Chapter 3 - Examples of use of saline waters for irrigation

United States of America
Israel
Tunisia
India
Egypt

A selected review of some representative examples of the commercial use that has been made of saline waters for irrigation under different circumstances around the world follows. The examples were chosen to be representative of the worldwide experience of such use and because relevant information, including water quality, climate, soil type, crops, irrigation systems and methods, other management practices, yields and period of use, was available. These reviews supplement those given elsewhere (Rhoades 1990a) and serve to illustrate the wide range of experience that exists in using saline water for irrigation under different conditions and to demonstrate that waters of much higher salinities than those customarily classified as "suitable for irrigation" can, in fact, be used effectively for the production of selected crops under the right conditions. They also illustrate some of the management practices that have been found to be effective to facilitate such use.

United States of America

In the USA, saline waters have been successfully used for irrigation for periods of from 75 to 100 years in several areas of the Southwest, including the Arkansas River Valley of Colorado, the Salt River Valley of Arizona, and the Rio Grande and Pecos River Valleys of New Mexico and West Texas (Erickson 1980). Representative compositions of three of the irrigation waters used in these areas are given in Table 3 (see Water Nos. 1, 2 and 8 - 10). The principal crops grown in these areas are cotton, sugarbeet, alfalfa and small grains. According to Erickson, the "farming community of the Southwest has demonstrated that it is possible to adjust to the use of whatever water is available... as long as other factors permit irrigated agriculture to continue...". The following discussion gives more detail for some of these areas.

In the Pecos Valley of West Texas, groundwater averaging about 2500 mg/l TDS, but ranging far higher (at least to 6000 mg/l), has been successfully used to irrigate about 81 000 hectares of land for three decades (Moore and Hefner 1977; Miyamoto *et al.* 1984). A typical composition is given in Table 3 (see Water No. 2). In this Valley, the rainfall is less than 300 mm, most of which occurs in showers of less than 25 mm. The major crops include cotton, small grains, grain sorghum and alfalfa. The soils are calcareous (pH 7.5 to 8.3) with a calcium carbonate equivalent of between 20 and 30 percent; they are also low in organic matter and show little structural development. Soil textures range from silt loams to silty clay loams. Infiltration rates average about 0.5 cm per hour. Internal drainage is good; water tables are usually below 3 m. The soils display slaked-aggregate conditions immediately following rainfall; the resulting crusting often necessitates replanting of crops, if it occurs during the seedling establishment period. Generally the EC_e of the major rootzone is not more than 2-3 times that of the electrical conductivity of the irrigation water (EC_{iw}), about the same as EC_{iw} below the furrow and up to about 6 times EC_{iw}, in the seedbeds.

TABLE 3 Composition of some saline waters successfully used for irrigation

Constituent	Water Nos.											
	1	2	3	4	5	6	7	8	9	10	11	12
Ca $mmol_c/l$	18.8	11.6	5.6	10.0	12.8	2.5	1.4	22.6	27.2	25.0	14.5	28.9
Mg $mmol_c/l$	15.7	9.3	2.3	5.5	8.8	3.9	3.6	9.7	13.6	9.4	7.4	21.2
Na $mmol_c/1$	25.2	19.4	28.9	20.0	34.0	12.4	41.3	50.7	74.8	78.2	26.3	50.0
K $mmol_c/1$	-	0.4	-	-	-	0.4	-	-	-	-	-	-
HCO_3 $mmol_c/l$	5.1	4.1	7.4	2.4	2.2	4.6	9.6	2.4	1.8	15.6	4.1	5.0
SO_4 $mmol_c/1$	50.6	9.2	8.1	18.0	21.2	4.6	1.2	29.3	37.9	29.7	32.7	67.0
Cl $mmol_c/l$	4.1	27.0	20.6	14.0	19.6	12.6	35.2	19.7	34.5	32.8	11.4	28.0
N03 $mmol_c/l$	0.5	-	-	-	-	-	-	-	-	-	-	-
Total mg/l	4200	2558	-	-	-	-	-	3206	4652	4850	-	-
B mg/l	-	-	-	-	-	-	-	-	-	-	-	-
EC dS/m	4.3	4.1	3.2	3.2	5.3	2.3	5.6	5.1	7.5	6.9	4.2	7.1
SAR $(mmol_c/1)^{½}$	6.1	6.0	15.0	7.2	10.0	6.9	26.0	4.6	7.6	10.6	8.0	10.5
PH	7.7	7.8	7.5	-	-	8.2	-	-	-	-	8.3	8.1

Table 3 Cont'd

Constituent	Water Nos.								
	13	14	15	16	17	18	19	20	21
Ca $mmol_c/l$	7.35	4.6	11.4	11.7	26.0	9.4	14.4	8.75	17.0
Mg $mmol_c/l$	-	2.9	11.8	1.2	13.0	5.1	9.3	6.9	8.4
Na $mmol_c/l$	-	0.1	33.6	3.4	50.6	11.7	25.3	27.9	6.2
K $mmol_c/l$	-	0.1	0.3	0.1	0.2	0.5	0.6	-	-
HCO_3 $mmol_c/l$	14.2	2.9	5.0	1.6	2.5	1.0	2.2	5.5	-
SO_4 $mmol_c/l$	10.9	9.2	26.9	1.9	37.8	5.2	14.4	10.7	21.7
Cl $mmol_c/l$	12.2	4.3	23.5	2.8	49.5	13.5	23.6	26.8	7.7
NO_3 $mmol_c/l$	-	-	-	-	-	-	-	-	-
Total mg/l	2700	-	-	-	-	-	-	-	-
B mg/l	-	0.3	3.0	0.1	6.0	-	-	-	4.0

EC dS/m	3.6	1.5	4.6	0.7	7.9	1.8	3.0	4.2	2.5
SAR $(mmol_c/l)^{½}$	5.8	6.1	10.0	2.9	11.4	5.3	7.3	10.0	1.7
pH	-	7.9	-	-	-	-	-	7.7	-

[1] Arkansas River, near Granada, Colorado, USA (Miles 1977)

[2] Well water Pecos Valley of West Texas, USA (Moore and Hefner (1977)

[3] Representative well water SW Arizona, USA (FAO 1985)

[4] Blended drainage water, Broadview Water District, California, USA (Tanji 1977)

[5] Medjerda River, Tunisia, in dry season (Van't Leven and Haddad 1968)

[6] Irrigation water used for vegetable production in United Arab Emirates (Savva *et al.* 1984)

[7] Nahal Oz well water, Israel (Hadas and Frenkel 1982)

[8] Irrigation water used near Carlsbad, New Mexico, USA (Erickson 1980)

[9] Irrigation water used near Red Bluff, Texas, USA (Erickson 1980)

[10] Irrigation water used near Hudspeth, Texas, USA (Erickson 1980)

[11] & [12] irrigated waters used in lysimeter experiment (Jury *et al.* 1978)

[13] Tubewell used in field-plot experiment (Bhatti 1986)

[14] & [15] Colorado River and drainage waters used under commercial and experimental conditions (Rhoades *et al.* 1989a)

[16] & [17] California aqueduct and well waters used together in small-plot experiment (Rhoades *et al.* 1980)

[18] & [19] Water used for irrigation at beginning and end of season in plot experiment in Italy (Fierotti *et al.* 1984)

[20] Well water used in field plot experiment in Texas, USA (Thomas *et al.* 1981)

[21] Waste water used in field experiment in Utah, USA (Hanks *et al.* 1 984)

TABLE 4 Representative composition of irrigation waters used in the major irrigated area of the Far West (after Miyamoto *et al.* 1989)

	Middle Rio Grande Area			Trans-Pecos Area		

	Project water	**Well water (El Paso)**	**Well water (Hudspeth)**	**Van Horn Valentine**	**Dell City**	**Pecos**
EC dS/m	1.1 ± 1	3.8 ± 1	7.0 ± 2	0.6 ± 0.3	3.7 ± 1	4.4 ± 2
TDS mg/l	800	2800	5140	380	2720	3230
Na mmolc/l	6.0	21.0	43	4.3	13.0	18.0
Ca	4.3	9.8	16.0	1.2	20.0	23.0
Mg	1.3	3.2	9.5	0.5	14.0	11.0
HCO_3	3.8	4.4	3.7	2.4	2.7	1.8
Cl	3.0	19.0	48.0	1.0	17.0	16.0
$S0_4$	5.0	13.0	15.0	1.8	25.0	32.0
SAR (mmolc/l) ½	3.6	8.2	12.0	4.7	3.1	4.4

Cotton is grown successfully with a gypsiferous water of up to 8 dS/m EC using alternate-row, furrow irrigation and double-row plantings on wide beds or by using single-row plantings on narrow beds and then "decapping" the peaks of the beds to remove resulting salt crusts prior to seedling emergence. Sprinkler irrigation of cotton is carried out during night or twilight hours using water of up to about 5 dS/m in EC. Alfalfa and several other forages are produced with minimal yield losses using waters of up to 3 to 5 dS/m, as have been tomatoes. Representative compositions of these waters are given in Table 4. Representative cotton yields are given in Table 5. Alfalfa yields in saline areas near Dell City have been 12.3 to 13.4 t/ha, whereas yields of 17.9 to 20.1 t/ha are common in the van Horn area.

Traditionally, most field crops in Far West Texas have been irrigated by furrow methods. When saline water is applied to every furrow, the highest salt concentration occurs in the ridge of the bed and the lowest concentration occurs beneath the furrow. This accumulation of salt in the bed often causes seedling mortality, or reduced germination. To minimize such salt accumulation, alternate-furrow irrigation is frequently used in the Trans-Pecos area. Under this system, salts are "pushed" towards the non-watered furrows. In the Hudspeth irrigation district, where irrigation water salinities are quite high, this method is usually used for the first one or two irrigations, thereafter every furrow is irrigated so as to prevent excessive salts from eventually accumulating under the dry furrows. Dragging the top of single-row, round-top beds with a chain or metal rod shortly before crop emergence is a practice undertaken in the El Paso Valley to prevent salt crust damage to emerging seedlings. This method also eliminates the soil crust that often develops in clay-textured soils after rains or excessive sprinkler irrigation. This method appears to work well with cotton and chilli peppers, but not so well with fast-emerging shallow seeded crops such as lettuce.

Double-row planting on flat beds is practised with lettuce, onions and in some cases with cotton. Seeds are planted on the edges of the bed where salt accumulation is minimal. Excellent stand and production of cotton have been obtained using this system with water of 5.4 dS/m in EC. This practice does not prevent seedling damage caused by saline-water splash associated with light rains and the presence of high surface accumulations of salts near the seedlings. Planting seed in the water-furrow is advantageous because the lower levels of salinity that occur there, but this practice has serious disadvantages as well. As soil in the furrow crusts badly and is colder, seedling diseases and weed infections are worse. Thus this method is used only in extremely saline soils for the establishment of some forage crops. Sprinkler irrigation in the

Trans-Pecos region has been used mostly for alfalfa and forage crops. When the irrigation water salinity is as high as is found in this region, foliar-induced salt damage is sometimes a problem. In the Dell City area, alfalfa leaves frequently show margin leaf-burn, although no major yield reductions are reported, when sprinkler-irrigated with water of up to 3.0 to 5.0 dS/m in EC. Sprinkler irrigation of cotton is also used in several areas of the Trans-Pecos. A 15 percent reduction in lint yield typically results when cotton is sprinkled during the daytime with water of 4 dS/m in EC. Severe leaf bum and extremely poor yields result from daytime sprinkling with saline water having an EC of 5.0 dS/m. In both cases, no significant yield reduction is observed when such waters are applied at night.

TABLE 5 Representative yields of cotton in El Paso and Hudspeth portions of the Middle Rio Grande Basin (after Miyamoto *et al.* 1984)

Year	Yield in bales/acre (540 kg/ha)			
	Upland		Pima	
	El Paso	Hudspeth	El Paso	Hudspeth
1975	0.93	0.73	0.44	0.47
1976	1.26	1.18	0.99	0.94
1977	1.28	1.46	-	1.11
1978	1.54	1.16	1.16	0.60
1979	0.70	0.81	0.89	0.69
1980	1.05	1.07	1.13	0.72
1981	1.22	1.42	0.83	1.09
1982	1.18	1.14	1.31	1.33
Average	1.14	1.00	0.96	0.87

NB: Areas involved in El Paso and Hudspeth districts are on average 3000 and 1500 ha for Upland-cotton, and 6500 and 1500 ha for Pima-cotton, respectively.

A linear, mobile system that delivers water directly into the furrows (which often contain micro-dams) at low pressures of 34 - 55 kPa through "drop-tubes" from an overhead boom, rather than through spray nozzles which wet the plants as with conventional sprinkler methods, has more recently become popular in the area, because foliar damage from use of the saline water and water losses through wind-drift are largely avoided with this system. Yields of cotton obtained with this system have been equal to or greater than those of conventionally, furrow-irrigated cotton, even when using water of up to 8 dS/m in EC.

In summary, the experience in Far West Texas shows that good crop production of suitable crops can be achieved with use of saline waters (up to about 8 dS/m in EC) for irrigation if care is taken to obtain stand.

Saline groundwaters (ranging in EC from 3 to 11 dS/m; see Water No. 3 of Table 3) have been used successfully for irrigation for decades in some hot, dry regions of Arizona (Dutt *et al.* 1984). The fields are typically planted to cotton and germinated using water from lower salinity wells and alternate-furrow irrigation. Irrigations using the saline well waters are given after germination. The seasonal averaged irrigation water salinities and crop yields of four surveyed fields are given in Table 6. All these yields are near the value of 1238 kg/ha which is the statewide average yield of lint cotton, though the maximum yield is about 2310-2500 kg/ha in the absence of any serious yield-limiting factor. These data demonstrate that the successful commercial production of suitable crops is possible even in a hot, dry climate and when using relatively saline, sodium/chloride-type irrigation waters.

TABLE 6 Irrigation water salinities and lint cotton yields at four locations in Red Mountain Farms, Arizona (after Dutt *et al*. 1984)

Parameters	A	B	C	D
Yield kg/ha	1614	995	834	1076
Water salinity dS/m	6.2	4.6	4.0	11.1

O'Leary (1984) has shown in pilot-sized operations that several halophytes (such as *Atriplex nummalaria*) have potential for use as crop plants and can be grown with seawater. Yields of forage have been achieved which exceed the average yield of conventional crops, like alfalfa, irrigated with freshwater. The most productive halophytes yielded the equivalent of 8 to 17 metric tonnes of dry matter per hectare. These yields contributed the equivalent of 0.6 to 2.6 metric tonnes of protein per hectare, which compares to that obtained for alfalfa irrigated with fresh water. These halophytes yield even more when grown with water of lower salinity. For example, about double the above yields were obtained using water of 10 000 mg/l TDS for irrigation. Some halophytes, such as *Salicornia,* appear to have even better potential as oil seed crops. The use of secondary drainage waters for the growth of such crops after their first use for more conventional crops would facilitate the disposal of drainage waters by reducing the ultimate volume needing such disposal, as proposed by Rhoades (1977) and van Schilfgaarde and Rhoades (1984). Limited commercial use of such halophytes is now being attempted in various places in the world, but insufficient long term results are available to document its success.

Israel

Considerable use has been made of saline waters for irrigation in Israel. The majority of the saline groundwaters range between 2 and 8 dS/m in EC (about 1200 to 5600 mg/l in TDS). The average annual evapotranspiration is about 20 000 m^3 per hectare. Average annual rainfall exceeds 200 mm in over half of the country and is about 500 mm in the main agricultural area (600 mm in the coastal plain); most of the rain falls in the winter season. The climate is Mediterranean with a moderately hot, dry summer (April to March). Heavy dews occur in many parts of the country, especially near the coast. Mostly sprinkler or drip irrigation is used. The soils are generally permeable and drainage is good. Much of the saline water is introduced into the national carrier system; thus it is diluted before use. Because most of the crops are irrigated by sprinkler methods, some crops suffer poor emergence related to crusting. Thus they are sometimes started by furrow irrigation. Extra water (equivalent to about 25 to 30 percent in excess of evapotranspiration) is typically given for leaching. According to Israeli general recommendations, light- and medium-textured soils can be irrigated with any saline water in the range of the salinity tolerance of the crop, and heavy soils can be irrigated with waters having EC values of up to 3.5 to 5.5 dS/m where artificial drainage is provided (gypsum applications are advised for such waters). Cotton is successfully grown commercially in the Nahal Oz area of Israel with saline groundwater of 5 dS/m in EC and 26 of SAR (see Water No. 7 in Table 3) provided the silty clay soil is treated annually with gypsum and national carrier water is used (usually during the winter) to bring the soil to field capacity through a depth of 150 to 180 cm prior to planting (Frenkel and Shainberg 1975; Keren and Shainberg 1978).

Tunisia

The saline Medjerda River water of Tunisia (average annual EC of 3.0 dS/m; see Water No. 5 in Table 3) is successfully used to irrigate date palm, sorghum, barley, alfalfa, rye grass and artichokes. The soils are calcareous (up to 35 percent $CaCO_3$) heavy clays with low infiltration rates, especially after winter rainfall. During the growing season large cracks form (fissures of up to 5 cm in width) as the soil dries, subsequently permitting water to enter rapidly when first irrigated. Winter rainfall produces leaching of salts only to depths in the soil of about 15 cm. However, with properly timed irrigations and use of appropriate crops, such saline waters are being successfully used in Tunisia for the irrigation of even such relatively impervious soils (Van't Leven and Haddad 1968; van Hoorn 1971).

In 1962, the Tunisian Government created a Research Centre for the Utilization of Saline Waters for Irrigation (CRUESI), with the assistance of the Special Fund of the United Nations and Unesco. A technical report describes their findings through 1969 (Unesco/UNDP 1970). This work was carried out at the scale of commercial farming operations to ascertain how various crops would yield when irrigated in various ways (all surface methods) with saline waters. Experiment stations were chosen to be representative of the various combinations of soils, climates and irrigation water compositions prevalent in Tunisia. The soils varied in texture from light to heavy, the irrigation waters varied in salinity from 2000 to 6500 mg/l TDS and the rainfall varied from 90 to 420 mm. The SAR values of the waters were low (usually less than 10) and boron was not a problem. Representative compositions of the well waters used for irrigation are given in Table 7. The following is a summary of the major conclusions reported by this research team.

TABLE 7 Representative compositions of saline irrigation waters studied in Tunisia (after Unesco/UNDP 1970)

	Stations				
	Ksar Gheriss	**Tozeur**	**Messaoudia**	**Nakta**	**Zarsis**
EC dS/m	4.9	3.1	2.8	5.5	9.2
TDS mg/l	4000	2100	2000	3800	6500
pH	7.5	7.7	7.6	7.6	7.9
SAR (mmolc/l)½	7.1	6.3	6.1	11.7	24.8
Ca mmolc/l	18.0	9.0	11.2	13.5	14.8
Mg mmolc/l	15.5	6.7	3.1	7.5	6.2
NA mmolc/l	29.0	17.6	16.3	37.8	81.3
K mmolc/l	0.6	0.6	0.5	0.5	0.8
Cl mmolc/l	20.9	17.6	12.4	36.7	70.2
$S0_4$ mmolc/l	37.9	13.0	14.4	20.8	32.6
HCO_3 mmolc/l	3.2	2.4	3.8	3.0	2.1

The chemical content and composition of the irrigated soils become stable after about four years of irrigation, subject to variation in crop rotation effects. Sodicity does not become a significant problem. Winter rainfall can be effectively exploited for leaching purposes by keeping the soil high in water content just prior to rain events. (It should be noted that rainfall is higher in the coastal regions of Tunisia than is typical of most semi-arid regions; furthermore, much of the rainfall occurs in relatively intense storms in the winter months.) Good yields of appropriate crops can be obtained with use of typical well waters for irrigation (though with some reduction relative to the use of freshwater) provided certain precautions are taken. Salinity in the irrigation waters is concluded not to be an insurmountable barrier.

It primarily affects the summer crops whereas the winter crops are more strongly influenced by amount of rainfall and initial level of salinity present in the soil in the autumn of the year. Germination and emergence (especially the latter) are crucial to the success of cropping and establishment of stand is the major bottleneck. The physical condition of the soil surface layer has a major effect on emergence and methods of irrigation and tillage are very influential in this regard and given too little attention compared to salinity in management considerations. Poor aeration is a major problem when excessive amounts of irrigation water are given, such as might be encouraged when saline waters are used.

These Tunisian studies point out the need to pay close attention to other factors besides salinity *per se* (some of which, however, are influenced by salinity) which must also be controlled if successful irrigation with saline waters is to be achieved.

India

Crops are successfully grown in some parts of India under conditions quite different from those existing in typical, semi-arid regions. Much of the research and experience in India through 1980 has been summarized by Gupta and Pahwa (1981). Of particular benefit to the continued use of saline waters for irrigation in parts of India are the monsoon rains. It has been observed that very saline waters can be used for irrigation in these areas without excessive long-term build-up of soil salinity because of the extensive seasonal leaching that occurs there (Pal *et al.* 1984; Jain 1981; Manchanda and Chawla 1981; Tripathi and Pal 1979). These findings illustrate the high potential to gain benefit from the use of quite saline waters for irrigation in regions which receive sufficient rainfall to prevent the build-up of excessive soil salinity over time.

TABLE 8 Representative yields (in %) by crop and irrigation water salinity in survey of Hissar area of Haryana, India (after Boumans *et al.* 1988)

Crop	Tubewell salinity, EC in dS/m		
	2-4	4-6	6-8
Cotton	100	70	55
Millet	100	79	52
Wheat	100	89	60
Mustard	100	86	67
Average	100	81	59

A field survey made during the period 1983-1985 showed that extensive use (104 000 shallow tubewells pumping 106 000 hectare-metres of water per year) is being made (since about 1975) of shallow-saline groundwater of EC up to 8 dS/m for irrigation in nine districts of Haryana State India (Boumans *et al.* 1988). In four of the districts, the saline water is solely used for irrigation, while in the remaining five it is used either after it is blended with fresh canal water or in alternation with the canal water. Mean rainfall in these areas ranges between 300 and 1100 mm. The soils are dominantly sandy loam in texture. Shallow water tables exist and surface flooding occurs following the monsoons. Table 8 presents the yield reductions found in a survey of the districts for the dominant crops when irrigated solely with the tubewell waters of the indicated levels of salinity. Only a few wells had EC values exceeding 7 dS/m, hence it appears that this level is about the maximum that the farmers have found to be acceptable for long-term use. Yield depressions of 30-40 percent are apparently acceptable to these farmers. The farming practices being used were not given, so it is not possible to evaluate whether opportunities may exist to improve yields through the adoption of modified practices. Still it is obvious that saline waters have been used successfully, even as the sole supply, for irrigation in these districts of India. Whether their use could be better facilitated by blending or alternating with freshwater supplies is discussed later.

Egypt

Egypt is a predominantly arid country and the scattered rain showers in the north can hardly support any agricultural crops. Agriculture thus depends mainly on irrigation from the River Nile (55.5 BCM per year). The needed increase in food production to support the acceleration of population growth (2.7%), compels the country to use all sources of water (i.e. drainage water, groundwater and treated sewage water) for the expansion of irrigated agriculture.

The policy of the Egyptian Government is to use drainage water (up to salinity of 4.5 dS/m) after it is blended with fresh Nile water (if its salinity exceeds 1.0 dS/m) to form blended water of a salinity equivalent to 1.0 dS/m. The drainage water presently used for irrigation amounts to 4.7 BCM per annum and it is likely to increase to 7 BCM per annum by the year 2000 (see Table 9).

TABLE 9 Quantity of drainage water, salinity levels and estimated reuse in years 1988 and 1992 (adapted by Mashali based on data reported by Amer and Ridder (1988) and Rady (1990)

Regions	Quantity of drainage water in MCM					Total	Estimated reuse	
	Salinity levels EC in dS/m						Year 1988	Year 1882
	<1	1-2	2-3	3-4	>4			
Eastern Delta	949	1565	1055	310	433	4312	1130	2000
Middle Delta	330	1421	1832	273	1191	5047	686	1400
Western Delta	473	412	1291	901	1914	4991	554	1050
Total	1752	3398	4178	1484	3538	14350	2370	4450

In fact, direct use of drainage water for irrigation with salinity varying from 2 to 3 dS/m, is common in the districts of Northern Delta where there are no other alternatives or in areas of limited better water quality supply. Farmers in Beheira, Kafr-El-Sheikh, Damietta and Dakhlia Governorates have successfully used drainage water directly for periods of 25 years to irrigate over 10 000 ha of land, using traditional farming practices. The soil texture ranges from sand, silt loam to clay with calcium carbonate content of 2 to 20 percent and very low in organic matter. The major crops include clover "Berseem", rice, wheat, barley, sugarbeet and cotton. Yield reductions of 25 to 30 percent are apparently acceptable to local farmers. Yield reductions observed are attributed to waterlogging and salinization resulting from over-irrigation and other forms of poor agricultural, soil and water management.

Pilot studies carried out in Kafr el Sheik and Beheira Governorates showed that by applying appropriate management practices (i.e. crop selection, use of soil amendments, deep ploughing, tillage for seedbed preparation, land levelling, fertilization, minimum leaching requirements, mulching and organic manuring), drainage water of salinity 2 to 2.5 dS/m can be safely used for irrigation without long term hazardous consequences to crops or soils (see Table 10)

TABLE 10 Yields of dominant crops in Kafr el Sheikh and Beheira Governorates using drainage water for irrigation (after Mashali 1985)

Irrigation water	Average yields				
	Rice tons/ha	**Clover (berseem) tons/ha**	**Barley tons/ha**	**Cotton tons/ha**	**Squash kg/ha**
Drainage Water					
Kafr El Sheikh	8.0	150	-	-	-
(EC = 2-2.5 dS/m)					
Drainage water Beheira	8.2	155	3.7	1.9	330
Fresh Nile water	8.5	160	3.7	2.0	350
(EC = 0.4 dS/m)					

In Fayoum Governorate, the annual average volume of drainage water available amounts to 696 MCM, of which 350 MCM per year are used at present after blending with canal water. Results of pilot demonstrations in Ibshwai District during the period 1985 to 1987 on direct and cyclic use of drainage water (EC = 2.8 dS/m) with fresh Nile water are presented in Table 11.

TABLE 11 Effect of irrigation with different salinity levels on principal crops grown in the area (adapted by Mashali based on data reported by Rady 1990)

Source of irrigation water (EC in dS/m)	Wheat Grain dry tons/ha	Onion tons/ha	Maize tons/ha	Summer tomato tons/ha	Winter tomato tons/ha	Pepper tons/ha
Drainage water (2.8 dS/m with SAR 22)	5.0	6.5	1.8	2.5	8.0	12.5
Fresh Nile water for seedling establishment and then drainage water	3.0	6.5	2.0	4.0	8.7	20.0
Fresh Nile water (0.5 dS/m with SAR 4)	5.0	9.7	2.5	7.5	12.5	25.0

The following strategy emerges from these demonstrations, i.e. to irrigate sensitive crops (maize, pepper, onion, alfalfa, etc.) in the rotation with fresh Nile water and salt tolerant crops (wheat, cotton, sugarbeet, etc.) directly with drainage water, and moderately sensitive crops (tomato, lettuce, potato, sunflower, etc.) can be irrigated with drainage water but after seedling establishment with fresh Nile water. Based on these results, the Governorate is planning to reclaim 4000 ha using the drainage water.

The estimated present annual abstraction from groundwater resources in the Nile Valley and Delta is about 2.6 BCM (for agricultural, municipal and industrial use) with an average salinity of 1.5 dS/m but ranging far higher, at least to 4.0 dS/m (the estimated use of this groundwater resource by the year 2010 is 4.9 BCM). Saline groundwaters ranging 2.0 to 4.0 dS/m have been successfully used for decades to irrigate a variety of crops in large areas of scattered farms in the Nile Valley and Delta. Crops now grown are mostly forage, cereals and vegetables. In the Delta, saline waters of EC 2.5 to 4 dS/m has been used successfully to grow vegetables under greenhouse conditions. In the New Valley (Oases, Siwa, Bahariya, Farafra, Dakhla and Kharga) there is potential to irrigate about 60 000 ha utilizing groundwater (salinity ranging from EC 0.5 dS/m to 6.0 dS/m), of which 17 000 ha are already under cultivation. Siwa Oasis has the largest naturally flowing springs in the New Valley. Siwa once contained a thousand springs, of salinity ranging from EC 2 to 4 dS/m, which were used successfully to irrigate olive and date-palm orchards, with some scattered forage areas. At present 3600 ha are irrigated from about 1200 wells. Of these 1000 are hand dug to depths of 20-25m (salinity ranging from EC 3.5 to 5.0 dS/m and in some locations as much as 10 dS/m), and the remaining 200 wells were drilled deep (70-130 m) with salinity of EC 2.5-3.0 dS/m - the SAR values varying from 5 to 20. Presently about 235 MCM/year is being used successfully to irrigate olive and date-palm orchards, alfalfa, cereals and wood trees (of which 60 MCM from continuing flowing springs). Due to over-irrigation without appropriate drainage facilities, seepage as well as run off to low lying land, salinity and waterlogging have developed in some lands of the oasis.

To reduce drainage water volumes, minimize water pollution and safely dispose of the ultimate unusable final drainage water, new strategies are being developed and experimented by the Government authorities in Siwa Oasis (similar problems exist in Dakhla oasis). These include:

- use of natural flowing springs to irrigate winter crops such as cereals and forage;

- use of saline water over 5 dS/m to irrigate salt tolerant crops like barley, vetches, Rhodes grass, sugarbeet, etc.;

- use of biologically-active drainage water for the production of windbreak and growing wood trees;

- use of drainage water for stabilization of sand dunes;

- reuse of drainage water (average salinity is EC 6.0 dS/m with SAR values of 10 to 15) after blending with good quality water (recently drilled deep well of salinity EC 0.4 dS/m with SAR of 5) or by alternating the drainage water with good water.
