Chapter 13 Quality of Water Supply

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652.1300 General

When determining water availability for irrigation, information is required on its quality. Water quality must be evaluated on its suitability for the intended use. Often water (and effluent) use is based on the desires of the decisionmaker and not the crop. Specific uses can have different water quality needs. The irrigator must know the quality of water used for irrigation. If contaminants are present, the type and concentration must be determined.

Irrigation water used for agriculture can contain undesirable contaminants, such as dissolved salts (salinity and sodicity), suspended sediment, gypsum, naturally occurring toxic elements, nematodes, and water borne diseases. Tailwater (runoff) from surface irrigation systems can be reused as a water supply, but can also contain contaminants, such as sediment, agricultural fertilizers, pesticides, and organic material. Discharge from subsurface drainage systems, treated municipal sewage, industrial wastes, agricultural food processing, and wastes from confined livestock and fish feeding operations can also be used to supplement existing supplies.

Disposal of wastes on cropland as plant nutrients and soil amendments is encouraged by regulatory agencies. Naturally occurring microbial activity helps break down (metabolize) organic solids and contaminants. Caution must be exersized, however, when applying treated municipal sewage and industrial wastes to cropland. Depending on treatment level, these sources can contain pathogens, viruses, coliforms, salts, toxic metals, or acids. Geothermal (hot) water can also be used for irrigation, but generally must be cooled by sprinkling or storage before being applied to crops. It can also contain elements toxic to soils and plants (i.e., boron, chloride, sodium, sulfur, and toxic metals). Cold water can retard plant growth for short periods of time.

Good quality water promotes maximum yield if good soil and water management practices are used. With lesser quality water, soil and cropping problems can be expected, unless appropriate management practices are adopted. It may be desirable to use low quality water for irrigation of specific crops in specific areas rather than allow low quality water to discharge into public surface water. However, high quality water may be required for irrigating certain specialty crops because of required crop quality or soil contaminant standards or to meet interstate transportation and marketing requirements. Nursery potted plants is one example.

Typically lesser quality water can be used to irrigate growing crops than is required for germination and sprouting. Generally poor quality water should not be mixed with high quality water. On the surface, mixing high quality water with low quality water may seem to improve the low water quality. In reality a poor water quality still exists, and using it can allow contaminants (i.e., salts) to accumulate in the soil profile throughout the irrigation season. As an example, with proper salinity management, poorer quality water can be used to grow many crops during most of the growing season. The high quality water is then available for germination, sprouting, and leaching of accumulated salts, as well as meeting plant water needs for low salt-tolerant crops.

Annual leaching can be eliminated by growing crops less tolerant to toxic elements early in the crop rotation following leaching. As toxic elements accumulate (usually in the soil profile), more salt-tolerant crops are grown. Leaching is performed following the last crop in the rotation. Crop rotation examples are:

- beans, corn, wheat, and barley
- lettuce, cantaloupe, sorghum, and cotton
- beans, cauliflower, cucumber, broccoli, and squash

Physical contaminants and organic particles can adversely affect some irrigation systems. They also present challenges for design of screening devices that will satisfactorily remove contaminates. Physical contaminants include suspended debris, moss, and submersed aquatic plants. Algae and bacterial slimes are organic particles.

Particulates, including small aquatic organisms, can plug nozzles and orifices in sprinkle and micro irrigation systems. Floating trash and debris may cause trouble in systems that discharge water through larger gates or openings. Small aquatic organisms including snails, freshwater clams, and other invertebrates can plug pump screens if large numbers congregate at the intake. Different sizes and types of screening and filtration devices are required to prevent these problems.

Suspended and floating debris in irrigation water can cause malfunction of flow meters, measuring devices, plugging of siphon tubes, and gates in gated pipe. Debris can also accumulate within and potentially plug almost any water control structure. Good irrigation water management requires complete control of water delivery.

Water suitability for irrigation is determined by the potential to cause soil, plant, or management problems. Appropriate management practices should be selected to avoid unacceptable levels of biomass or yield reduction. Suitability must be evaluated at the farm level for specific use and potential hazard to crops and personal health. Available farm management and the farm situation must be considered. Removing larger sized floating debris by irrigation organization facilities (trash racks, rotating screens) may be desirable.

Water quality is a major consideration when selecting irrigation method. Adequate data on water quality is essential in the selection process. All irrigation water contains some dissolved solids (salts). Significant build-up of these salts can occur without proper irrigation method selection, operation, and management. The leaching capability of the irrigation method is a consideration. It becomes increasingly important as salt content of the irrigation water increases.

652.1301 Effect of water quality on irrigation system, soil, and crops

Suitability of water for irrigation depends on the total amount and kind of salts, ions and other toxic elements in the water. Suitability must also consider crops grown, irrigation water management, cultural practices, and climate factors. Guidelines for evaluating water quality for irrigation are given in table 13–1. These guidelines are limited to water quality parameters that are normally encountered and that materially affect crop production. Laboratory determinations and calculations needed to use the guidelines are displayed in table 13–2.

Additional information and details on effects of specific ions are provided in the National Engineering Handbook (NEH), Part 623, Chapter 2, Irrigation Water Requirements. Also see American Society of Civil Engineers (ASCE) Report 71, Agricultural Salinity Assessment and Management.

(a) Salinity and sodicity

Salinity or sodicity relates to water quality if the total quantity of salts in the irrigation water is high enough that salts accumulate in the crop root zone or on the plant and to the extent that crop growth and yield are affected. Where excessive soluble salts accumulate in the root zone, plants have increasing difficulty in extracting water from the soil profile. Reduced water uptake by the plant can result in slow or reduced growth. This can cause the appearance of a drought condition (i.e., plant wilting) even with relative high soil moisture conditions. Crops have different salinity and sodicity tolerance levels, plus effects of salinity and sodicity can vary with growth stage. Tolerance to salinity or sodicity can be very low at germination and small seedling stage, but usually increases as the plant grows and matures.

Table 13–1 Irrigation water quality guidelines [1]

Potential irrigation water quality problem	Describing parameter	- - - - - Degree of restriction on use - - - - -		
		None	Slight to moderate	Severe
Salinity				
(affects crop water availability)	EC_i [2], mmho/cm	< 0.7	0.7 – 3.0	> 3.0
	or TDS [3], mg/L	< 450	450 – 2,000	> 2,000
Infiltration				
(affects water infiltration rate—evaluated by using EC_i and SAR together) [4]	SAR		EC_i, mmho/cm	
	0 – 3	> 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				
(affects sensitive crops)				
Sodium (Na) [5]				
surface irrigation	SAR	< 3	3 – 9	> 9
sprinkler irrigation	meq/L	< 3	> 3	
Chloride (Cl) [5]				
surface irrigation	meq/L	< 4	4 – 10	> 10
sprinkler irrigation	meq/L	< 3	> 3	
Boron (B) [6]	meq/L	< 0.7	0.7 – 3.0	> 3.0
Miscellaneous effects				
(affects susceptible crops)				
Bicarbonate (HCO_3)				
(overhead sprinkling only)	meq/L	< 1.5	1.5 – 8.5	> 8.5

1/ Adapted from Ayers and Westcot (1985), FAO 29, revision 1.

2/ EC_i means electrical conductivity of the irrigation water reported in mmho/cm at 77 °F (25 °C).

3/ TDS means total dissolved solids reported in mg/L.

4/ SAR means sodium adsorption ratio. At a given SAR, infiltration rate increases as water salinity increases.

5/ For surface irrigation—Most tree crops and woody plants are sensitive to sodium and chloride, so the values shown should be used. Because most annual crops are not sensitive, the salinity tolerance values in table 2–34 should be used. For chloride tolerance of selected fruit crops, see table 2–35 in NEH, Part 623, Chapter 2, Irrigation Water Requirements. With overhead sprinkler irrigation and low humidity (<30%), sodium and chloride may be absorbed through the leaves of sensitive crops. For crop sensitivity to absorption, see table 2–36 in NEH, part 623, chapter 2.

6/ For boron tolerances see tables 2–37 and 2–38 in NEH, Part 623, Chapter 2, Irrigation Water Requirements.

Electrical conductivity of the irrigation water (EC_i) is used as a measure of salinity. Electrical conductivity of the saturated soil extract (EC_e) is a measure of soil water salinity which affects the availability of water for plant growth. The electrical conductivity of irrigation water plus infiltrated precipitation water (EC_{aw}) affects the saturated soil extract. Figure 13–1 displays divisions for classifying crop tolerance to salinity. Table 13–3 displays salinity tolerance of selected crops and projected yield decline. See discussion of salinity, sodicity, and leaching in NEH, Part 623, Chapter 2, Irrigation Water Requirements.

SAR is used as a measure of sodium affected water and soil. A permeability problem occurs when the soil or water is relatively high in sodium, and low in calcium. Where exchangeable sodium is excessive, soil permeability is reduced for a given salinity level of the infiltrating water and soil pH. Low salinity and high pH also decrease soil permeability as much as sodium.

Table 13–2 Determinations normally required to evaluate irrigation water quality problems 1/

Determination		Symbol	Valence	Unit of measure 2/	Atomic weight	Usual range in irrigation water
Total salt content						
Electrical conductivity		EC	—	mmho/cm	—	0-3
Concentration or total dissolved solids		TDS	—	mg/L	—	0-2000
Sodium hazard						
Sodium adsorption ratio 3/		SAR	—	—	—	0-15
Constituents						
Cations:	Calcium	Ca	+2	meq/L	40.1	0-20
	Magnesium	Mg	+2	meq/L	24.3	0-5
	Sodium	Na	+1	meq/L	23.0	0-40
Anions:	Bicarbonate	HCO_3	-1	meq/L	61.0	0-10
	Sulfate	SO_4	-2	meq/L	96.1	0-20
	Chloride	Cl	-1	meq/L	35.3	0-30
Trace elements						
Boron		B	—	mg/L	10.8	0-2
Acid/basic		pH	—	1-14	—	6.0-8.5

1/ Adapted from Ayers and Westcot (1985).

2/ Millimhos/cm (1 mmho/cm) referenced to 77 °F (25 °C).
mg/L = milligram per liter ≈ parts per million (ppm).
meq/L = milliequivalent per liter (mg/L ÷ equivalent weight = meq/L).

3/ SAR is calculated by the following equation, with each concentration reported in meq/L.

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

Figure 13–1 Divisions for classifying crop tolerance to salinity

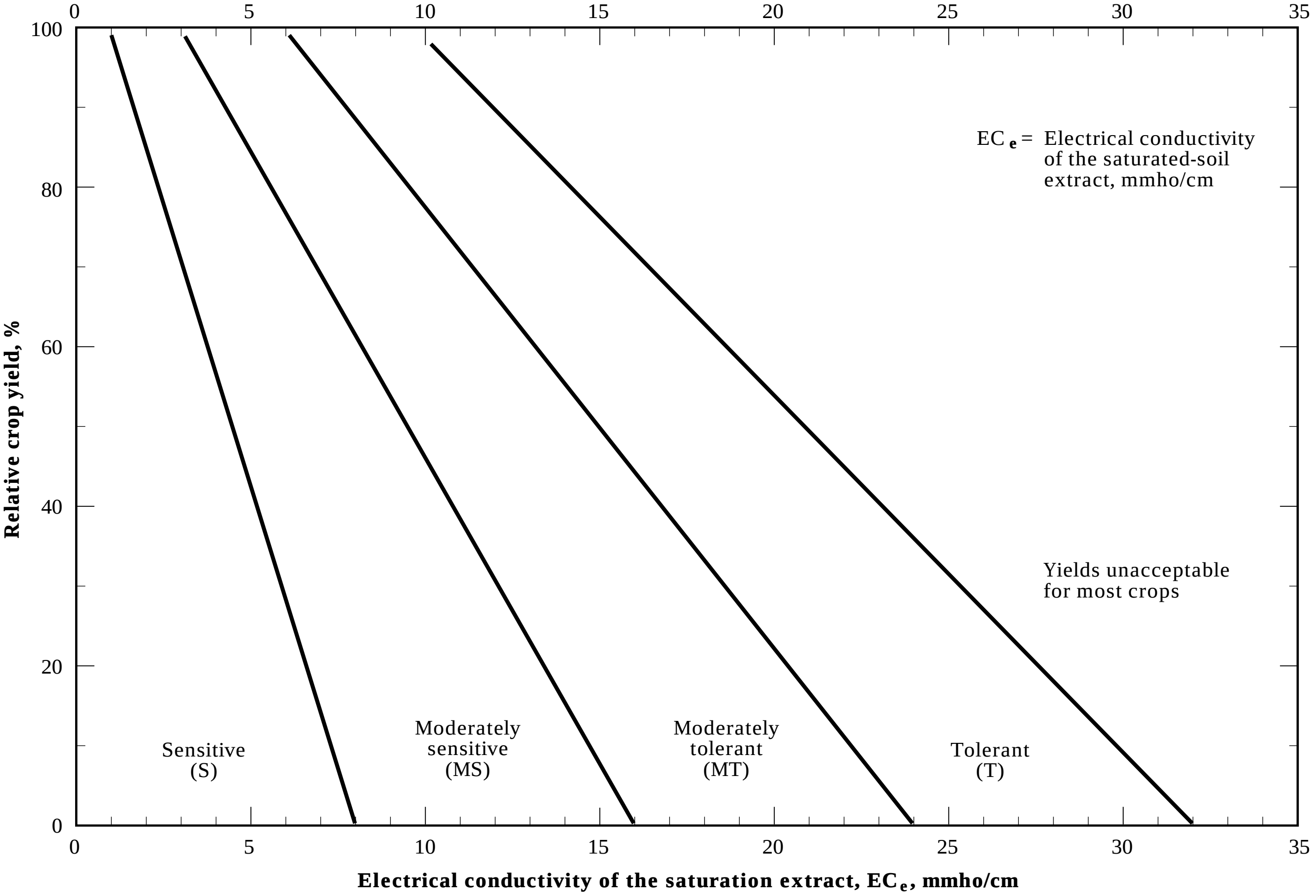


Table 13–3 Salt tolerance of selected crops [1]

Common name	Botanical name	Salt tolerance threshold [2] (EC_t)	Yield decline [3] (Y_d)	Qualitative salt tolerance rating [4]
		mmho/cm	% per mmho/cm	
Field crops				
Barley	*Hordeum vulgare*	8.0	5.0	T
Bean	*Phaseolus vulgaris*	1.0	19	S
Broad bean	*Vicia faba*	1.6	9.6	MS
Corn	*Zea Mays*	1.7	12	MS
Cotton	*Gossypium hirsutum*	7.7	5.2	T
Cowpea	*Vigna unguiculata*	4.9	12	MT
Flax	*Linum usitatissimum*	1.7	12	MS
Guar	*Cyamopsis tetragonoloba*	8.8	17.0	T
Millet, foxtail	*Setaria italica*	—	—	MS
Oats	*Avena sativa*	—	—	MT
Peanut	*Arachis hypogaea*	3.2	29	MS
Rice, paddy [5]	*Oryza sativa*	3.0	12	S
Rye	*Secale cereale*	11.4	10.8	T
Safflower	*Carthamus tinctorius*	—	—	MT
Sesame	*Sesamum indicum*	—	—	S
Sorghum	*Sorghum bicolor*	6.8	16	MT
Soybean	*Glycine max*	5.0	20	MT
Sugar beet	*Beta vulgaris*	7.0	5.9	T
Sugarcane	*Saccharum officinarum*	1.7	5.9	MS
Sunflower	*Helianthus annuus*	—	—	MS
Triticale	*x Triticosecale*	6.1	2.5	T
Wheat	*Triticum aestivum*	6.0	7.1	MT
Wheat (semidwarf)	*T. aestivum*	8.6	3.0	T
Wheat, durum	*T. turgidum*	5.9	3.8	T
Grasses and forage crops				
Alfalfa	*Medicago sativa*	2.0	7.3	MS
Alkaligrass, nuttall	*Puccinellia airoides*	—	—	T
Alkali sacaton	*Sporobolus airoides*	—	—	T
Barley (forage)	*Hordeum vulgare*	6.0	7.1	MT
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
Burnet	*Poterium sanguisorba*	—	—	MS
Canarygrass, reed	*Phalaris arundinacea*	—	—	MT

See footnotes at end of table.

Table 13–3 Salt tolerance of selected crops[1/]—Continued

Common name	Botanical name	Salt tolerance threshold [2/] (EC_t)	Yield decline [3/] (Y_d)	Qualitative salt tolerance rating [4/]
		mmho/cm	% per mmho/cm	
Grasses and forage crops (continued)				
Clover, alsike	*Trifolium hybridum*	1.5	12	MS
Clover, berseem	*T. alexandrinum*	1.5	5.7	MS
Clover, hubam	*Melilotus alba*	—	—	MT
Clover, ladino	*Trifolium repens*	1.5	12	MS
Clover, red	*T. pratense*	1.5	12	MS
Clover, strawberry	*T. fragiferum*	1.5	12	MS
Clover, sweet	*Melilotus*	—	—	MT
Clover, white Dutch	*Trifolium repens*	—	—	MS
Corn (forage)	*Zea mays*	1.8	7.4	MS
Cowpea (forage)	*Vigna unguiculata*	2.5	11	MS
Dallisgrass	*Paspalum dilatatum*	—	—	MS
Fescue, tall	*Festuca elatior*	3.9	5.3	MT
Fescue, meadow	*F. pratensis*	—	—	MT
Foxtail, meadow	*Alopecurus pratensis*	1.5	9.6	MS
Grama, blue	*Bouteloua gracilis*	—	—	MS
Hardinggrass	*Phalaris tuberosa*	4.6	7.6	MT
Kallar grass	*Diplachne fusca*	—	—	T
Lovegrass	*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 cereale*	—	—	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
Siratro	*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	MS
Trefoil, narrowleaf birdsfoot	*L. corniculatus tenuifolium*	5.0	10	MT
Trefoil, broadleaf birdsfoot	*L. corniculatus arvenis*	—	—	MT

See footnotes at end of table.

Table 13–3 Salt tolerance of selected crops[1]—Continued

Common name	Botanical name	Salt tolerance threshold [2] (EC_t)	Yield decline [3] (Y_d)	Qualitative salt tolerance rating [4]
		mmho/cm	% per mmho/cm	
Grasses and forage crops (continued)				
Vetch, common	*Vicia angustifolia*	3.0	11	MS
Wheat (forage)	*Triticum aestivum*	4.5	2.6	MT
Wheat, durum (forage)	*T. turgidum*	2.1	2.5	MT
Wheatgrass, standard crested	*Agropyron sibiricum*	3.5	4.0	MT
Wheatgrass, fairway crested	*A. cristatum*	7.5	6.9	T
Wheatgrass, intermediate	*A. intermedium*	—	—	MT
Wheatgrass, slender	*A. trachycaulum*	—	—	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
Vegetable and fruit crops				
Artichoke	*Helianthus tuberosus*	—	—	MT
Asparagus	*Asparagus officinalis*	4.1	2.0	T
Bean	*Phaseolus vulgaris*	1.0	19	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	S
Cauliflower	*B. oleracea botrytis*	—	—	MS
Celery	*Apium graveolens*	1.8	6.2	MS
Corn, sweet	*Zea mays*	1.7	12	MS
Cucumber	*Cucumis sativus*	2.5	13	MS
Eggplant	*Solanum melongena esculentum*	1.1	6.9	MS
Kale	*B. oleracea acephala*	—	—	MS
Kohlrabi	*B. oleracea gongylodes*	—	—	MS
Lettuce	*Lactuca sativa*	1.3	13	MS
Muskmelon	*Cucumis melo*	—	—	MS
Okra	*Abelmoschus esculentus*	—	—	S
Onion	*Allium cepa*	1.2	16	S
Parsnip	*Pastinaca sativa*	—	—	S
Pea	*Pisum sativum*	—	—	S
Pepper	*Capsicum annuum*	1.5	14	MS
Potato	*Solanum tuberosum*	1.7	12	MS

See footnotes at end of table.

Table 13–3 Salt tolerance of selected crops[1]—Continued

Common name	Botanical name	Salt tolerance threshold [2] (EC$_t$)	Yield decline [3] (Y$_d$)	Qualitative salt tolerance rating [4]
		mmho/cm	% per mmho/cm	
Vegetable and fruit crops (continued)				
Pumpkin	*Cucurbita pepo pepo*	—	—	MS
Radish	*Raphanus sativus*	1.2	13	MS
Spinach	*Spinacia oleracea*	2.0	7.6	MS
Squash, scallop	*Cucurbita pepo melopepo*	3.2	16	MS
Squash, zucchini	*C. pepo melopepo*	4.7	9.4	MT
Strawberry	*Fragaria sp.*	1.0	33	S
Sweet potato	*Ipomoea batatas*	1.5	11	MS
Tomato	*Lycopersicon lycopersicum*	2.5	9.9	MS
Turnip	*Brassica rapa*	0.9	9.0	MS
Watermelon	*Citrullus lanatus*	—	—	MS
Woody crops				
Almond	*Prunus dulcis*	1.5	19	S
Apple	*Malus sylvestris*	—	—	S
Apricot	*P. armeniaca*	1.6	24	S
Avocado	*Persea americana*	—	—	S
Blackberry	*Rubus sp.*	1.5	22	S
Boysenberry	*Rubus ursinus*	1.5	22	S
Castor bean	*Ricinus communis*	—	—	MS
Cherimoya	*Annona cherimola*	—	—	S
Cherry, sweet	*Prunus avium*	—	—	S
Cherry, sand	*P. 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	S
Guayule	*Parthenium argentatum*	8.7	11.6	T
Jojoba	*Simmondsia chinensis*	—	—	T
Jujube	*Ziziphus jujuba*	—	—	MT
Lemon	*C. limon*	—	—	S
Lime	*C aurantiifolia*	—	—	S
Loquat	*Eriobotrya japonica*	—	—	S
Mango	*Mangifera indica*	—	—	S
Olive	*Olea europaea*	—	—	MT
Orange	*C. sinensis*	1.7	16	S
Papaya	*Carica papaya*	—	—	MT

See footnotes at end of table.

Table 13–3 Salt tolerance of selected crops[1]—Continued

Common name	Botanical name	Salt tolerance threshold [2] (EC_t)	Yield decline [3] (Y_d)	Qualitative salt tolerance rating [4]
		mmho/cm	% per mmho/cm	
Woody crops (continued)				
Passion fruit	*Passiflora edulis*	—	—	S
Peach	*Prunus persica*	1.7	21	S
Pear	*Pyrus communis*	—	—	S
Persimmon	*Diospyros virginiana*	—	—	S
Pineapple	*Ananas comosus*	—	—	MT
Plum; prune	*Prunus domestica*	1.5	18	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

1/ Adapted from Maas and Hoffman (1977) and Maas (1990). Data serve as a guide to relative tolerances. Absolute tolerances depend upon climate, soil conditions, and cultural practices. Note: 1 mmho/cm = 1 dS/m.

2/ Salt tolerance threshold (EC_t) is the mean soil salinity at initial yield decline. Salinity expressed as EC_e in mmho/cm referenced to 77 °F (25 °C).

3/ Percent yield decline (Y_d) is the rate of yield reduction per unit increase in salinity beyond the threshold.

4/ Qualitative salt tolerance ratings are sensitive (S), moderately sensitive (MS), moderately tolerant (MT), and tolerant (T) as shown in figure 2–32.

5/ Values are for soil-water while plants are submerged. Less tolerant during seedling stage.

(b) Infiltration and permeability

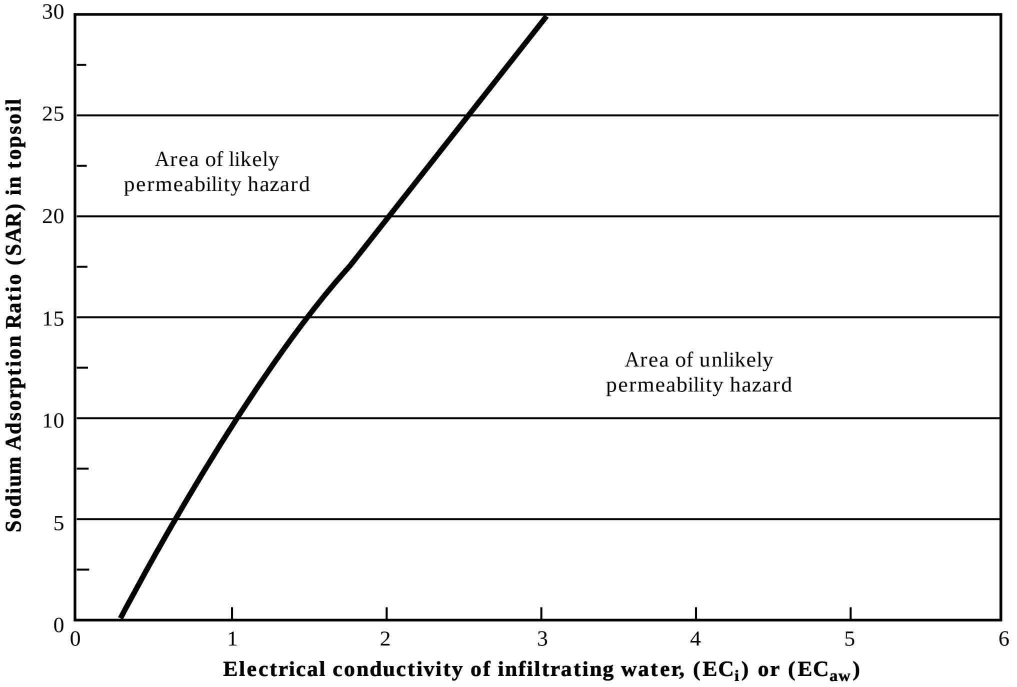
Permeability problems occur when the soil or the irrigation water is relatively high in sodium and low in calcium. Infiltration rate can decrease to the point that sufficient water cannot infiltrate to adequately supply the crop. Sodium causes soil particles to disperse, resulting in a massive soil structure with low permeability. Where exchangeable sodium is excessive, soil permeability is reduced in low calcium level soils. Low salinity and high pH can also decrease soil permeability as much as sodium. Sodium Adsorption Ratio (SAR) is most often used to define infiltration and permeability problems; however, a combination of SAR and EC_i may be more indicative of problems. See figure 13–2 for threshold values of a combination of SAR and ECi for potential infiltration and permeability hazards. Adjusted SAR is used where bicarbonates are present. Often, gypsum (calcium) is added to the soil to improve infiltration and permeability.

(c) Toxicity

Crop toxicity problems occur when certain elements are available in the soil-water solution and taken up by the plants. Toxic elements can accumulate in amounts that result in reduced crop yield or quality. Toxicity normally results when certain ions are absorbed by the plant with soil water, move with the plant transpiration stream, and accumulate in the leaves at concentrations that cause plant damage. This is usually related to one or more specific ions available in irrigation water, i.e., boron, chloride, and sodium. Not all crops are sensitive to these ions. White deposits on leaves or other plant parts may indicate the presence of salt. White deposits can occur on fruit or leaves as a result of sprinkler irrigation where water with high bicarbonate concentration is used. Toxicity often accompanies or complicates a salinity or infiltration problem. It may appear even when salinity is low.

Certain other highly toxic elements occur in irrigation water, especially drainage system discharge in some soils. Most of these elements, i.e., selenium, arsenic, and mercury, are not necessarily toxic to plants, but in small concentrations are toxic to animal life.

Figure 13–2 Threshold values of sodium adsorption ratio (SAR) of topsoil and electrical conductivity of infiltrating water (ec_i) associated with the likelihood of substantial losses in permeability



(d) Sediment

Suspended sediment and bedload material in an irrigation water supply can be a problem. Bedload material settles when transport energy is reduced. Sediment can plug water control structures in open and closed conveyance systems. Suspended sediment can be beneficial, however, for sealing coarse soils in open channel conveyance systems, on-farm ponds, and some irrigated soils. As sediment is deposited with each irrigation and as tillage takes place, additional fines accumulate in the tillage depth. Soil available water capacity (AWC) also increases in the surface layer within the tillage depth.

Suspended sediment that reduces soil intake rates on coarse textured soils improves distribution uniformity with surface irrigation systems (i.e., furrows and borders). Intake rates can be reduced under sprinkler systems, causing surface water translocation and runoff. Sediment in the water supply can cause wear on pump impellers and sprinkler nozzles. In some extreme cases, sprinkler nozzles and bearings must be replaced annually, or more often. Increased nozzle discharge resulting from wear and abrasion must be considered when making water management decisions. A twist drill shank can be used to check nozzle wear. A nozzle is considered worn when a twist drill shank 1/64-inch larger than the stamped size on the nozzle can be inserted.

When irrigation water containssuspended sediment, additional settling, screening, and filtering is necessary for most micro irrigation systems, perhaps to the point that makes management of micro irrigation impractical. Settling basins of substantial size and cyclone sand separators can be used to reduce the size and cost of filtering systems, especially when using sand media filters. See Chapter 6, Irrigation System Design, for additional information on filtration and treatment requirements for micro systems.

(e) Agricultural, industrial, and municipal wastes

Land application of municipal, industrial, and agricultural wastes requires careful planning. The goal should be to recycle nutrients in waste material as fertilizer, in amounts than can be used by the crop, and as a soil amendment that will not degrade soil, water, plant, and air resources. In addition, the soil in the upper part of the profile is an ideal environment for microbiological activity to breakdown many undesirable contaminants.

Because elements and nutrients can occur in high concentrations, it is advisable to use these wastes as supplemental irrigation water in a total water management program. Adequate plant biomass and water must be present to use applied nutrients. The irrigation decisionmaker should know the total chemical and nutrient content of applied wastes and know the amount being applied with each application. For example, most organic and agricultural wastes contain nitrates (NO_3), phosphates (P_2O_5), potash (K_2O), and, in the case of agricultural wastes, high amounts of organic material. All these nutrients are essential for good crop growth. However, when applying agricultural wastes from dairy and other livestock operations to crops that don’t use all of these nutrients annually, accumulation in the soil profile can occur. This accumulation of excess nutrients can be a potential source of surface and ground water contamination especially when excess irrigation water is applied or when excess precipitation occurs. Waste from food processing operations can contain high volumes of salt, organic material, and other chemicals used in processing and bacteria control. Waste from confined livestock feeding also contains salts from urine.

A properly designed and operated sprinkler irrigation system can provide uniform waste application; however, to achieve proper irrigation water management, a separate application system may be required for irrigation. The type of application system depends upon the consistency of the waste and physical site conditions. Size of solids contained in waste affects application patterns for each type of system. During pumping, the concentration of solids may change with time. In some cases, agitation or dilution of wastes before or during pumping may be required.

Manure and wastewater effluents containing less than 5 percent solids are considered liquids. With proper screening these wastes can be applied with almost any sprinkler or surface irrigation system. Application uniformity is a prime consideration. Pump intake screens should be sized with openings no larger than the smallest sprinkler orifice. Slurries containing 5 to 15 percent solids require special pumping equipment and sprinklers with large nozzles (gun types). Slurries can be transported by either tank wagon or pump and pipeline. The viscosity and specific gravity of a slurry or liquid are dependent on the type and amount of solids in suspension. Effects by variations in specific gravity should be evaluated on an individual basis. Waste containing trash, abrasives, bedding, or stringy material is not suitable for sprinkle application unless it is preconditioned by chopping or grinding.

Where practical and suitable for soil conditions, it is recommended slurries be diluted to a liquid consistency before application. Consult NEH, Part 651, Agricultural Waste Management Field Handbook (AWMFH), for quantities of water required to achieve specific dilution requirements. Waste with 10 to 22 percent solids content (semi-solid) can be transported and spread using box type spreaders and dump trucks. Manure with more than 20 percent solids must be handled as a solid waste. Separators can be used to remove solids from the liquid fraction. The liquids can then be applied through most sprinkler systems. The amount of water applied needs to be considered as a part of the total water budget. This is specially the case with liquids and slurries. For more information see the AWMFH.

Organic solids in liquid waste cause a decrease in specific gravity, but a higher viscosity relative to that for clean water. Changes in these fluid properties require net additional energy to overcome the effects of turbulence, velocity head, and pipe friction. The result is an increase in friction head and horsepower requirements. However, pipe friction typically reduces with time. For liquid waste, AWMFH recommends using the same friction factors as those for water, but to increase the power requirement by at least 10 percent.

The effects of viscosity are most pronounced in pipelines when velocities are slow, solids content is high, or long pipelines are involved. Under these conditions, a higher total dynamic head (TDH) is required than when pumping clean water. The overall effect is similar to a throttling valve on the inlet pipeline at the pump. For centrifugal pumps designed for water, the motor will not overload because the decrease in flow rate tends to decrease horsepower requirement. However, with an increase in viscosity, cavitation is more likely to occur because of the higher required net positive suction head (NPSH). Cavitation occurs when NPSH available is less than required, leading to the formation of vapor pockets in the liquid, typically near the eye of an impeller or around sharp obstructions in the suction pipeline. The collapse of these pockets causes the noise associated with cavitation (sounds like gravel moving through a pump or steel pipeline). Cavitation can damage the pump. The damaged area appears as corrosion.

Generally, where fluid velocities are greater than 3.5 feet per second and solids content less than 7 percent, pipe friction can be assumed to be the same as that for water. Any increase in fluid viscosity, however, creates a higher required NPSH than for water. For pumping slurries, the pump dealer must be provided the percent solids as well as the desired flow rate and pumping head. NPSH should be evaluated for the most viscous fluid condition encountered during the pumping operation. Pipe friction can be evaluated for the average condition. Appropriate specialty pumping handbooks are recommended as a design aid to estimate pipe friction for slurry flow and to calculate available NPSH.

If the same pump is used for pumping clean water and water containing solids, the pump will operate at a different efficiency for each liquid. Selecting the most efficient pump for dual application depends on determining: total volume of clean water, total volume of wastewater, solids content of the wastewater, desired flow rate, and total dynamic head. Knowing these factors allows the pump engineer or dealer to select a pump that has the highest average efficiency for the two conditions.

(1) Application rates and amounts

To avoid excessive runoff or ponding, application rates cannot exceed the soil intake rate and soil surface storage. Under sprinkler systems, exceeding the soil intake rate and soil surface storage decreases application uniformity resulting from translocation of water on the ground surface. The result is low areas receive disproportionate amounts of water and nutrients, and deep percolation probably occurs in these areas. Design application rates should be guided by local experience and the maximum clean water application rate values displayed in chapter 2 of this guide. Soil intake characteristics for clean water and water containing waste are different.

Application of organic solids, contained in municipal, industrial, and agricultural wastes reduces soil infiltration rates. Appropriate management and associated cultural practices should be used to offset this effect on most soils.

Maximum quantities of waste application should be based upon the seasonal crop nutrient requirement. In addition, waste applications should be timed such that the applied nutrients are available when needed by the crop. When the field receiving waste is irrigated, total water applied (wastewater + effective precipitation + irrigation) should not exceed available soil-water storage in the crop root zone. This avoids excess leaching and runoff.

Water and nutrient budgets can be used as planning tools in evaluating this aspect. Crop evapotranspiration and net irrigation requirements for various crops are displayed in chapter 3. A nutrient analysis of the waste and the knowledge of how much of each nutrient is being applied are highly recommended to the irrigator. How the waste is handled, stored, and applied somewhat dictates the availability of nitrates. Nitrates can be easily lost to volatilization and denitrification, whereas through careful handling and application, more of the nitrates can be made available for crop use.

(i) Sprinkle irrigation systems—Both gun types and conventional sprinkler heads can be used for application of liquid agricultural wastes. Large nozzle gun types are also well suited to application of waste slurries. Slurry application uniformity can be a problem. Application systems can be continuous or periodic move. Screening is necessary when using conventional set type sprinkler systems, generally because the nozzles used are smaller. With any system, lower flow rates (slower velocities) near the ends of laterals can lead to the settling of solids. Pumping clean water for 10 to 15 minutes following waste application helps to minimize this problem. Handmove systems are not recommended for waste application because of the physical contact with effluent. Pipelines should be drained or protected from freezing during cold weather.

(ii) Surface irrigation systems—Surface irrigation systems, typically furrows and borders, can be used to apply waste if good application uniformity of both waste and water is obtained. Runoff and ponding must be prevented. Runoff containing waste can contaminate surface and ground water.

(iii) Micro irrigation systems—Screening and filtration requirements typically render micro irrigation systems unsuitable for most waste applications.

(2) Major management concerns

Waste should be applied uniformly and in a manner that prevents runoff or excessive deep percolation. Nutrients in applied waste should not exceed crop usage with allowance for application losses; i.e., denitrification. Proper application rates and timing are essential to meet these considerations. These concerns should be addressed in the selection and design of the irrigation application system and in the operation and maintenance plan.

Where the goal is to maximize the utilization of nitrogen, applying the waste in the first half of the irrigation application period helps to incorporate the nitrogen and decrease denitrification losses. Where the goal is to protect ground water or surface water supplies from excess nitrogen, applying clean irrigation water before the waste increases volatilization losses and maintains nitrogen in the upper part of the plant root zone. Both cases require good water management. Apply only the amount of water the soil can hold within the plant root zone. Allow for expected precipitation.

Odors from animal waste (manure) and some municipal or industrial waste being applied through sprinkler systems can be a major problem. Where possible, select locations downwind from neighbors or heavily traveled roadways. Avoid application on hot or humid days or when the wind direction is toward these areas. Visiting with the neighbors regarding the least offensive time for applications is a good management practice.

Sprinkler applications of manure and wastewater should be followed with at least a 10- to 15-minute flush of clean water to clear solids from the pipelines. Deposited solids can reduce flow capacity and accelerate corrosion of aluminum and steel pipelines. Deposited solids can also dislodge during subsequent applications to cause clogging of even the largest sprinkler nozzles. Clean water flushing also washes solids off plant leaves, preventing ammonia burn during hot weather.

The following management strategies may be appropriate for protection of ground water from excess deep percolation of nitrates:

(i) Deficit irrigation**—**During the irrigation in which waste is applied, deficit irrigation (not completely filling the plant root zone) is a good management practice. This reduces opportunity for deep percolation because of application nonuniformity. To use this strategy, the operational flexibility of the irrigation system must accommodate a shorter time between irrigation applications. The amount of deficit irrigation should be based upon local precipitation patterns, crop rooting depth, and water holding capacity of the soil.

(ii) Reduced application**—**Apply only part of the waste allowed for a single application, reserving the rest for a later application, but within the period in which the plants take up nitrogen and other nutrients. The sum of nitrates and other nutrients for all the applications should not exceed the crop uptake after losses are considered.

(iii) Irrigation water before wastewater—Apply irrigation water before wastewater, reserving enough clean water for a 10- to 15-minute flush of pipelines. This helps keep nitrates in the upper part of the plant root zone.

(3) Other management considerations

Provide timely and correct maintenance of equipment is a good management practice. Application of wastewater is frequently done during the non-irrigation season. Winter storage and maintenance are crucial factors in assuring that the system functions throughout the next season. Rodents nesting in open pipes or control boxes, plugged pipelines, and undrained pipes that have frozen and burst are common problems.

See NEH, Part 651, Agricultural Waste Management Field Handbook, Chapter 11, Land Utilization, for land application of agricultural wastes through irrigation systems.

For planning and design of land application of municipal wastewater through irrigation systems, see the United States Environmental Protection Agency's (USEPA) publication, Process Design Manual, Land Treatment of Municipal Wastewater. October 1981 (including Supplement on Rapid Infiltration and Overland Flow, October 1984), EPA 625/1-81-013 and 013a. Additional local design procedures and regulations may also apply.

(g) Miscellaneous

Other water quality problems that may arise in specific locations need to be considered when planning irrigation systems. They can include:

- Extreme temperature water
- Tailwater
- Drainage effluent
- Pesticides
- Toxic ions (i.e., salts), heavy metals, and other elements not normally found in waste effluent

(1) Extreme temperature (hot or cold) water

Geothermal water can generally be used without cooling when using a moderate to high pressure sprinkle irrigation system. Water that is sprayed through the air will be close to or below ambient air temperature when it strikes the ground surface or crop canopy. When applying hot water through a low pressure sprinkler, micro, or surface irrigation system, the hot water generally must be cooled so that the plant crown and tubers close to ground surface are not cooked. Pump design should consider water temperature where it is above 90 degrees Fahrenheit.

Geothermal water may also contain undesirable chemicals, such as boron, chloride, sodium, sulfur, and heavy metals. Therefore, a water quality test is necessary before using it for irrigation purposes. Some of these chemicals can be toxic to a wide variety of plants, animals, and humans.

Irrigating soils with extreme cold water (or excess amounts of water) can delay soil warm-up, thereby retarding plant growth. In some areas glacier melt or snow melt is available during most of the growing season. A 4 to 8 degree Fahrenheit decrease in soil temperature in the upper 6 to 8 inches of the soil profile have been measured after applying 3 inches of 54 degree Fahrenheit water with surface systems. This temporary drop in soil temperature may be short (4 to 16 hours), but it can retard plant growth during the cool down period. Sprinkle irrigation can help warm cold water if ambient air temperature is higher than the temperature of the water. Applying too much irrigation water early in the growing season (or for frost protection when the ground surface is bare) can retard plant growth because of excess soil surface evaporation and excessive water in the plant root zone.

(2) Tailwater (surface runoff)

Where the opportunity exists and is legal, tailwater from irrigated fields can be reused as a water supply or to supplement existing supplies. Runoff water from irrigation can contain nutrients, sediment, pesticides, and in some areas nematodes. Use of water containing these contaminants may be restricted. For example, runoff from a field irrigation system used to apply fertilizers and pesticides cannot be used on fresh vegetables, but can be used on many field crops. It is preferred to reuse this water for irrigation of field crops rather than allow it to return to public water. Tailwater reuse can improve onfarm irrigation efficiency and reduce use of high quality water.

Sediment in tailwater, often resulting from irrigation induced erosion on highly erosive soils, can degrade downstream surface water for public recreation, municipal water supply, wildlife, and fishery uses. It may also be undesirable for irrigation purposes because of sediment deposition problems in conveyance systems. Technically, tailwater reuse on the same or downslope field should be a part of every surface irrigation system. Except for closed level basin, border, or furrow systems, runoff is necessary for best irrigation uniformity. Blocked ends can improve application uniformity on nearly level fields where ponded water covers the lower fourth to third of the field. On steeper fields, blocking furrows and borders to limit runoff generally increases deep percolation. Level furrows and basins in arid areas typically have no runoff.

(3) Drainage effluent

Internal drainage and removal of drainage water used for leaching (for salinity control) are essential. However, disposal of effluent can be a problem. Disposal alternatives include:

- Discharge into salt sinks (ocean, salt basins, underground saline aquifers)
- Discharge into a waste disposal operation.
- Reuse on cropland by irrigating high salt-tolerant plants.
- Discharge into an onfarm evaporation pond
- Reclaim salt(s) for use in the United States salt market (livestock feed, food processing for human consumption, industrial).

By far the best solution is good onsite water management to minimize the amount of effluent to be disposed, but yet maintain proper soil salinity control in the plant root zone. Drainage effluent can contain naturally occurring soil elements. Some of these elements (i.e., boron, selenium) can be toxic to wildlife.

Drainage effluent from salinity control irrigation management can contain high concentrations of salts and is unsuitable for reuse on most common crops. It has been demonstrated, however, that drainage effluent from fields with intensive salinity control can be used for irrigation of very high salt-tolerant plants (agroforestry). Incorporating crop residue containing salt returns the salt to the soil, perhaps with very little, if any, net salt removal. Some of these plants are commercially useful and can be grown economically and irrigated with very high salt concentration drainage effluent. When irrigating high salt-tolerant plants, good internal drainage and removal of excess water used for leaching for salinity management are also essential. The final, smaller volume of drainage effluent with a very high salt concentration is typically discharged into an onfarm evaporation pond. The remaining salts can then be mined. High salt-tolerant plants are listed in table 13–4.

Research has also demonstrated that certain trees and halophytes are useful in the uptake of selenium from the soil water. The trees include:

- Eucalyptus
- Casuarina
- Athel

The halophytes include:

- Quail bush (atriplex)
- Iodinebush
- Fivehook bassia
- Jose tall wheatgrass

(4) Pesticides

Pesticides and their metabolites can be highly toxic to humans and wildlife. Some are persistent and mobile in water. Excessive irrigation water application and precipitation that leaches below the plant root zone can carry these contaminants into ground water. Tailwater (surface runoff) containing these contaminants may be suitable for reuse to irrigate many crops, but even small concentrations may be hazardous to fish, water fowl, wildlife, domestic animals, and humans. Operating irrigation systems is difficult without coming in physical contact with the irrigation water or without having small areas of standing water within or near irrigation operations. Surface water attracts wildlife in a wide range of species and sizes.

Table 13–4 High salt-tolerant plants

Plant	Notes
Tolerance level: EC_i = 8 to 10 mmho/cm	
Eucalyptus trees	Used as biomass for organic fuel fired power generating plants.
Casuarina trees	Is not frost tolerant.
Athel	Used in windbreak plantings.
Tolerance level: EC_i = 20 to 35 mmho/cm	
Fivehook bassia	
Saltgrass	Useful as ground cover in windbreaks or for erosion control.
Jose tall wheatgrass	
Cordgrass	
Fat-hen	
Red sage	
Tolerance level: EC_i = > 40 mmho/cm	
Iodinebush	
Quail bush (atriplex)	

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