/l

Physical and Biological Parameters:
- Colour,
- Odor,
- Turbidity NTU,
- BOD 5 mg/l (Biochemical Oxygen Demand)

- COD mg/l (Chemical Oxygen Demand)
- SS mg/l (Suspended Solids)
- Total Coliforms/100 mg
- Faecal Coliforms
- Intestinal Nematodes

Impact on soils and plants

The evaluation of the treated wastewater as it is concerned with its chemical quality is well understood, as it has already been described previously. It is made for any possible long-term effect on irrigated soils and plants and groundwater protection. Experience gained so far, suggests that with proper management (improved irrigation system, proper irrigation schedule) salinity/toxicity and nitrogen effects on soil can be under control. Excess NO3 may cause some problems to the plants. The trace elements and heavy metals, which are present in many treated effluents rarely, exhibit serious toxicities to plants although in most cases they accumulate in the plants themselves. When the plants are consumed by livestock possible health hazards can developed. E.g. lead and vanadium is toxic to forage crops at normal and low concentrations respectively. Still the time required for development of health hazards to the livestock is very long, 20–50 years and if repeated applications of heavy metals in excess of the maximum permissible are practiced. Even then it does not mean that phytotoxicity will occur. No problem has been observed with the accumulation of heavy metals in the crops or in the soil. In fact the conventional fertilizers were found to add far greater quantities of heavy metals.

Effects on the environment

As it is concerned with the effects on the environment, the values of the chemical and biological parameters for the treated effluents should be at levels acceptable for the purpose of use and disposal. There is always the risk that wastewater irrigation may facilitate the transmission of intestinal nematode infections and faecal bacterial diseases to both consumers and agricultural workers. In fact there is no practical experience and knowledge on the wastewater pollutants movement downwards and the current devices and sensors detecting the contaminants within the soil are too expensive. However, it is known that nitrates contained in the irrigation water are mobile and eventually reach the groundwater. There is no doubt that the same happens with boron. As regards with the toxic heavy metals, studies have indicated that more than 85 percent of the applied trace elements accumulate in the surface few centimetres of the soil. Yet it is possible that long term application of treated effluents with toxic elements, especially under acid soil conditions and on sandy soils might lead ultimately to their mobilization and leaching down in deeper layers and finally to pollute the groundwater. It must be underlined that no such cases have been reported until recently.

Effects on the irrigation system

Treated wastewaters contain generally large quantities of suspended organic matter, other waterborne trash and impurities of inorganic origin that cause blockages and clogging of emitters on the irrigation systems.

Health protection (after WHO)

From the standpoint of public health protection, the available measures can be grouped under the following four main categories:

- ***Treatment process and degree of pathogens removal:***
  Removal of pathogens is the prime objective in treatment of wastewaters for reuse. Various conventional processes for primary and secondary treatments, **plain sedimentation, activated sludge, biofiltration (trickling filters), aerated lagoons, oxidation ditches, row-sewage disinfections and waste stabilization ponds** cannot remove the bacterial and helminth egg effectively. **Supplementary disinfections and filtration** (tertiary treatment) is needed to produce quality water at accepted levels to comply with recommendations for unrestricted irrigation. In arid and semi-arid regions the Waste stabilization ponds are used. With a minimum retention time of 11 days and depending on the temperature with about twice that time this treatment process may achieve adequate pathogens removal (helminth and bacteria) to meet the recommended standards for reuse. Additional "polishing" ponds are needed to the conventional treatment plants.

- ***Crop selection:***
  Based on the treated water quality the various crops to be grown without risk to the consumer are categorized (A, B and C) in accordance with the required extent of measures for health protection. (WHO recommended microbiological quality guidelines for wastewater use in agriculture, 1989)?

  - Category A - protection for field workers includes industrial crops, grains and forestry and food crops for canning.

  - Category B - protection for consumers, farmers and the general public, applies to pasture, green fodder and tree crops, as well as to fruit and vegetables that are peeled or cooked before eating.
  - Category C - unrestricted irrigation, covers fresh vegetables, spray irrigated fruit, grass and lawns in public parks, sport fields etc.

  It must be underlined that the crop selection in category B provides protection only to consumers and not to the farmers and field workers. Additional measures should be applied, such as control of human exposure.

- ***Method of irrigation application:***
  Irrigation with pressurized irrigation systems has many advantages over the traditional surface methods. Gravity surface methods expose the farmers to the greatest risk. This is eliminated with the use of Pipes Distribution surface systems. However if the treated water is not recommended for unrestricted irrigation, sprinkling and spraying methods should not be used for crops likely to be eaten uncooked, fruits and for grass and lawns in public parks, sport fields etc. Drip irrigation (conventional) and bubblers can give a great degree of health protection. Drip irrigation with mulching and sub-surface gives the highest protection.

- ***Human exposure:***
  The people at potential risk from the use of treated wastewater are the farmers and their families, the crop handlers, the consumers of products and those living near the effected fields. The risk can be reduced by several precaution measures such as are the proper management, the immunization against typhoid and hepatitis and other infections, the limited exposure by the use of the right clothe and footwear, thorough cooking of food, and other hygiene measures.

National guidelines and standards (The Cyprus case)

The national guidelines for reuse of treated wastewater for irrigation in many countries mostly comply with those published by WHO. The objectives of WHO is to provide background and guidance to governments for developing their national standards with respect to international health matters, the protection of the public health and the preservation of the environment. An excellent example is the “Cyprus case”. In this country the reuse of treated effluents is a relatively new practice, it started in mid-eighties, however a lot of progress has been made through and now it can be used as a model for many other countries.

The Cyprus Standards

The Sewage Effluent and Sludge Technical Committee under the Ministry of Agriculture, Natural Res. and Environment of the Republic of Cyprus prepared quality standards for the treated effluents and sludge to be reused in agriculture and amenity areas. The standards are composed of two parts, *the Guidelines and the Code of Practice* and at the moment they seem to be the most advanced as compared with other national standards, so they are used in this chapter.

The *“Guidelines”* includes the variables of BOD as the main indicator for better monitoring and control of the treatment process, Suspended

Solids for the effective disinfections against pathogens and especially viruses, as well as for the elimination of filters clogging and micro-emitters blockages. Faecal Coliforms are included as an indicator of pollution and Intestinal Nematodes as the parameter directly referring to a group of pathogens and as an indicator for protozoa removed from the treated wastewater as intestinal warms. The methods of treatment (secondary, tertiary/storage and disinfections or stabilization maturation) are also included to ensure the quality parameters. The *"Code of Practice"* is complementary regulations yet inseparable part of the *"Guidelines"* specifying treatment techniques, irrigation methods for each crop and criteria for handling the systems of irrigation, security measures, etc. It incorporates additional measures, which act as barriers to the transmission of diseases. The techniques/methods for tertiary treatment are also specified.

Pressurized irrigation with treated wastewater

All pressurized irrigation systems described in this Handbook can be used for irrigation with treated wastewater. The water microbiological quality standards, the farming practice, and the kind of crop are the main interrelated factors that affect the selection of the irrigation system. Different techniques and methods are suggested for the irrigation of different crops for many reasons.

The micro-irrigation systems in general (drip, low-capacity sprinklers, bubbler and mini-sprinkler) are suitable for irrigation with this type of water, as these permanent localized methods secure for the minimum contact of treated water with crops and farmers (Figures 7.2 and 7.3). Conventional sprinkling (solid installations) and mechanized spraying systems (center pivot and traveller boom) are conditionally suitable. Low-cost systems (hose-basin, hose furrow and pipe distribution surface systems) are also recommended. Their use mainly depend on the quality of the effluent, the kind of crop, the potential risk to the health of the workers, the public and the environment and finally on the background and skill of the farmers to handle this type of water. For further details please read the *"Cyprus Code of Practice"* (see Table 7.13), which provides adequate and specific information for nearly all crops and the appropriate irrigation techniques. The installation of efficient filtration at the Control Head of the systems is of major importance as it is the arrangement for automation in sprinkling and spraying methods of water application.

FIGURE 7.2 - Drip maize with recycled water.

FIGURE 7.3 - Sprinkling with treated municipal water.

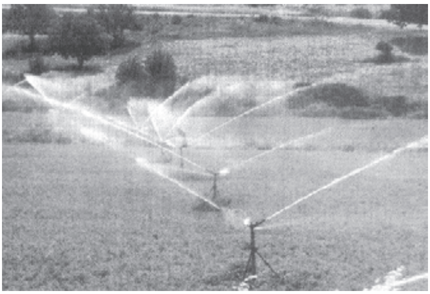


TABLE 7.13 - Cyprus Guidelines for Domestic Treated Effluents use for Irrigation

Irrigation of:		BOD mg/l	SS mg/l	Faecal Coliforms /100 ml	Intestinal Worms/l	Treatment required
All crops (a)	(A)	10*	10*	5* 15**	Nil	Secondary and Tertiary and Disinfection
Amenity areas of unlimited access. Vegetables eaten cooked (b)	(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* 45**	200* 1 000**	Nil	Secondary and Storage > 7 days and Disinfection or Tertiary and Disinfection
	(B)	--	--	200* 1 000**	Nil	Stabilization-maturation ponds total retention time > 30 days or Secondary and storage> 30 days
Fodder crops	(A)	20* 30**	30* 45**	1 000* 5 000**	Nil	Secondary and Storage > 7 days and Disinfection or Tertiary and Disinfection
	(B)	--	--	5 000*	Nil	Stabilization-maturation ponds total retention time > 30 days or Secondary and storage> 30 days
Industrial crops	(A)	50* 70**	--	3 000* 10 000**	--	Secondary and Disinfection
	(B)	--	--	3 000* 10 000**	--	Stabilization-maturation ponds total retention time > 30 days or Secondary and storage> 30 days

(A) Mechanized methods of treatment (activated sludge,
(B) Physical methods of treatment (Stabilization Ponds)
* These values must not be exceeded in 80 percent of samples per month. Min. No of samples 5
** Maximum value allowed
(a) Irrigation of leafy vegetables, bulbs and corms eaten uncooked is not allowed
(b) Potatoes, 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 effluent.

Code of Practice for Treated Sewage Effluent used for Irrigation in Cyprus

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

2. Skilled operators should be employed to attend the treatment and disinfection plant, following formal approval by the appropriate authority that the persons are competent to perform the required duties, necessary too ensure that conditions (1) are satisfied.

3. The treatment and disinfection plant must be attended every day according to the program issued by the Authority and records to be kept on 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 unauthorised persons. All such outlets must be coloured red and clearly labelled so, as to warn the public that 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 satisfactory marked with red 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.

6. Irrigation methods allowed and conditions of application differ between different plantations as follows:

   6.1. Park lawns and ornamental in amenity areas of unlimited access:
   - Subsurface irrigation methods
   - Drip irrigation
   - Pop-up sprinklers, low-pressure, high precipitation rate lo-angle < 11°. Sprinkling preferably practiced at night and when people are not around.

   6.2. Park lawns and ornamental in amenity areas of limited access, industrial and fodder crops
   - Subsurface irrigation
   - Bubblers

- Drip irrigation
- Surface irrigation methods
- Low capacity sprinklers
- Spray or sprinkler irrigation, is allowed with a buffer zone of about 300 meters.

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 this sewage. Veterinary services should be informed.

6.3. Vines:
- Drip irrigation
- Mini-sprinkler and sprinklers (in case where crops get wetted, irrigation should stop for two weeks before harvesting).

Moveable irrigation systems not allowed No fruit should be selected from the ground.

6.4. Fruit trees
- Drip irrigation
- Hose-basin irrigation
- Bubbler irrigation
- Mini-sprinklers irrigation

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

6.5. Vegetables
- Subsurface irrigation
- Drip irrigation

Crops must not come in contact with effluents.
Other irrigation methods could also be considered.

6.6. 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 or environment.

7. The following tertiary treatment methods are acceptable:

   7.1. Coagulation plus flocculation followed by rapid sand filtration
   7.2. Slow Sand Filters
   7.3. Any other method, which may secure the total removal of helminth ova and reduce faecal coliforms to acceptable levels, must be approved by the appropriate Authority.

8. Appropriate disinfection methods should be applied when sewage effluents are 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 one hour of contact time should be at least 0.5 mg/l and not greater than 2.0 mg/l.

9. Suitable facilities for monitoring of the essential quality parameters should be kept on site of treatment.