8. EXPERIENCES USING WATER OF VARIOUS QUALITIES

8.1 INTRODUCTION

Marginal and poor quality water is being used in several places in the world. Its use requires careful management to prevent or cope with the potential problems related to the water. Often this water is the only supply available and while crop yields may not be at a maximum, they continue to provide an economical return. In other instances, agriculture may have to re-use wastewater from both agricultural and urban sources. Awareness is growing that this wastewater must be treated and returned to supplement the main water supplies. Most of this wastewater, while degraded, is still usable and its utilization often reduces the total volume of wastewater that must be disposed of ultimately. Many irrigation projects will be faced with this re-use problem as competition increases for existing supplies.

The following summaries are of cases where such water is being successfully managed and used for crop production. The summaries are not meant to be in-depth reviews, but point out successful experiences and give references, so that the reader can judge and decide whether any of the concepts are worthy of trial in his own situation. The reader should guard against directly transferring other experiences without a thorough evaluation and field testing under local conditions. Each of the following experiences refers to a specific water quality analysis which is listed in the table, Annex I, at the end of the text.

8.2 PROTECTION OF IRRIGATION WATER QUALITY - Sacramento-San Joaquin Delta, USA

The Sacramento-San Joaquin Delta in California, USA, is the confluence of California's two largest rivers: the Sacramento River flowing south and the San Joaquin River flowing north. The Delta is a vast lowland, freshwater area which is subject to tidal intrusion from the Pacific Ocean through the San Francisco Bay. Two major water distribution systems, the Delta-Mendota Canal and the California Aqueduct, withdraw water from the Delta for agricultural and municipal use elsewhere in California. If the water withdrawals become excessive, the salinity of the remaining Delta water increases as seawater intrudes further into the Delta due to tidal action. In addition, most of the natural San Joaquin River flow into the Delta from the south is diverted upstream and the flow in the lower river for a greater part of the year consists mostly of irrigation return flows and drainage water which eventually reaches the Delta. Export of Delta water must be carefully controlled to match inflow to the Delta to prevent water quality degradation from seawater coming from the San Francisco Bay.

The Delta area has about 230 000 hectares of some of the world's most productive land. A significant portion of this irrigated land, including 60 000 hectares of organic (peaty muck) soils, is irrigated mostly by subsurface irrigation. Because of the increasing salinity in the Delta water, there is concern that maize, a major Delta crop, will suffer yield losses due to salinity. If water salinity increases, it becomes increasingly difficult to control soil salinity using subsurface irrigation. An intensive field trial was conducted in the Delta to establish tolerance of maize to salinity under subsurface irrigation management and to compare subsurface irrigation with sprinklers as a satisfactory form of management for salinity control and continued production of maize on the organic-peat soils. The field trials showed that the salt tolerance of maize was not appreciably affected by the method of irrigation as long as sufficient leaching could be achieved to control salts below the threshold level at which yield loss occurs. The 400 mm winter rainfall was generally adequate to leach surface soils free of salts and allow good seed germination. In the absence of sufficient rainfall, leaching by sprinklers or surface flooding is needed to assure germination.

An important finding of the trial was that subirrigated organicpeat soils did not show the same relatively constant degree of concentration of applied salts in the irrigation water as occurs with mineral soils (Table 3), regardless of whether sprinkler or subirrigation is used. The concentration factor for applied-water salinity to soil-water salinity for the Delta peat soils varied with the concentration of salts in the applied irrigation water. Figure 24 illustrates the change in the concentration factor for the Delta peat soils. At low water salinity the concentration factor is relatively high, but it decreases as water salinity increases. References include: United States Bureau of Reclamation (1980); Hoffman **et al.** (1983); Prichard **et al.** (1983); and Maas and Hoffman (1983).

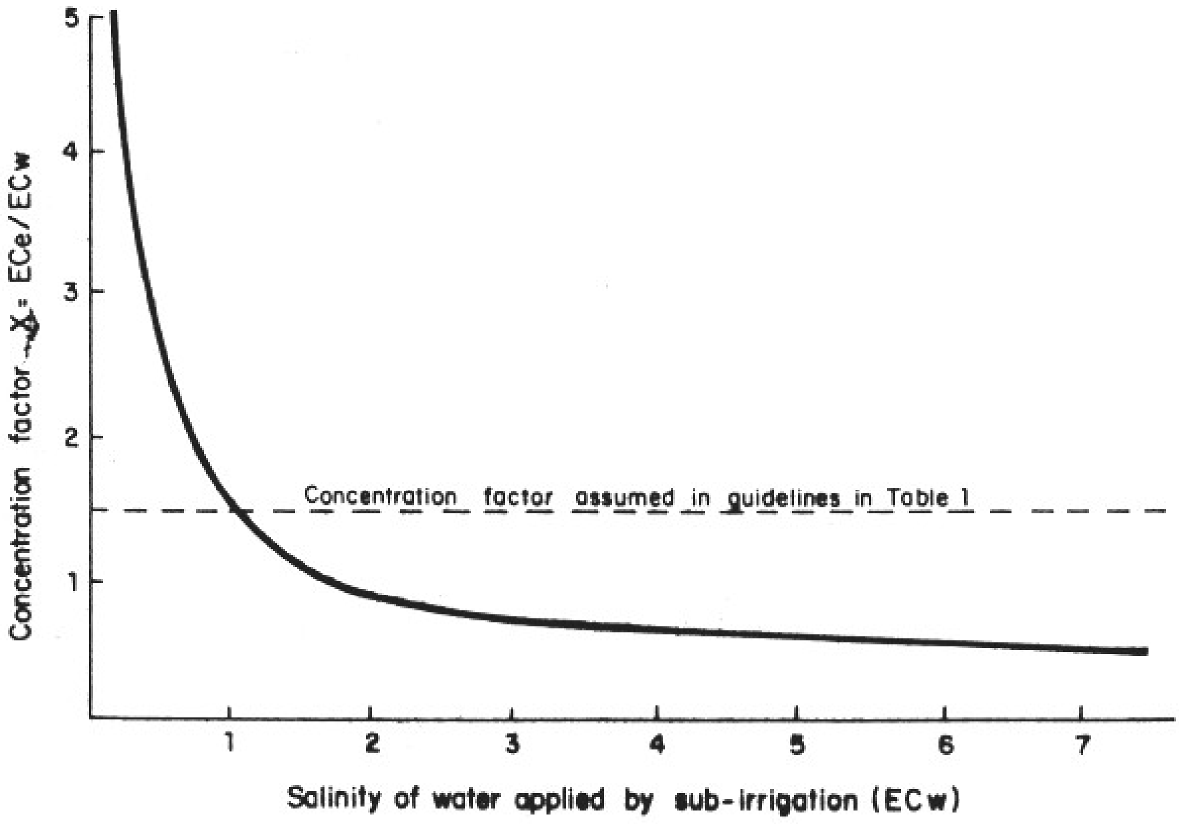

Fig. 24 Concentration factor from applied water (EC_w) to soil salinity (EC_e) under subirrigation on organic peatland in the Sacramento-San Joaquin Delta, California, USA (Prichard **et al.** 1983)

8.3 RE-USE OF AGRICULTURAL DRAINAGE WATER - Broadview Water District, USA

The Broadview Water District lies on the western side of the San Joaquin Valley in an area that receives less than 100 mm of annual rainfall. This 4600 hectare district receives surface water from the Delta area of California (ECw 0.3–0.5 dS/m) through the Delta-Mendota Canal and applies approximately 0.95 metres per hectare, of which about 50 percent comes from the surface water supply and 50 percent from drainage water recirculated back into the irrigation canals. A typical analysis of the surface water, the recycled drainage water and the blended water are given in Annex I (nos. 210–212). Until 1982, this district did not discharge any of its surface return flows and since 1956 has been re-using all of its subsurface drainage water. The blended supply is considerably degraded in quality, particularly as regards salinity, boron, sodium and SAR.

The blending of water has resulted in an increased water supply to lands within the district but crops grown must be selected for tolerance to the blended water. As time has passed, the quality of the blended water has deteriorated and the cropping pattern has changed. From 1960 to 1975, the district averaged about 40 percent of the land cropped to tomatoes; by 1980, no tomatoes were planted due to yield losses caused by salinity. Crops now grown include a much larger proportion of barley and cotton, both being crops more tolerant to the salinity than tomatoes. Continued recirculation of all the drainage water causes concern regarding salt build-up. Since 1982, the district has been discharging about 20 percent of its tile drainage water in an effort to improve the blended water quality. References include: Tanji (1976; 1977).

8.4 USE OF AN EXCEPTIONALLY LOW SALINITY WATER - Friant-Kern Canal, San Joaquin Valley, California, USA

The Friant-Kern Canal transports irrigation water from the San Joaquin River, delivers it to farms along the east side of the San Joaquin Valley and extends from near Fresno to areas to the south of Bakersfield, a distance of 250 km.

The water is mostly snowmelt runoff, stored behind Friant Dam for later release for irrigation. Salinity is exceptionally low with the ECw ranging between 0.05 and 0.01 dS/m which often causes severe water infiltration problems on soils planted to moisture sensitive crops like potatoes and citrus. The water SAR by itself is not high enough to account for the poor rates of infiltration observed (SAR = 0.5).

For a potato crop, gypsum applied and disked into the soil at rates as high as 10 t/ha/year has resulted in a greatly improved rate of infiltration. Likewise, water-applied gypsum administered nearly continuously at a rate sufficient to raise the water calcium content to 2 to 3 me/l Ca has also been effective.

In a few cases, a limited quantity of an alternative, higher salinity well water has been available. In these cases, it has been possible to use the well water on the potato crop and canal water on the deeper rooted, less moisture sensitive crops like cotton, grapes and tree crops.

The Friant-Kern Canal water analysis is included in Annex I as San Joaquin River at Friant, California (see water analysis no. 230).

8.5 HIGH BICARBONATE WATER USED FOR OVERHEAD SPRINKLER IRRIGATION - Denver, Colorado, USA

Cut flowers are grown principally in glasshouses. In Colorado, USA, cut flower growers must contend with a moderately high bicarbonate concentration in their irrigation water. Wells supply their irrigation water and typical chemical analyses of two such wells are given in Annex I (nos. 228 and 229). Although the bicarbonate concentrations are moderate by agricultural criteria (Table 1), they present quality problems for marketing of a product that must have an attractive eye appeal and few blemishes. The Colorado flower growers believe that the bicarbonate ion is the cause of white deposits on leaves if they are watered by overhead spray and that it also causes plugging of localized (drip) irrigation emitters. In addition, the higher water pH accompanying the bicarbonate interferes with other ion uptake and it is thought that this may even be toxic itself to roses. From Table 11, Ca_x is at a deficiency level.

The Colorado growers do not now water any flower crop with overhead sprays. Their experience is that even with the moderate bicarbonate concentrations, overhead sprinkling or misting that wets the foliage invariably results in unsightly foliage and, in some cases, foliar damage. For overhead misting of cut flowers for market, they feel total salinity cannot exceed 0.10 dS/m (personal communication, Hanan 1980).

Most growers use spray irrigation systems which apply water to the base of the plant. Many growers are shifting to localized (drip) irrigation systems which have the advantage of not wetting any foliage. These systems are not without management difficulties; they are prone to blockage from slimes and from precipitation of carbonate or fertilizer salts. One corrective measure used to reduce HCO_3 is to reduce the water pH and reduce the bicarbonate by adding an acid. Growers feel that the sulphuric acid (H_2SO_4) raises the total salinity unnecessarily since 1 me/l of SO_4 is sufficient to meet plant requirements. If nitric acid (HNO_3) or phosphoric acid (H_3PO_4) are used, these not only lower the pH but also supply a needed fertilizer element (NO_3 -N or PO_4 -P). These growers use 1 equivalent of acid for each equivalent of bicarbonate. None of these acids are easy to work with but if controlled to add only what is required to change the pH to about pH = 6.5, they present little danger to metal piping systems and materially reduce the HCO_3. References include: Hughes and Hanan (1978); Schekel (1971); Hanan (1973; 1976).

8.6 USE OF POOR QUALITY WATER - Bahrain

Bahrain is an island nation off the east coast of Saudi Arabia and has an arid climate that is modified by maritime influences. The main characteristics of the climate are high summer temperatures (May-October), mild winters (November-April), high relative humidity, irregular and scant rainfall (average 70 mm) mostly in winter, and persistent winds prevailing from the northwest.

The cultivated land totals about 3700 hectares principally on the northern part of the main island. Farmers grow a wide range of crops. Date palms are most widely planted, followed by alfalfa and vegetable crops. These include tomato, cabbage, cauliflower, eggplant, peppers, celery, onions, and carrots in the winter months and melon and okra in summer.

The salinity of the groundwater used for irrigation varies but is generally high. In a survey of 47 farms, irrigation water salinity was found to range from 3.25 to 4.95 dS/m (nos. 141–144 in Annex I). In spite of the high salinity, boron was low to moderate (0.4–1.2 mg/l). Most farms surveyed were devoted to vegetable production. Because of the salinity, maximum yields of vegetable crops are not possible, but better yields could be obtained if proper attention were given to leaching and more frequent irrigation.

Experiments and trials are now underway to determine whether vegetable yields can be improved by use of greenhouses or plastic tunnels. Results to date show promise (Amer 1983). The main concern with using the present irrigation water is both salinity and sodium toxicity. In Bahrain, sodium toxicity appears to be less than might be expected, perhaps due to the abundance of calcium from carbonates and gypsum present in the soils. Boron toxicity is not expected to become a problem since most of the vegetable crops grown are sufficiently tolerant or semi-tolerant to the existing concentrations of boron.

8.7 DRAINAGE PROBLEMS - Imperial Valley, California, USA

The Imperial Valley lies in the Colorado Desert adjacent to Mexico and separated from the Gulf of California (100 km to the south) by the wide Colorado River delta (maximum elevation about 12 metres). Much of the irrigated area of the Imperial Valley is below sea level. Water diverted from the Colorado River near Yuma, Arizona, flows through the All American Canal by gravity (100 km) before delivery to the farmers is the Valley. Delivery from the main canal to the individual farms is through a very extensive network of open, lined and unlined smaller canals.

The Imperial Irrigation District maintains the system, controls the water and schedules deliveries. The water is supplied “on demand”, meaning water is ordered by the user by written or telephoned request for a desired flow for a requested number of days beginning on the desired date for delivery. For example, 100 litres per second for a period of three days might be a typical water order for irrigation of a field of 20 ha planted to alfalfa.

During the early years of development (1905–1930), seepage from canals and inefficiencies of irrigation caused damaging water tables to form rapidly and place much of the best land in jeopardy due to salinity and waterlogging. Without adequate drainage, production declined and the future of the Valley looked very hazardous.

To solve the drainage problems required an extensive, valleywide network of deep (2 to 6 metres) open drains and equally extensive on-farm buried (tile) drains to control the on-farm water tables. With the water tables under control and stabilized at depths below 2 metres, leaching to remove salts and achieve a favourable salt balance became possible. Today most of the Imperial Valley farms are tile drained (tile spacing is 60–120 metres between tile lines; depth of lines is 1.5–2.7 metres). Drainage effluent from the farm drainage system discharges to a district-maintained open drain and flows by gravity to the Salton Sea, a naturally occurring salt sink in the trough of the Valley where it can only evaporate. (Salton Sea elevation is about -70 m.) The on-farm drainage systems and the extensive network of main and collector drains allow the Valley to maintain a long-term salt balance.

Farmers soon learned that with adequate drainage, salts could be kept under control and a wide variety of crops could be successfully grown. They include alfalfa, vegetable crops (lettuce, carrots, asparagus, onions, sweet corn, and others), fruit crops (cantaloupe, watermelon, citrus, dates, table grapes), winter grown cereals (barley and wheat), and many other important crops such as cotton, sugarbeets, sorghum and Sudan grass.

Most of the irrigation is by surface methods (strip-check or border-check, furrow, and basin). One of the most difficult problems to manage is the high salinity during germination of salt sensitive crops. For such crops, like lettuce, solid set sprinkler systems capable of low application rates of water (2.5–5 mm/hour) are placed in the field and turned on once or twice a day to wet and keep surface soils moist during germination and early seedling growth. This daily wetting continues for perhaps 10 to 14 days after which the sprinklers are removed to another field to repeat the procedure. Irrigation following this initial sprinkling is the standard surface method (flood or furrow).

Colorado River water (the irrigation source water) has an ECw ranging from 1.1-1.4 dS/m and an SAR = 3.1 (see nos. 219 and 235 in Annex I).

8.8 NEED FOR DRAINAGE - Tigris-Euphrates River Basin, Iraq

The Tigris-Euphrates River Plain is an area that suffers with both salinity and high water tables. This is one of the oldest known irrigated areas of the world. River water salinity for most of the irrigated area is low (ECw = 0.3–0.7 dS/m); however, salinity still became a problem. Records indicate that salinity problems were present in some areas by 2400 BC and farmers were turning from wheat to barley because barley was a more salt tolerant crop. In other areas of the Plain, salinity problems were delayed until about 100 BC (Jacobsen and Adams 1958). Early irrigators apparently understood the advantages of irrigation but did not understand the need for areawide drainage.

Most of the Tigris-Euphrates Plain today is severely troubled with both salinity and high water tables. Since the natural water quality of both the Tigris and the Euphrates has been excellent, salinity should normally not be a problem (see water analyses nos. 164 and 166 in Annex I). However, with inadequate drainage and the resulting high water tables that developed, there was no way to control and permanently leach any significant portion of the salts being applied in the irrigation water. Salts slowly accumulated and productivity declined. Drainage and reclamation projects are now being implemented and the area will no doubt again become a very productive agricultural area (Dieleman 1963).

8.9 HIGH SALINITY WATER USE - Arizona, USA

The State of Arizona has very little surface water for irrigation use and must rely on well water pumped from the underground water table, much of which is relatively saline. The Safford Experimental Station of the University of Arizona is a principal research facility in this State for developing ways to utilize higher salinity irrigation water under a hot, dry (arid) climate. Soils on the experiment station are clayey and saline. The groundwater used for irrigation during the cropping season ranges in quality from ECw = 3.1–3.5 dS/m and an SAR = 14 (no. 221 in Annex I). Crop yields reported from tests conducted at the station with cotton, barley, sugarbeets and safflower are reported in Table 33. These yields are also compared with statewide averages. In most cases, the yields from the experimental trials equal or exceed the average yield for these crops grown on commercial farms throughout Arizona.

Red Mountain Farm, a commercial farm near Dateland in southwest Arizona, uses well water ranging in salinity (ECw) from 3–11 dS/m. Soils are sandy. A survey of four fields conducted in 1982 indicated that three of the fields (Field Nos. 4, 10 and 14) were irrigated from a single canal receiving water from wells ranging in salinity (ECw) from 3–8 dS/m. The fields were planted to cotton and germinated using water from the lower salinity wells with alternate furrow irrigation.

Table 33 SELECTED CROP YIELD FROM THE SAFFORD EXPERIMENT STATION AS COMPARED TO AVERAGE FARM YIELDS[1]

Crop		Yield	Statewide Average
Cotton	(1970)	1258 kg/ha	1120 kg/ha
Barley	(1972)	4117 kg/ha	3214 kg/ha
Sorghum	(1971)	7820 kg/ha	4892 kg/ha
Sugarbeet	(1972)	56.0 t/ha	56.7 t/ha

[1]From Dutt **et al.** (1984).

Table 34 RED MOUNTAIN FARMS LINT COTTON YIELDS (kg/ha)[1]

	Field			
	4	10	14	29
Replication 1	1507	1076	1022	1022
2	1668	1076	807	1130
3	1345	861	807	1130
4	1937	967	700	1076
Average	1614	995	834	1076
Statewide Average (kg/ha)	1238			
Applied Water Salinity (EC_w dS/m)	6.2	4.5	4.0	11.1

[1] From Dutt **et al.** (1984).

Irrigation after germination was with water from all wells. Seasonal average salinity of the water used and lint cotton yield is given in Table 34 for each field.

The fourth field (Field No. 29) was also planted to cotton but germinated and grown on well water with ECw = 11 dS/m. Yield of lint cotton for field 29 is also included in Table 34.

From Table 4, a water of ECw = 6.2 dS/m should be capable of producing a better than 90 percent yield and a water of ECw = 11 dS/m should be capable of at least a 50 percent yield. On that basis, a full yield from field 4 would be about 1800 kg/ha and from field 29 about 2200 kg/ha. Both these projected maximum yields are approaching reported good near maximum lint cotton yield from other areas where there are no limiting factors to production (2300–2500 kg/ha of lint cotton).

8.10 USE OF AGRICULTURAL DRAINAGE WATER FOR PRODUCTION OF SELECTED CROPS - Imperial Valley and San Joaquin Valley, California, USA

In certain areas of both the Imperial Valley and San Joaquin Valley of California, an existing high water table (less than 1 1/2 metres) must be controlled and stabilized in order to achieve and maintain acceptable yields of adapted crops. Covered tile drain lines have been installed at about 2 metres depth with distances between lines varying from 30 to 120 metres. Drainage water is collected in open drain ditches and flows downslope to an acceptable disposal area.

Collection and transport to a distant disposal area is costly and, in some cases, wasteful of a valuable resource - the wastewater itself. Only when it is no longer usable should it go to a disposal site. Typical drainage water is relatively salty (ECdw = 3 to 6+ dS/m), contains appreciable boron (B = 3 to 10+ mg/l) and has a relatively high sodium hazard (SAR = 6 to 20+).

Trials are now underway to test the feasibility of using this highly saline drainage water for production of selected crops. To date, it seems entirely feasible to use much of this drainage wastewater to produce yet another crop. By this means, the final volume of unusable wastewater will be reduced, requiring less extensive transport and disposal facilities.

Strategies are being field tested for use of saline (brackish) drainage water for irrigation of selected salt tolerant crops while still striving to maintain full production potential of the land being so irrigated. Two field tests are underway - one in San Joaquin Valley-Westside (Lost Hills area) started in 1978; the other, in the Imperial Valley, started in 1982 (Oster and Rhoades 1983).

In the San Joaquin Valley test, a cotton crop was germinated and seedlings established using California aqueduct water (ECw = 0.5 dS/m; SAR = 2.9). After this early period, very saline water (ECw = 7.8 dS/m; SAR = 17) was used (nos. 216 and 217 in Annex I). The 1982 cotton lint yield (the fourth year of the test) was 1290 kg/ha as compared to 1570 kg/ha produced using only the low salt canal water. When only the saline water was used for both germination and production, lint yield dropped to 840 kg/ha.

The cotton planting beds were listed prior to the rainy winter season and benefited from leaching rainfall. Then, a pre-plant irrigation followed later by irrigations for germination and seedling establishment further reduced accumulated salinity to allow good germination and seedling establishment before the change-over to irrigating with the saline water. Wheat is to be the next crop, but grown with canal water only to desalinize the soil before again planting cotton (or sugarbeets).

In the Imperial Valley test (started in 1982), two crop rotations are being followed - wheat, sugarbeets and melons in one trial; in the second, cotton for several years will be followed by wheat, and then by alfalfa. For the first trial (wheat, sugarbeets, melons), Colorado River water (ECw = 1.4 dS/m; SAR = 4.9) is being used for preplant and early irrigations of wheat and sugarbeets and for all irrigations of melons. Later irrigations of the wheat and sugarbeets are with Alamo River (drainage) water (ECw = 4.6 dS/m; SAR = 9.9). The detailed chemical analyses of both the Colorado River water and the drainage water from the

Alamo River are given as nos. 219 and 220 in Annex I. In the other trial (cotton, wheat, alfalfa), the cotton is to be grown with the Alamo River (drainage) water for all or part of its irrigations, and the wheat will be irrigated with the better water (Colorado River) to reduce soil salinity sufficiently to allow a normal alfalfa crop to be grown using the usual canal water (Colorado River). To date, one wheat crop and one cotton crop have been harvested and the highest yields were actually obtained in both cases with the treatment which received the greatest amount of drainage water substitution for Colorado River water - 75 and 100 percent respectively (Rhoades 1984a; 1984b).

8.11 USE OF MARGINAL QUALITY WATER - Medjerda Valley, Tunisia

Soil conditions and high salinity of the irrigation water make the lower Medjerda Valley of Tunisia difficult to farm. The Medjerda River flows from west (in Algeria) to east into the Gulf of Tunis in the Mediterranean Sea. About 40 km west of the town of Tunis the river enters a wide coastal plain characterized by heavy clay soils with a lime ($CaCO_3$) content up to 35 percent. The soils have a very low infiltration rate and the low salinity winter rainfall may stand on the surface for extended periods of time. During the growing season, the soils dry quickly and shrink and crack (fissures up to 5 cm wide) and water quickly enters the soil through the cracks until they swell and close.

The quality of the Medjerda River varies considerably during the year (nos. 193 and 194 in Annex I). Table 35 shows the monthly mean salinity during 1962 and 1963. The salinity (ECw) ranges from 1.3 to 4.7 dS/m. The 1962 data represent conditions of a dry year and 1963 a wet year.

Table 35 SALINITY OF THE MEDJERDA RIVER AT EL AROUSSIA, TUNISIA[1]
(monthly mean in dS/m)

	1962	1963
January	3.7	2.2
February	1.3	1.3
March	2.1	2.1
April	2.5	2.2
May	3.2	2.6
June	4.1	3.2
July	4.7	4.2
August	4.2	3.5
September	4.1	2.8
October	3.0	3.3
November	2.4	3.9
December	2.6	2.7

[1] From Unesco (1970).

During much of the year, the Medjerda River water can be used for irrigation of medium to high salt tolerant crops such as date palm, sorghum, forage barley, alfalfa, rye grass, and artichokes. The soil conditions in summer (large cracks) make efficient leaching difficult, while in winter the rainfall only partially leaches salts from the top soil layer of the clayey soils (15 cm). This leaves the soil surface with such poor structure and low infiltration rate (high ESP and low ECe) that leaching the entire profile during this winter period becomes nearly impossible.

The Government of Tunisia and Unesco developed a full field research programme to assess the management needed to farm this area. The results of this programme have been useful in Tunisia as well as other Mediterranean countries that face similar problems of using poor quality water on heavy coastal soils. The main recommendation of the study was for proper timing of leaching to save water and the use of cropping patterns which include crops tolerant to the expected salinity build-up. The management principles developed during the study are transferable to other similar areas. References include: Van't Leven and Haddad (1968); Unesco (1970); and Van Hoorn (1971).

8.12 USE OF POOR QUALITY WATER FOR IRRIGATION - United Arab Emirates

The United Arab Emirates faced a number of problems when developing their national irrigation programme; a scarcity of water, moderate to high salinity in most water supplies, lack of labour, and poor farming practices. The Soil and Water Investigations Unit of the Ministry of Agriculture and FAO/UNDP initiated an extensive field programme in 1976 to improve their irrigation practices. This programme has identified several practices to improve yields while using the high salinity water. A few of these are highlighted here (the water quality is shown as no. 195 in Annex I).

a. Drip irrigation improved the general growth of tomatoes as compared to furrow irrigated tomatoes. These differences were consistent regardless of whether the tomatoes were field seeded or transplanted (Table 36).

Table 36 EFFECT OF IRRIGATION METHOD ON TOMATO YIELD (kg/ha)[1]

Drip irrigation	109 000
Furrow irrigation	65 000

[1] From Savva **et al.** (1981).

b. New lemon plantings showed that sprinkling reduced growth during the first 16 months as compared to bubbler, drip and basin irrigation. Extensive leaf burn and defoliation were caused by the concentrations of sodium and chloride in the irrigation water. Table 37 shows the differences in sodium and chloride concentrations in the lower leaves on trees irrigated by the four different methods. The higher sodium and chloride with sprinklers was attributed to the adsorption through leaves wetted by low angle sprinklers during the early growth stages. Eventually the trees grew above the reach of these low angle sprinklers and growth accelerated.

Table 37 EFFECT OF IRRIGATION METHOD ON SODIUM AND CHLORIDE CONCENTRATION OF THE FOLIAGE OF LEMON TREES [1]
(Dry weight basis)

Irrigation System	Percent Sodium in lower leaves	Percent Chloride in lower leaves
Basin	0.39	0.88
Bubbler	0.28	0.84
Drip	0.39	0.61
Sprinkler	1.50	1.43

[1] From Savva (1981).

c. A comparison of sprinkler and furrow irrigated potatoes showed improved yield resulting from night sprinkling. There was an increase in yield of 77 percent and a water saving of 25 percent due to night sprinkling as compared to day sprinkling. Furrow irrigation at night showed no yield increase. Onions irrigated by sprinkler at night showed yield increases of 25–50 percent as compared to sprinkling during the day. The differences are attributed, in part, to lower toxicity resulting from less leaf adsorption of the toxic sodium and chloride from the applied water.

References include: Savva **et al.** (1978; 1981; 1984).

8.13 IRRIGATION WATER QUALITY - Lake Chad, Africa

Lake Chad is being considered for expanded development including increased diversion of the lake water for irrigation. The lake has always been considered quite unusual because the salinity level in it remains relatively low and stable. The lake is a land-locked sink with no outflow but a continued inflow from rivers discharging into it. These rivers carry varying quantities of salt.

The main river flowing into Lake Chad is the Chari River. The salinity level of the lake is dependent on the river Chari discharges and within the lake there are pronounced regional variations in salinity which chiefly depend on the position in the lake relative to the Chari discharge (Figure 25). Irrigation withdrawal sites must take these variations into account as well as fluctuations in lake levels caused by seasonal changes due to inflows and evaporation.

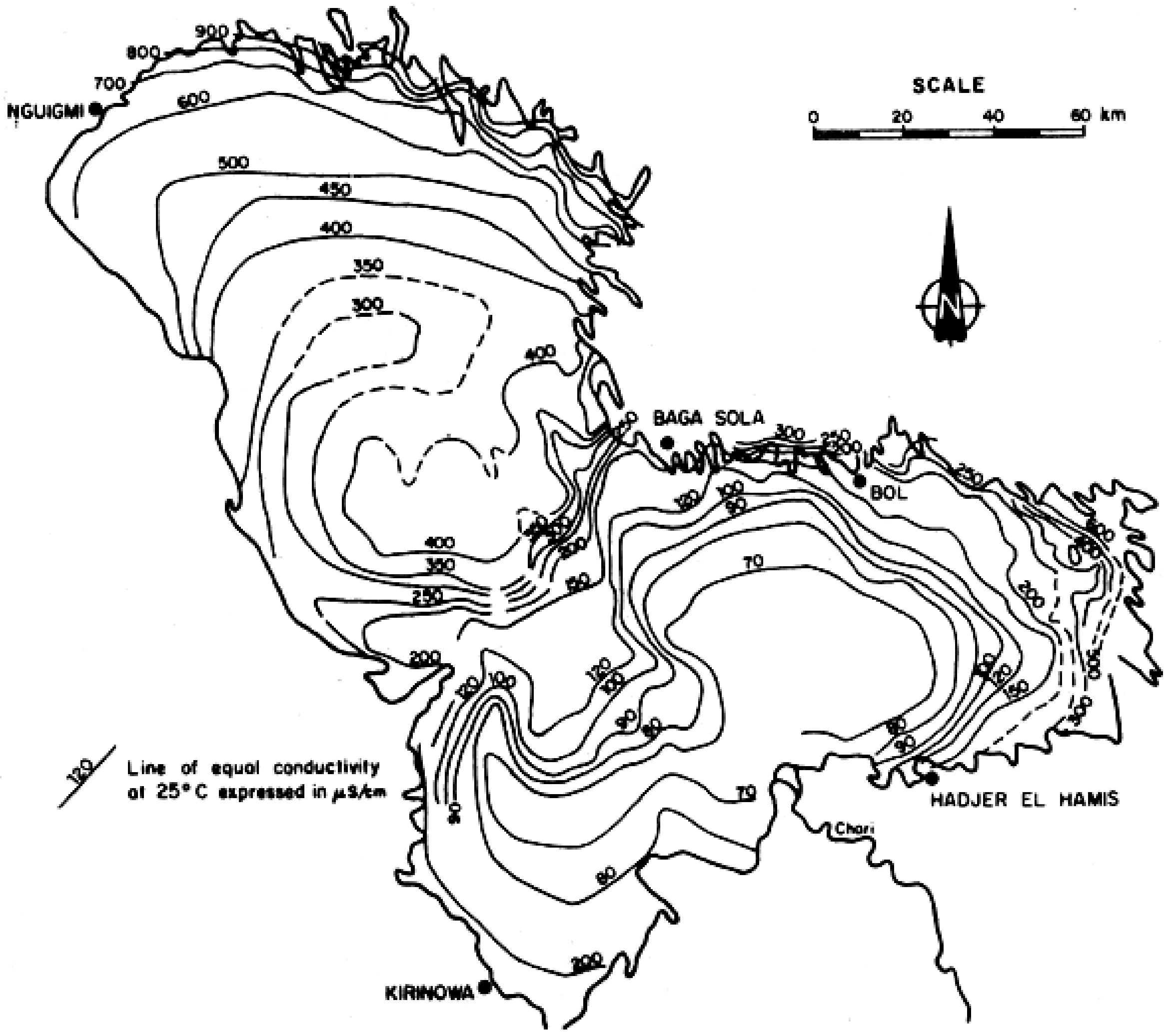

Fig. 25 Electrical conductivity of Lake Chad from 26 February to 10 April 1967 (FAO 1973)

The chemical quality of Lake Chad and two of its inflow rivers, the Ebeji and the Chari, are shown as nos. 3–5 in Annex I. It is interesting to note in Annex I that the inflow river water to Lake Chad and Lake Chad itself show no measurable concentrations of the chloride ion. This, coupled with the known leakage from the lake into local groundwater, may explain why this land-locked lake has not experienced an increase in salinity with time. The groundwater in the vicinity of Lake Chad shows the similar characteristics of high bicarbonate and low chloride. The salinity (ECw) of the groundwater generally ranges from 0.7–1.5 dS/m, except where sulphates are present and then ECw may even exceed 4.0 dS/m. Typical groundwater in the lake area is shown in nos. 6–8 in Annex I (FAO 1969; 1973).

8.14 RIVER WATER QUALITY VARIATIONS - Ethiopia and Somalia

River water quality is often inversely related to flow; dilution due to runoff in the rainy or snowmelt periods usually keeps total salt concentration low. A unique exception is the Wadi Shebelle that originates in the highlands of Ethiopia, flows south through the Ogadan plateau of Ethiopia and Somalia and discharges into the Indian Ocean.

During a greater part of the year the river flow originates mostly from the upper highlands of Ethiopia, which are a basalt formation. River water salinity from runoff originating in this upper catchment area rarely exceeds ECw = 0.75 dS/m and is often well below ECw = 0.50 dS/m (see no. 158, Annex I). With good management, such water presents few problems.

The river quality changes significantly in the periods from late April until early June and again in October and November (see nos. 159 and 160, Annex I). During these periods, river water salinity ranges from ECw = 0.75–2.0 dS/m and occasionally ECw exceeds 2.5 dS/m. The increased salinity in the Wadi Shebelle during this time is associated with high intensity rains that cause runoff from the Ogadan plateau which consists of rock formations of marine origin. The infrequent, high intensity rains on the Ogadan plateau feed the Wadi Shebelle for periods which last up to two weeks following each heavy rain. The water characteristics show a relatively high concentration of gypsum ($CaSO_4$) reflecting the rock formations on the plateau. As cropping takes place on a year-round basis in the river basin, careful management of the high salinity water is needed to ensure continued good crop production. Because most irrigation practices using Wadi Shebelle water are poor and spate irrigation is widely practised, a common management step is to avoid using the Wadi water for several days following increased river flows caused by rainfall in the Ogadan plateau (Ochtman 1975).

8.15 GROUNDWATER DEGRADATION - Wadi Dhuleil, Jordan

The Wadi Dhuleil irrigation scheme is the largest groundwater irrigation project in Eastern Jordan. The project was originally planned for 3600 donums (900 ha) but now comprises 6250 donums (1560 ha). Construction began in 1967 and irrigation began in 1970. The irrigation water supply comes entirely from the groundwater. Water pumped from the Dhuleil - Halabot aquifer was initially of good quality with ECw in the range of 0.4 to 0.6 dS/m. In the northeastern part of the project lower quality water was found with ECw ranging between 1.05 and 1.35 dS/m.

Since irrigation began in 1971 there has been a slow deterioration in water quality. For example, well D-16, which initially showed an ECw of 0.43 in 1971, had risen to ECw of 0.80 by 1974 and to ECw of 2.52 dS/m by 1977 (nos. 170–172 in Annex I). The source of degradation is thought to be salts being leached down to the groundwater by deep percolation of irrigation water. The main sources of salt, however, are lenses deeper in the soil profile and not salt from the root zone. New wells in new irrigated areas show the same degradation trend after a few years of operation.

Salt damage to tomatoes became clearly evident after just a few years. With the increase in salinity in the applied water, the present problem is inadequate leaching to maintain soil salinity within the tolerance of the crops being grown. The wells at present being used cannot suply water in sufficient amounts to meet both crop ET and the leaching requirement in the expanded project area. A lack of adequate supply, coupled with poor irrigation practices has resulted in poor salinity control. Most investigations show that the farmers do not understand the need for increased leaching or the methods and timing of leaching applications. Other alternatives also need to be considered, such as reducing the planted area to allow adequate leaching, sprinkling at night, water applications for leaching in winter, and selecting crops more tolerant to the increasing water salinity (Natural Resources Authority 1978; and Wye College 1975).

8.16 SURFACE WATER QUALITY DEGRADATION - Yemen Arab Republic

Water quality degradation due to sequential use and re-use of a single water supply for irrigation is strikingly illustrated in the stream flow in the upper Wadi Al Hama, near Taiz, in the Yemen Arab Republic. The upper reach of the stream is of excellent quality (ECw = 0.5 dS/m; SAR = 1.0). Much of it is diverted for irrigation of valley lands adjacent to the stream and all drainage, both underground and surface, returns to the stream to be re-used for irrigated lands downslope, but in depleted volume and higher salinity.

Rainfall and runoff from surrounding rocky hillsides is almost entirely diverted for spate irrigation of terraced lands above the reach of the diverted Wadi. No surface runoff reaches the Wadi except during very infrequent periods of intensive rainfall. Within a distance of 25 to 35 km, the Wadi flow drops from an estimated 300 to 400 litres per second to a mere 15 to 30 litres per second and the salinity increases from ECw = 0.5 to near 8.0 dS/m (see nos. 203–207 in Annex I).

Cropping patterns for the irrigated crops change along the Wadi as salinity rises. Relatively sensitive beans, maize and tomatoes give way to the more tolerant sorghum and, finally, reliance is almost entirely on seasonal spate irrigation of maize or grain sorghum using runoff from nearby rocky hillsides (Hazen and Sawyer 1979).

A similar degradation pattern can be seen for other rivers from the data in Annex I: Rio Grande River, USA (nos. 222–227); Pisco River, Peru (nos. 127 and 128); James River, USA (nos. 240 and 241); Euphrates River, Iraq (nos. 164 and 165); San Joaquin River, USA (nos. 230 and 242); and the Tigris River, Iraq (nos. 166 and 167).

8.17 SEDIMENT IN THE IRRIGATION WATER SUPPLY - Ethiopia

The Awash River is the major source of irrigation water for crop production in the middle and lower regions of the Awash River Basin in Ethiopia. The water has been found to be of good chemical quality for irrigation at most of the sampling locations in the upper and middle reaches, with the ECw value ranging from 0.2 to 0.7 dS/m, and specific ion toxicity hazards are practically non-existent. However, the suspended sediment contained in this water has been a major concern to most projects utilizing it for irrigation and other uses.

In the Middle Awash region the sediment load has been monitored for quite some time and results show that the suspended sediment content of the water varies widely, ranging from less than 0.5 g/1 during the dry months (December-April) to about 15–20 g/l during heavy floods.

The two major contributors of suspended sediments to the Awash River in the Middle Awash Region are the Arba and Kesem tributaries.

One of the major irrigation projects implemented recently in Ethiopia is the Amibara Irrigation Project which irrigates 10 285 ha of land through a main canal which has a capacity to carry 13 m^3/sec and is 27 km long. Water is diverted into this canal from the Awash River by means of a rockfill diversion weir, 4 m high and 100 m long. Supply of irrigation water commenced in May 1980, and in March 1981 it was estimated that 23 000 cubic metres of silt had accumulated in the upper reach of the primary canal. This volume occupied most of the canal waterway in the 2 km reach between the headworks and the first offtake. The headworks included a scour culvert which was designed to remove coarser sediment of the bed load entering the intake gates of the primary canal.

In view of the high suspended sediment load and the fact that this cannot be excluded at the intake, a settling basin (a widened canal section, 400 m long) was constructed in the primary canal head reach.

At the end of the first year of operation, sediment deposition in the settling basin and the upper reaches of the primary canal was so great that it was impossible for the project to convey the necessary amount of water at the required time. The most difficult situation encountered was with the control of intake gates which became jammed by silt building up behind them.

Various remedial measures were suggested to improve the situation, such as:

a. construction of silt ejectors;

b. flushing of settling basin; and

c. more frequent mechanical or manual clearing of silt in the silting basin and the primary canal.

All these measures add to the cost of the project and interfere with irrigation operations.

In March 1982, an enormous quantity of silt was excavated from the primary canal from the headworks right through to the last outlet (approximately 20 km), and was piled on the bank. The disposal of the dredged material has not yet been resolved and this will be an added cost to the project.

The present trend shows that de-silting of primary canals is required every year, which means that water supply is interrupted for about 2–3 months each year. Although this is planned during the period from February to April, which is after the harvest of the cotton (the major crop of the project), the unavailability of water is a serious limitation to the farms where double cropping and perennial cropping systems are practised.

Reduced permeability and surface crusting observed in the lowlying areas and along the lower portions of farms are other important ill effects of sediment-rich irrigation water. Surface crusting has been positively identified as one of the causes of poor seed germination in certain fields in the Amibara Irrigation Project.

The operation of sprinklers for pepper nurseries has been seriously affected by the Awash River water. The clogging has resulted in uneven watering and low efficiency, and has increased the cost of operation because of the need for frequent replacement of nozzles.

Another serious problem related to the ‘silty water’ of the Awash is the damage caused to pumping units in some of the ‘old farms’ where gravity supply is not available. The impellers of these pumps wear rapidly and, on average, replacement is required once in 2–3 years.

The experience in the Middle Awash irrigation projects shows that the sediment content of the water is one of the important quality criteria that should be considered in evaluating irrigation water. This evaluation should enable the engineer as well as the farmer to adopt special management practices to minimize the ill effects of sediments in irrigation water or to look for a better source (personal communication, Kandiah 1984).

8.18 HIGH FLUORIDE IN ANIMAL DRINKING WATER - New Mexico, USA

Low fluoride levels (<1 mg/l) in drinking water are beneficial to both animals and humans. High levels (>1.5 mg/l), however, can be harmful and may cause mottled teeth, and at higher concentrations can cause bone problems. The World Health Organization (WHO) Guidelines for Human Drinking Water Quality recommend less than 1.5 mg/l fluoride. Animal drinking water standards (Table 30) recommend less than 2 mg/l fluoride.

The greatest concern in drinking water supplies for animals is that shallow groundwater, commonly a major source of animal drinking water, is frequently of poor quality. Recent surveys in several countries have shown alarmingly high levels of fluoride in some shallow groundwater. For example in the province of La Pampa, Argentina, groundwater contains as much as 3 to 9 mg/l fluoride. In Ethiopia over 200 wells tested have concentrations in excess of 3 mg/l and in one area 30 percent of all wells tested indicated 12 to 30 mg/l fluoride content. In Tanzania, concentrations from 3.2 to 9.2 mg/l have been found, while in Algeria, irrigation and drinking supplies were as high as 6.0 mg/l. Kenya is now checking groundwater supplies throughout the country to determine fluoride levels.

An example of the effects of fluoride in animal drinking water comes from New Mexico, USA. Fluoride levels in groundwater in New Mexico are generally below 1 mg/l but concentrations as high as 3 mg/l are not uncommon, especially in those wells drawing shallow groundwater. A few values range as high as 26 mg/l. Three selected wells from different areas of New Mexico are given as nos. 213–215 in Annex I. Table 38 gives the trace element concentrations (including fluoride) of these wells. It is not uncommon in New Mexico and Eastern Texas, USA, to see examples of mottled teeth in cattle and horses that drink only well water over prolonged periods. The New Mexico State Veterinary Service recently reported on a case of animal drinking water that contained high fluoride levels. Their report summary states:

> “A herd of approximately 200 brangus cattle had difficulty eating. Oral examination of more than 20 animals revealed mottled, eroded, and irregular permanent incisor teeth. The molar teeth were black with irregular table surfaces. Fluoride contents of well water samples are recorded (Table 39). Three of eight water sources from the ranch had fluoride levels above 3 mg/l. Three mg/l fluoride in drinking water can cause chronic toxicity.

Table 38 TRACE ELEMENT CONCENTRATIONS OF THREE WATER SUPPLY WELLS IN SELECTED AREAS OF NEW MEXICO, USA[1]

	Columbus Well No. 1	Clovis Well No. 4	Llano Chimayo Well No. 1
	mg/l[2]		
(As) Arsenic	0.020	-	0.04
(Ba) Barium	<1.0	<0.5	<1.0
(B) Boron	0.34	<0.25	<0.5
(Cd) Cadmium	<0.01	<0.01	<0.01
(Cr) Chromium	<0.05	<0.05	<0.01
(Cu) Copper	0.02	<0.025	<0.025
(F) Fluoride	6.40	2.80	26.00
(Pb) Lead	<0.05	<0.01	-
(Hg) Mercury	<0.0002	-	-
(Ni) Nickel	<0.050	<0.10	<0.10
(Se) Selenium	0.008	<0.01	<0.01
(Zn) Zinc	<0.03	<0.025	0.06

[1] Data from state water records.

[2] < means the trace element, if present, was below this detection level.

Table 39 FLUORIDE IN WELL WATER in mg/l[1]

South Dirt Tank	0.09
East Pino Dirt Tank	0.07
East Selitre Dirt Tank	0.22
East Selitre Well	3.20
East Dirt Tank	0.46
Draw Tank Well	1.98
House Well[2]	3.32
Boot Hill Well	3.03

[1] From Hibbs and Thilsted (1983).

[2] Manager's son has pitted teeth.Horses also had indications of dental fluorosis.

Analysis of tissues from one animal revealed the following concentrations of fluoride: Rib 2400 ppm; metacarpal 1300 ppm; mandible 2015 ppm. Normal fluoride content of bones ranges from 401 to 1221 ppm. Chronic borderline fluorosis occurs with bone concentrations between 1605 and 3788 ppm. The high fluoride content of the bone, the characteristic dental changes, and the elevated fluoride levels in 3 or 8 water sources substantiate the diagnosis of fluoride toxicosis. One or two horses examined had characteristic dental fluorosis. The family dentist informed the manager of the ranch that one son had lesions suggestive of fluoride toxicosis. The highest fluoride concentration was found in water from the well that supplied the house and barn.

The owner of the ranch with this fluoride-contaminated well water could have prevented some of the dental damage by supplementing the diet with calcium, low fluoride phosphorus, and aluminium salts. Slaked lime could also be added to the drinking water. Efforts should also have been made to minimize evaporative concentration in watering areas. The key to this type of toxicosis is prevention. To be undertaken, preventative measures depend on a correct diagnosis including water quality.” (Hibbs and Thilsted 1983; Tijook 1983).

8.19 POOR QUALITY GROUNDWATER FOR LIVESTOCK DRINKING WATER - New Mexico, USA

Shallow groundwater and other sources of poor quality water are often used as a drinking water source for animals. In addition, evaporation at the water point often causes increases in concentration over that of the source water. Two recent case studies (Hibbs and Thilsted 1983) illustrate the need to check the drinking water quality closely against the guidelines presented in Tables 28–30 and Annex I.

Case 1

In early June, calves were weaned from a group of 180 Hereford cows, and the cows were moved to a 1600 hectare section of native grass pasture located in northeastern New Mexico, USA. The water source for the animals was a large metal stock tank supplied from a well. In addition to the stock tank, there was a small shallow lagoon which received the overflow water from the stock tank as well as rainfall runoff from the area around the tank. No creeks or rivers flowed through the pasture. When the cattle were first placed on the pasture, they were driven to the water source and were observed to drink from the tank. During the week following their introduction into the pasture, the cows were observed to be drinking from both the stock tank and the overflow lagoon. The cows received no supplementary feed; salt blocks were available. At the end of the second week the owner observed a large number of dead cows in the pasture.

The day after the losses were first discovered there were 40–50 dead cows and an approximately equal number with signs of marked muscular weakness, mild greenish diarrhoea and moderate dehydration. The owner reported that several affected animals fell into the tank or lagoon when attempting to drink. Muscle fasciculations were evident in many affected animals. The more severely affected animals were in sternal or lateral recumbency. All of those severely affected eventually died. The last death occurred three days after the first losses were discovered. A total of 91 cows died out of the herd of 180.

The preliminary diagnosis was nitrate poisoning. Water samples from both the stock tank and the overflow lagoon were analysed for salts and the sample from the stock tank was also analysed for heavy metals. Both water samples contained very high levels of sodium salts. No significant amounts of nitrates or heavy metals were found (Table 40).

Table 40 SALT AND TRACE ELEMENT CONTENT OF A CATTLE WATER SOURCE[1]

Water Source	Na	Cl	$CaCO_3$	SO_4	NO_3	Se	Ar	Ba	Cd	Cr	Pb	Ag
	mg/l											
Stock Tank	4370	789	612	3361	0.16	0.034	0.028	0.10	0.001	0.034	<0.05	<0.001
Lagoon	21160	3980	597	11983	4.4	ND	ND	ND	ND	ND	ND	ND

[1] From Hibbs and Thilsted (1983).

ND Not Determined

The stock tank water contained 4370 mg/l of sodium. The cattle should have been able to tolerate this level of sodium in the water; however, some animals were observed to drink the lagoon water which had a sodium concentration of 21 160 mg/l. It is hypothesized that evaporation of water from the lagoon resulted in its marked salinity, and that it was consumption of this extremely saline water in the absence of a non-saline water source which precipitated the episode of salt toxicosis.

This case illustrates the danger of providing saline water as a sole water source for cattle. The previous winter a group of steers had been grazed on this pasture with no problems. However, a second well had been in operation and the winter temperatures were much lower. It is interesting to note that a similar episode of heavy loss had occurred in the same pasture 5-years earlier. The water was suspected to be responsible for the losses at that time but a definitive diagnosis was not made.

It was recommended to the owner that the lagoon be drained and a new water supply be provided for the pasture.

Case 2

Approximately 200 head of yearling Hereford calves of both sexes were confined to a feed lot at the Agua Negra Ranch in New Mexico, USA, and fed alfalfa hay and a commercial protein supplement which contained a 'self-limiting' feed ingredient (1.5 percent organosulphate). The formula was not an open formula so the source of the sulphate is not known. Water was supplied in a tank from a well.

Thirty-one cattle developed signs of polioencephalomalacia; nine animals died. The protein supplement was removed and no new cases developed. The supplement was again given to the cattle at the suggestion of the feed representative. Polioencephalomalacia again developed in approximately 38 animals and 13 died. The commercial supplement was again removed and no new cases developed.

Water samples from the water tank contained 1814 mg/l of sulphate (Table 41). This is considered high. The feed supplement contained 1.5 percent inorganic sulphate which, when added to the water sulphate, may have been enough to induce brain damage. Unfortunately, brain sulphate analysis was not done in this case.

Table 41 WATER ANALYSES FOR THE AGUA NEGRA RANCH (mg/l)[1]

	Tank	Well
Alkalinity	126	143
pH	3.07	7.33
SO_4	1814	1789
Na	236.9	230
K	4.29	3.12
Cl	281.2	376.2

[1] From Hibbs and Thilsted (1983).

8.20 FRESNO IRRIGATION SCHEME USING TREATED WASTEWATER - California, USA

Fresno is located in the San Joaquin Valley, California, USA.

The Fresno wastewater treatment facility treats 1.5×10^5 m^3 of water daily. Approximately 275 hectares of city-owned land are farmed to cotton and maize and irrigated with the treated wastewater, as well as approximately 1350 hectares of private land adjacent to the treatment facility. The crops grown on the adjacent lands using treated wastewater include cotton, barley, alfalfa, almonds, grapes, silage maize, oats, wheat, sorghum, and seed beans.

A typical water analysis of the treated wastewater is shown in Annex I as no. 250. Trace element concentrations in the treated wastewater are shown in Table 42. Interviews with several of the farmers indicate that they apply little or no supplemental chemical fertilizers to their crops due to the nitrogen content of the treated wastewater. Also they feel that little intentional leaching is required for salt control because the water is of sufficiently good quality. The farmers have not experienced any health problems associated with the treated wastewater. In addition to the direct usage during the irrigation season, a substantial part of the treated wastewater is percolated to the groundwater. During the non-irrigation season, all the treated wastewater is percolated for recharge of the groundwater. During the irrigation season, 21 separate extraction wells pump the groundwater mound formed during this recharge. They discharge it into a main distribution canal to serve as an agricultural supply of water for farmers further away from the treatment facility. This well field supplies 37×10^6 m^3 per year. Percolating the reclaimed water through the soil profile and extracting it through these reclamation wells gives a form of tertiary wastewater treatment which is accomplished at a very low cost (State Water Resources Control Board 1981; and City of Fresno 1980).

Table 42 TRACE ELEMENT CONCENTRATIONS IN FRESNO MUNICIPAL WASTEWATER[1]

Element	Concentration[2] (mg/l)
Ag (silver)	<0.001

As (arsenic	0.002
Ba (barium)	0.005
Be (beryllium	<0.001
Cd (cadmium)	<0.001
Cr (chromium)	<0.001
Cu (copper)	0.013
Hg (mercury)	0.0003
Ni (nickel)	0.030
Pb (lead)	0.050
Se (selenium)	0.003
Zn (zinc)	0.041

[1] From City of Fresno (1980).

[2] < means the element, if present, was below this level of detection.

8.21 AGRICULTURAL USE OF TREATED WASTEWATER - Braunschweig, FR Germany

Wastewater utilization for crop production has been practised at Braunschweig, FR Germany, for almost 100 years. In 1954, the utilization system was expanded to 3000 ha of sprinkler irrigated cropland. The treated wastewater is distributed to about 300 farmers through a 100 km buried pipeline. The original sprinkler system was a hand-moved system, but these are now phased out in favour of self-movable spraying machines with flexible polyethylene plastic pipes. One hundred of these irrigation machines are necessary to irrigate the 3000 ha. Instead of 20 spray attendants employed in the original system, only seven are now required.

During the dry summer season, the daily flow of wastewater is not sufficient to match the water requirements of all crops (there are no storage facilities). Wells have been installed to augment the flow. The treated wastewater is sprinkled in six applications of 50 mm each - three in summer and three in winter. The six applications are an average with exact amounts applied to various crops as follows:

Potatoes	2 applications of 30 mm
Winter grain, Spring barley	3 applications of 50 mm
Oats	4 applications of 50 mm
Spring wheat, Sugarbeets	5 applications of 50 mm

The present cropping pattern in the treated wastewater use area is 25 percent winter grain, 30 percent spring grain, 20 percent sugar-beets, 10 percent asparagus, 10 percent grassland, and 5 percent potato. No problems have been experienced with the agricultural cropping pattern using the treated wastewater because the climate is mild and rainfall and over-application of water keeps salinity under control. An analysis of the treated wastewater used is given as no. 80 in Annex I. Of interest are nos. 81 and 82 in Annex I which are samples of the Oker and Erse Rivers which flow through the re-use site. These samples represent the water before it enters the re-use farming area. Groundwater samples taken inside and outside the irrigation area also show quality nearly the same as the treated wastewater used for irrigation. Table 43 gives trace element analysis for these water samples. The trace elements Manganese (Mn), Cobalt (Co) and Cadmium (Cd) in the treated effluent exceed the guidelines given in Table 21 for protection of the soil resource. Further investigation is needed to determine whether these elevated levels could cause problems in the future and whether steps are necessary to reduce their discharge to the sewage system (Tietjen **et al.** 1978).

Table 43 WATER QUALITY IN AND AROUND THE BRAUNSCHWEIG TREATMENT WASTEWATER USE AREA[1]

	Treated Wastewater[2]	Oker River[2,3]	Erse River[2,3]	Groundwater inside[4] the irrigation area	Groundwater outside[5] the irrigation area
	mg/l				
NH_4 - N (ammonium-nitrogen)	49.0	7.0	14.2	2.8	2.9
NO_3 - N (nitrate-nitrogen)	0.2	8.4	7.0	30.0	8.7
P (phosphorus)	13.0	0.9	0.7	0.5	0.4
K (potassium)	32.0	11.0	55.0	33.0	85.0
Fe (iron)	2.0	1.2	0.8	12.0	8.3
Zn (zinc)	0.9	0.6	0.5	0.4	0.7
Cu (copper)	0.15	0.03	0.04	0.06	0.05
Mn (manganese)	0.3	0.4	0.9	1.7	2.1
Co (cobalt)	0.2	0.12	0.27	0.14	0.19
Cd (cadmium)	0.02	0.01	0.02	0.01	0.02
Pb (lead)	0.04	0.02	0.03	0.07	0.04

[1] From Tietjen **et al.** (1978).

[2] Values given are an average of 12 or more samples.

[3] Samples taken before the rivers reach the irrigation area.

[4] Values given are an average of 242 wells.

[5] Values given are an average of 58 wells.

8.22 WASTEWATER IRRIGATION - Bakersfield, California, USA

The City of Bakersfield, located in the southern end of the San Joaquin Valley, has used treated wastewater to irrigate cropland for more than 65 years. Normal annual rainfall is 150 mm and occurs mostly in the winter months of December to the end of February. Because of the mild climate, irrigation can be practised all the year round.

The present treatment system provides primary treatment followed by aerated deep lagoons (21 ha) and storage reservoirs which can provide up to 90 days of storage, if needed. Treatment in combination with lagoons is equivalent to secondary treatment. The treated wastewater analysis is listed as no. 246 in Annex I.

The treated wastewater is used to irrigate approximately 2250 hectares of city-owned land. The city leases the land to one farmer and the lease sets very specific requirements on cropping patterns. The present crops include barley, maize, alfalfa, sorghum, and permanent pasture. Over half of the city farm land is high in salinity and sodicity. The city, through the terms of its lease, encouraged the farmer to implement a land reclamation programme that consisted of ripping to a depth of 0.8 m, followed by land grading to permit flood or furrow irrigation. For reclamation, a pre-plant leaching irrigation was given, followed later by 20 metric tons of 60 percent pure gypsum per hectare, disked into the upper 15 cm of the soil. Barley was then planted in the autumn of the first year and heavily irrigated in the winter and spring to accomplish leaching. Following the barley, a summer crop of Sudan grass or grain sorghum was planted and irrigated by border check. In late summer, the field was planted to pasture or alfalfa, and flood irrigated. Soil conditions were monitored until salinity levels reached a level safe enough to grow other crops under furrow irrigation.

In areas of higher salinity where additional leaching was necessary, the farmer planted rice as a reclamation crop. The goal was to allow the large quantities of water needed for rice to leach the high level of salts from the soil. While this practice was effective, the use of the treated wastewater in flooded rice fields created an abnormally high mosquito problem. The exact reasons are unknown, out field studies and observations by vector biologists clearly showed a significantly higher vector population in the rice fields receiving treated wastewater at Bakersfield and other sites using treated wastewater to irrigate paddy rice. Preliminary data show that the mosquitoes are attracted to standing water containing high levels of organics. Because of the concern for serious disease problems in the adjacent urban population, the use of treated wastewater for the irrigation of paddy rice has been halted in California. On other crops, the treated wastewater does not create vector problems as the fields are not continuously flooded and water does not pond for long enough to allow mosquitoes to propagate.

The amount of nitrogen in the treated wastewater is about 250 kg/ha per metre of water applied. This amount will satisfy the nitrogen fertilizer requirements of most crops. In the past, problems have occurred with certain crops such as cotton owing to excessive vegetative growth. This was probably due to the presence of excess available nitrogen in the irrigation water during the latter part of the growing season. To correct this problem, the farmer now uses the treated wastewater, with its beneficial nitrogen, during the early part of the season, and switches to low nitrogen well or canal water in the later part of the season or blends the treated wastewater with these alternate supplies to reduce the nitrogen content (Crites 1974; State Water Resources Control Board 1981; and EPA 1979).

8.23 WASTEWATER IRRIGATION - Tuolumne Regional Water District, California, USA

The Tuolumne Regional Water District collects urban wastewater, treats it and conveys the treated wastewater to private landowners for irrigation of 500 hectares of forage and pasture land. After treatment, the reclaimed water moves through a 14.2 km pipeline to a 1.85×10^6 m^3 storage reservoir. During the winter non-irrigation season, all the reclaimed water flows to the reservoir and is stored in it. During the irrigation season, reclaimed wastewater is supplied directly from the treatment plant to 10 farmers whose lands lie above the reservoir. If not needed for irrigation, the treated water moves to the reservoir, where it is released to farmers below the reservoir along with the reclaimed water stored during the previous winter.

The treated water can only be used for irrigation of pasture, fibre or seed crops, livestock water and landscape irrigation, and cannot be used where public contact is probable. The farmers in the area are satisfied with the quality of the reclaimed water (no. 249 in Annex I) because it presents few hazards to agricultural production. In the past, the only source of irrigation water was pumped groundwater. This was not economically feasible for the small farms. With the availability of reclaimed water, smaller sized parcels that were previously not economical are now being developed into permanent pasture.

The good quality of the reclaimed wastewater presents no potential problems and the trace element concentration is also far below maximum levels considered safe for irrigation (Table 21). The trace element concentrations for the Tuolumne Regional wastewater are presented in Table 44 (State Water Resources Control Board 1981; Tuolumne Regional Water District 1980).

Table 44 TRACE ELEMENT CONCENTRATIONS IN WASTEWATER FROM THE TUOLUMNE REGIONAL WATER DISTRICT [1,2]

	mg/l		mg/l
Ag (silver)	0.001	Fe (iron)	0.005

Al (aluminium)	<1.0	Hg (mercury)	<0.001
As (arsenic)	<0.01	Mn (manganese)	<0.05
Au (gold)	<0.01	Mo (molybdenum)	<0.01
Ba (barium)	<0.01	Na (nickel)	<0.01
Be (beryllium)	<0.01	Pb (lead)	<0.005
Br (bromide)	0.5	Sb (antimony)	<0.01
Cd (cadmium)	0.001	Se (selenium)	<0.005
Co (cobalt)	<0.01	Sn (tin)	<0.01
Cr (chromium)	<0.005	Ti (titanium)	<0.05
Cu (copper)	<0.05	Tl (thallium)	<0.01
F (fluoride)	1.5	Zn (zinc)	<0.01

[1] From Tuolumne Regional Water District (1980).

[2] < means the trace element, if present, was below this detection level.

8.24 IRRIGATION WITH WASTEWATER - Santa Rosa, California, USA

The City of Santa Rosa, USA, is located about 65 km north of San Francisco in a coastal Mediterranean climate. The city operates an extensive wastewater irrigation system which includes delivery of part of the water to farmers on demand. There are storage reservoirs which hold a 60-day supply and additional balancing reservoirs are located throughout the system. Twenty farmers use the reclaimed wastewater to irrigate 1600 hectares, mostly by sprinklers. The crops irrigated include maize (silage), Sudan grass, oats and winter feed for livestock. The farmers feel that the reclaimed water supplies approximately two-thirds of the fertilizer nutrients required by the crops.

The effluent supplements the winter rainfall and is delivered under contract to farmers adjacent to the pipeline. Effluent not used flows to a surface reservoir at the end of the pipeline for storage awaiting the time when demand is greater and the effluent can be reintroduced into the pipeline for use by the contracting farmers. Effluent is in surplus during the cooler part of the growing season but can be utilized both from storage and direct flow from the treatment plant during the warmer times when peak demand may exceed direct flow capacity of the pipeline.

Before the reclaimed water became available, most farmers were dry farming pasture for their dairy animals and purchasing supplemental feed. Now they are pasturing more and buying less supplemental feed.

Water analyses nos. 247 and 248 in Annex I show the influent city water (drinking water) quality and treated wastewater quality. The greatest percent change is in sodium and chloride and is typical of the change which takes place during urban usage of water in the USA. The treated wastewater salinity is EC_w = 0.7 dS/m. The salinity and SAR are within the range where cropping problems are not likely to occur. No problems have been recorded as a result of using this water since 1976.

The trace element content of the wastewater, shown in Table 45, is also within the suggested limits in Table 21. One important addition resulting from detergents added during urban use is in boron which is increased significantly (State Water Resources Control Board 1981; Bain and Esmaili 1976).

Table 45 TRACE ELEMENT AND NUTRIENT CONTENT OF WASTEWATER FROM THE CITY OF SANTA ROSA[1,2,3]

	Drinking Water (mg/l)	Treated Wastewater (mg/l)
NH_4-N (ammonium-nitrogen)	0	13
NO_3-N (nitrate-nitrogen)	1.0	1.9
Total Nitrogen	-	19
Total Phosphorus	-	19
K (potassium)	1.4	10
B (boron)	0.2	0.53
Al (aluminium)	<0.1	0.128
As (arsenic)	<0.001	0.003
Cd (cadmium)	0.002	0.006
Cr (chromium)	<0.001	0.003
Co (cobalt)	<0.001	<0.001
Cu (copper)	<0.008	0.040
Fe (iron)	0.07	0.21
Pb (lead)	0.003	0.017
Mn (manganese)	0.02	0.068
Ni (nickel)	0.004	0.04
Se (selenium)	<0.001	0.002
Zn (zinc)	0.02	0.06

[1] From Bain and Esmaili (1976).

[2] Composite Sample for 2 years - taken quarterly.

[3] < means the element was not present at that level of detection.

8.25 USE OF WASTEWATER HIGH IN BORON - Calistoga, California, USA

California suffered two years of severe drought during the winters of 1975–76 and 1976–77. Calistoga, a small community about 100 km north of San Francisco and in the northern part of the Napa Valley could no longer supply water to its golf course. Without water the golf greens and fairways were drying up and becoming unplayable.

Municipal wastewater was available but had to be piped about 3 km to a holding pond at the golf course before being put through the sprinkler system. Furthermore, the Calistoga mineral baths and spas use hot, mineral spring waters in their swimming pools and mud baths, and the springs flow more or less continually, discharging to the treatment plant. These mineral springs are high in boron and when mixed with the low boron domestic supply, produce a wastewater containing about 4 mg/l boron. It was therefore suspected that boron could be a problem if this water were used on the golf course.

At the beginning of the testing period to use the municipal wastewater in the holding pond at the Calistoga golf course it had a salinity (ECw) of 1.0 dS/m, boron at 3.8 mg/l and SAR = 3.5. During the two years of monitoring, boron ranged in the applied water from 3.0 to 7.8 mg/l. Boron in the root zone (saturation extract basis) of the greens ranged from 3.1 to 7.8 mg/l, and boron in the grass clippings from the greens (dry weight basis) ranged from 18 to 86 mg/kg. Frequent cutting apparently prevented any damaging accumulation of boron.

The golf greens and fairways were maintained by using the municipal wastewater for irrigation without any apparent damage from its high boron content. Conifer trees, however, in scattered plantings around the course showed appreciable leaf damage (tip burn). With the return of normal rainfall (500–800 mm/year) any potential damage due to boron has been kept to a minimum. Calistoga has continued to use the wastewater on the golf course (Donaldson **et al.** 1978).