



Interaction between Migration,
Land & Water Management and Resource
Exploitation in the Oases of the Maghreb

Irrigation

in arid and semi-arid environments

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INTRODUCTION

This paper treats of irrigation in arid and semi-arid environments. It has been written for the purpose of an EU project concerning the interaction between migration, land & water management and resource exploitation in the oases of the Maghreb. On the basis of data concerning these interactions and the ecological impact of the changes in land & water management and resource exploitation a model will be developed for increased investments and improved spin-off of allocation of remittances in sustainable agriculture, which will reduce migration (Technical annex, 1996).

Physical, socioeconomic and political research is needed to be able to identify the main obstacles and enabling conditions of sustainable land & water management. This paper serves as a theoretical basis for the physical component of this research. After a short introduction of land degradation and desertification irrigation and aspects such as water quality and salinisation will be discussed. This information will provide an insight in assessing the physical factors that contribute to the abandonment or reclamation of agricultural land.

Chapter 1

LAND DEGRADATION AND DESERTIFICATION

Soil and land degradation

A deteriorating soil fertility and water-holding capacity make crop production more difficult and more expensive. With large technical inputs soils can be restored. The increasing use of irrigation, fertilizer and other chemicals can mask productivity declines. To maintain the quality of the soil resource at acceptable costs without needing excessive inputs the application of proper technology is needed. Excessive inputs might damage the environment, the self-sufficiency for the land user and may harm the security for society. According to Stocking (1995), soil degradation is defined as a decrease in soil quality as measured by changes in soil properties and processes and the consequent decline in productivity in terms of production now and in the foreseeable future.

Six processes of soil degradation are usually recognized. These are water erosion, wind erosion, excess of salts, chemical degradation, physical degradation and biological degradation. *Water erosion* consists of splash, sheet and gully erosion, as well as mass movements such as landslides. *Wind erosion* is the removal and deposition of soil by wind. *Excess of salts* consists of processes of the accumulation of salt in the soil solution (salinisation) and of the increase of exchangeable sodium on the cation exchange of soil colloids (sodication or alkalinization). *Chemical degradation* comprises a variety of processes related to leaching of bases and essential nutrients and the build-up of toxic elements. *Physical degradation* consists of a negative change in properties such as porosity, permeability, bulk density and structural stability. A decrease in infiltration capacity and plant-water deficiency are common effects. *Biological degradation* is the increase in rate of mineralization of humus without replenishment of organic matter. These six processes interact in such manner that soil degradation will affect plant productivity in a number of ways simultaneously (Stocking, 1995). According to Oldeman *et al.* (in: Ghassemi *et al.*, 1995) human induced soil degradation processes can be grouped in two categories. The first concerns *soil degradation by displacement of soil material*, due to water and wind erosion. Water erosion comprises of loss of topsoil and terrain deformation. Common phenomena are the formation of rills, gullies and badlands. Wind erosion includes loss of topsoil, terrain deformation and overblowing. The second category considers *physical and chemical soil deterioration*. Physical deterioration includes compaction and crust forming, waterlogging and subsidence of organic soils. Chemical deterioration comprises of loss of nutrients and/or organic matter, salinisation, acidification and pollution.

On site soil degradation affects soil productivity. Nutrients are lost in sediment and run-off. In general the nutrients associated with organic matter (N and P) and the cation exchange of soil colloids (K and Ca) are most vulnerable. Nutrients in sediment are approximately ten times the quantity of those dissolved in run-off. As soil degrades, the infiltration capacity declines. Surface sealing and crusting

aggravate this process. The run-off water is lost to the soil and to plant growth. Because water erosion is selective of the finer, more fertile fraction of the soil, the eroded sediment usually has higher contents of nutrients and organic matter than the soil from which it is derived from. Eroded sediments may cause damage to off site canals, water storage, irrigation schemes and hydro-electric power plants. Consequences such as sediment accumulation, eutrophication, water shortages in irrigation schemes and damage to machinery's like turbines are prone to occur (Stocking, 1995).

Soil erodibility is mainly determined by soil type, topographic factors, physical measures, rainfall and cover of vegetation. *Topographic factors* are slope, steepness, length and shape. *Physical measures* consist of procedures such as contour building or terracing. The amount and intensity of rain and seasonality of storms determine the erosivity of *rainfall*. By intercepting the kinetic energy of raindrops and by absorbing water into leaves and organic matter *the vegetation cover* is the only protection of the soil from the erosivity of rainfall (Stocking, 1995).

In order to prevent or slow down the process of land degradation, soil conservation is practiced. This is a set of measures that controls or precludes soil erosion and maintains soil fertility. Water conservation, especially in drier zones, is very closely related. Many techniques of soil conservation achieve short-term benefit through increasing plant-water availability rather than through saving soil. Soil and water conservation promote a consistent and lasting production from land while keeping soil loss at or below the soil rate's renewal (Stocking, 1995).

The term land degradation is used to describe the total decrease of the productive potential of the land, including its major uses (rainfed arable, irrigated, rangeland, forestry), its farming systems (e.g. smallholder subsistence) and its value as an economic resource (Stocking, 1995). Land degradation is a constraint in the maintenance of sustainable agriculture. The origin of degradation can be natural, but also human induced. Changes in land and water management and resource exploitation might cross existing ecological thresholds, after which degradation will take place (Ghassemi *et al*, 1995).

North Africa

In arid zones soil and water salinisation is one of the major factors contributing to land degradation. Water and wind erosion of top soil caused by overgrazing, improper management of agricultural land and deforestation are other major factors (Ghassemi *et al*, 1995). Several centuries ago extensive land deterioration already occurred in arid regions. Three epicentres could be distinguished, among which the Mediterranean Sea and the Mesopotamian Valley. Recently salinisation and water logging of irrigated land is worst in the Nile valley and North Africa but also occurs elsewhere. The amount of crop yield reduction that could be attributed to salinisation and waterlogging in the Nile Valley is estimated to be at least 17 percent on 80 to 90 percent of the old irrigated land. In the newly irrigated lands east and west of the delta, a minimum of 25 percent yield reduction is likely to occur. Both problems are becoming even more serious in the future if no remedial measures are taken. The situation in Algeria and Tunisia is similar to that in Egypt

with respect to yield reductions. Salt-affected soils are common in Tunisia and Algeria where both surface and well irrigation waters frequently are saline (Dregne, 1986).

Desertification

Extensive land degradation may lead to desertification. Different authors handle different definitions. As Aubreville (1949) stated, desertification is the changing of productive land into a desert as a result of ruination of land by man-induced soil erosion. According to Dregne (1986) desertification is the impoverishment of terrestrial ecosystems under the impact of man. It is the process of deterioration in these ecosystems that can be measured by reduced productivity of desirable plants, undesirable alterations in the biomass and the diversity of the micro and macro fauna and flora, accelerated soil deterioration and increased hazards for human occupancy. Meckelein (1980) defines desertification as a set of natural and cultural processes leading to an encroachment or intensification of desert conditions in arid lands and their marginal zones. Clayton (1995) considers increased grazing, population growth, vegetation clearance and drought all to encourage a general deterioration summarized by the term desertification.

Some authors consider desertification as a process mainly caused by human actions, in which climate is of a minor influence. Others regard desertification as the degradation of an ecosystem, mainly in an arid or semi-arid environment, where causes may be natural as well as cultural. Desertification often has a natural cause, by which the process is aggravated by careless human acting. As Dregne stated (1986), desertification of rangelands is usually caused by overgrazing and woodcutting, whereas on the whole in rain-fed croplands desertification is due to accelerated water and wind erosion. Deterioration of irrigated lands is caused by improper water management, leading to salinisation.

North Africa

A large area that is severely affected by desertification are the mountain slopes and the plains of North Africa. Moderate to high salinity affects about 30 percent of the irrigated land in Egypt. Wind erosion is dominant in the drier regions and water erosion on the wetter sloping lands. The Maghreb countries of Algeria, Morocco and Tunisia have been subjected to especially serious water erosion (Dregne, 1986).

Chapter 2

IRRIGATION

Available soil water

Irrigation is the artificial watering of crops. In areas with insufficient rainfall this is practiced to ensure a good crop development. Rainfall can be insufficient during certain periods of the year or throughout the year. The available water storage capacity of the soil and consequently the water application depth and irrigation frequency are determined by the water-holding characteristics of the soil and by the root depth and root distribution of the crop. The depth and distribution of roots depend largely on the kind of the crop, the growing stage and the soil profile (EUROCONSULT, 1989).

The difference in volume percentage between field capacity and wilting point is called the available water holding capacity. It is predominantly determined by the texture and structure of the soil. All free moisture contained in the pore space of a soil is subject to capillary forces. This capillary pull causes a negative soil moisture tension, or suction, which is expressed as the height of the water column (h cm) that would rise from the water-table, against the force of gravity. This height is inversely proportional to the diameter of the pores; according to a simplified formula $h = 0.3/d$. The negative logarithm (pF) of the soil moisture tension in centimetres of water is used to indicate this tension. A specific pore size distribution of a given soil determines the specific relationship between its pF values and the corresponding moisture contents by volume, since at each pF level all pores wider than the corresponding critical pore diameter are empty (EUROCONSULT, 1989).

A soil can be characterized by its pF curve, which shows the relation between pF values or pore diameters and moisture content under laboratory conditions. The curve is also called the soil moisture characteristic. The most important pF values of this curve are:

- pF = 0: saturation point, at which the total pore space of undisturbed soil is virtually corresponding moisture contents by volume, since at each pF level all pores wider than the corresponding critical pore diameter are empty (EUROCONSULT, 1989). A soil can be characterized by its pF curve, which shows the relation between pF values or pore diameters and moisture content under laboratory conditions. The curve is also called the soil moisture characteristic. The most important pF values of this curve are:

pF = 0: saturation point, at which the total pore space of undisturbed soil is virtually all by volume or in millimeters per decimetre of soil. Once the pF curve of a certain soil is known its moisture content can be deduced from its soil moisture tension and, vice versa, its soil moisture tension can be deduced from its percentage pore space filled with moisture. Since all moisture infiltrating below the reach of plant roots is wasted, it is of interest in agricultural practice to know the available moisture that can be retained by the root zone of a crop. For this purpose the root zone is subdivided into layers having different physical characteristics. The soil moisture characteristic of each of these layers is determined. In this manner each

layer can be judged in terms of its available moisture and its air capacity. Not only the available soil moisture capacity, but also the depth of rooting zone determines the moisture available to the crop (EUROCONSULT, 1989).

Water availability is of consequence in arid and semi-arid zones. Problems related to water availability comprise water shortage and soil and water salinisation. Salinisation occurs when wrong irrigation techniques have been used. Water shortage develops when too much water is taken from natural or artificial sources. Shortages may be absolute and relative. When a well is finished or the ground water table is lowering and the land and water have been used in the same manner as before, one speaks about an absolute deficiency. When more water is used for more intensive agriculture, expansion of the area of cultivation or introduction of crops that require more water, these are called relative shortages. Inefficient or inadequate irrigation techniques may also cause water shortages. A valuable loss of water occurs when irrigation equipment is not well kept in repair.

Irrigation methods: surface irrigation

Three categories of irrigation methods can be distinguished. These are surface irrigation, sprinkler irrigation and localized irrigation. *Surface irrigation* is widely used and consists of labour intensive methods with relatively low capital costs (Ghassemi *et al.*, 1995). According to EUROCONSULT (1989), by surface irrigation a technique is meant where water is applied onto the field to form a water layer which infiltrates into the soil. The field may be wetted completely, such as border and basin irrigation, or partly, such as furrow and corrugation irrigation. The water layer may be moving during irrigation or it may be mainly stagnant. These are called flow irrigation and check irrigation respectively. Water application onto the field may be uncontrolled, in cases of inundation of the field determined by natural conditions, semi-controlled, when non-prepared or slightly prepared fields are irrigated from ditches, or controlled, when well-prepared fields are irrigated from ditches. Infiltration will be vertical under complete submersion, and vertical and lateral under partial submersion. Furrow and corrugation irrigation requires more labour than border and basin irrigation; graded irrigation requires more labour than level irrigation.

Border irrigation requires preparation of the land in order to distribute the water. The land is divided into long, narrow parallel strips separated by earth banks. The strips are arranged lengthwise in the direction of the maximum gradient of the land. Each irrigation strip has a watering conduit situated at the highest point from which the water flows down the gradient to the bottom, moistening the soil. Another type of surface irrigation is *basin irrigation*. The main differences between this type and the former are the crossbanks constructed at regular intervals on the contour down the slope and a pipeline or channel to supply water to each basin. The spacing of the crossbanks is determined by the steepness of the longitudinal slope. Once a basin is filled with water the flow is turned into another basin and the ponded water is allowed to soak into the soil. The last type of surface irrigation is *furrow irrigation*. Numerous furrows are used instead of the smooth surface of basins. Water is released from a supply point to head

channel or pipeline located on the highest land. If an open head channel is used water is released into the furrows by siphon tubes, outlet pipes or shovel cuts. The furrows may be V-shaped or U-shaped (Ghassemi *et al.*, 1995).

EUROCONSULT (1989) distinguishes level and graded irrigation. In level irrigation fields are ponded with the desired irrigation depth of water, which can then infiltrate. With graded irrigation the fields have a slope in the longitudinal direction. The types of surface irrigation mentioned above can be applied to either or both level and graded irrigation.

Infiltration family, surface roughness, stream size and application depth are important factors in designing the length of fields in level and graded surface irrigation. For graded infiltration, the longitudinal field slope is also of importance. Infiltration family is a term used to group soils with similar infiltration characteristics (EUROCONSULT, 1989). Appendix I shows tables of the main infiltration families and of other factors of importance when determining the length of a field.

Irrigation methods: sprinkler irrigation

Sprinkler irrigation is less labour intensive than surface irrigation, but demands high capital costs. A sprinkler system has four basic components, which are a pumping unit, main lines, lateral lines and sprinklers. Water is sprayed over the land surface. The advantage over surface irrigation is the avoidance of uneven penetration of water and its subsequent waste. The system is suited to a wide range of slopes, soils and crops. Because of high capital costs, the method is usually restricted to crops that render up a high return (Ghassemi *et al.*, 1995). According to EUROCONSULT (1989), several advantages exist. Land with irregular topography and shallow soils can be brought under irrigation, because irrigation can be applied by sprinkling with a minimum of levelling and disturbance of the top soil, which reduces costs of land preparation. In this way runoff and soil erosion can be eliminated. Sandy or highly permeable soils can be irrigated without excessive losses by deep percolation, so that drainage problems are reduced. Since there are no field ditches, no reduction in cultivable areas takes place. The absence of ditches eliminates one source of weed propagation. A greater efficiency in water use and labour can be achieved compared to surface irrigation, especially when the water supply is a small, continuous stream. Other advantages of sprinkler irrigation are the possibilities of adaptability to small applications, addition of soluble fertilizers and herbicides, adaptability to infiltration rate of the soil and a high degree of automation.

Limitations of sprinkler irrigation consist of the high initial cost of equipment, the higher operation costs compared with surface irrigation, the need of a pumping plant and the requirement of energy. Portable sprinkler systems require manual operation under wet field conditions. Water is susceptible to distribution to wind. Other limitations are the susceptibility of certain crops to leaf damage from sprinkling, the risk of fungus diseases and the possibility of damage by saline water to the crops by burning. Filtration of irrigation water may be necessary to prevent clogging of sprinklers (EUROCONSULT, 1989).

Important aspects one should take into account when designing a sprinkler system are application rate, uniformity of distribution, pressure, drop size, application efficiency, flexibility and leaching requirements. The basic infiltration rate of the soil should be higher than the maximum *application rate* of irrigation water. Appendix II shows a table with suggested maximum water application rates. The unevenness of *water distribution* should be taken into consideration. *Pressure* losses in pipes and differences in elevation cause pressure variations and consequently flow variations, since sprinklers operate optimal within a certain *pressure* range. The *drop size* is determined by nozzle size and pressure. High pressure and small nozzles give smaller drops, which are easily blown away by wind. Large drops may damage sensitive crops and may lead to deterioration of soil texture. Evaporation losses, runoff and percolation losses reduce the *application efficiency*. Different crops and different growing stages require different application depths, irrigation intervals, application rates and elevations of the sprinklers above the land surface (EUROCONSULT, 1989).

Sprinkler systems may vary in size, covering from a few to thousands of hectares. Sprinkler irrigation systems may be permanent, portable or semiportable. The sprinkler radius may vary from 12 to 100 m. The systems are either operated automatically or semi-automatically. (EUROCONSULT, 1989). *Portable* sprinkler irrigation can be moved in total from one place to another. *Semiportable* or *semipermanent* sprinkler systems have a fixed pumping unit. The mains and submains are underground and only the laterals are portable. A *permanent* sprinkler system has all components of the system permanently located (Ghassemi *et al.*, 1995).

Israel

In Israel, where climatic conditions change from semi-arid in the north to arid in the south, agriculture is completely depended on irrigation. The amount of water utilized annually exceeds 90 percent of Israel's entire water potential. To overcome the gap between the country's water consumption and its water potential, the Water Commissioner's Office has promoted a series of administrative, legal and technical steps to increase water saving in all three sectors of consumption, to wit domestic, industrial and agricultural.

Automation of irrigation is one of the means to raise crop production per unit of water. By the early fifties sprinkler irrigation was the most applied irrigation method in Israel. In the early sixties the weak points in Israel's irrigation system, which then was 90 percent sprinkler-based, were investigated. The results indicated a lack of accuracy in water application owing to the human factor involved in controlling the taps and a loss of water due to both portable and stationary pipes. Furthermore, a loss of water due to the topography of the irrigated areas was established. Wide pressure differences in the sprinklers cause erratic discharge rates of the individual sprinklers. In addition, the different shapes and sizes of the irrigated plots caused wastage of water in the margins, such as along plots and roads, as a result of inadequate sprinklers.

To offset the drawbacks of the 1960's, techniques and asseccoires were developed. The main ones are the promotion of automatic metering taps, PVC and flexible polythylene long pipes, cheaper and reliable pressure and capacity regulators and a complete new series of sprinklers, such as the tiny drip and trickle types, low and high capacity impact sprinklers and part-circle sprinklers. The *automatic metering taps* shut off the current of water after a preset amount has flown through it. Time-activated meters have been eliminated because of their inability to supply precise quantities. The *PVC and flexible polythylene long pipes* replace the aluminium detachable short pipes. The use of these appliances and techniques is estimated to bring about a saving in water of at least 15 percent of the total amount used in agriculture.

In general automatic control of sprinklers started in greenhouses or large turf areas where watering is limited to certain periods of use or subject to other limiting factors such as wind and sunshine. The scarcity and rising cost of skilled labour, the scarcity of water and the availability of cheaper and much more dependable and versatile control equipment accelerated the use of automatically controlled sprinklers. In Israel three principal types of automated irrigation may be distinguished, namely programmed irrigation, remote control and full automation. These types are not exclusive and variations of each type are possible. *Programmed irrigation* comprises equipment enabling a predetermined irrigation programme to be carried out automatically. The determination of the irrigation programme and the actual setting of the equipment to carry it out may or may not be automatic. The automatic metering valve, which is widely spread in Israel, is hydraulically controlled and provides a fairly precise control of the amount of water supplied in spite of variations in water pressure or other factors. This metering valve is preset manually to the desired amount of water to be supplied and shuts off automatically when this amount has flown through the valve. The northern border of Israel is an area where this kind of irrigation practise is applied frequently. *Remote control* comprises irrigation practises where the control of the water application system is made from a central location. It may be combined with pre-programmed irrigation. In 'Gaza Strip' settlements remote control is often used. When using *full automation* equipment the moment of irrigation and the quantity of water to be applied are determined automatically, without human intervention. Full automated equipment is used in Kfar Hayarok, Kibbutz Revivim and in greenhouses (Arlosoroff, 1970).

Irrigation methods: localized irrigation

Like the former type of irrigation, localized irrigation is less labour intensive than surface irrigation, but demands high capital costs. Common to the various localised irrigation types is the frequent application of water at low rates, keeping the soil around the roots near field capacity. In this manner crops are watered with increased uniformity, soil structure is preserved, water is saved because of reduced evaporation and a correct control of water quantities and nutrients reaching plants is possible. Disadvantages are the obstruction of small drippers because of water impurities, the appearance of biological or chemical formations, creation of an area of permanently saturated or near-saturated soil favouring the development of plant or animal pests and salin accumulation (Romita and Galbiati in: Ghassemi *et al.*, 1995). Without

remedial action zones of salt accumulation may occur, particularly at the outer edges of the wetted soil mass. Rain may move salts into the root zone. To control the salinity, supplementary sprinkler irrigation or surface irrigation may be needed for leaching purposes when rainfall is low. If the wetted zone is too small, root development may be inadequate. Yields may be effected and trees may be blown over by strong winds. Additionally the regular supply of water makes plants more susceptible to stress (EUROCONSULT, 1989).

Three types of localised irrigation can be distinguished, namely trickle or drip irrigation, microjet or microspray irrigation and mini-sprinkler irrigation. *Trickle or drip irrigation* is a method of applying water directly to the soil around the plant root at low rates of flow but frequently enough to keep the soil around the roots at or near field capacity. Next to a pumping unit, main, submains and laterals a filter and drippers are needed. Water should be filtered to avoid the deposition of material in lines and drippers. Fertiliser and pesticides can also be applied in the water. The interval between irrigations varies according to the soil structure and the evaporative demand. For very coarse soil with a small water-holding capacity, irrigation may be for a short period each day when plants are using the most water. For light sandy soil, the interval may vary from one to four days. For heavier loam and clay loam, the interval between watering may vary from two to eight days. The duration of application also varies with the type of soil. Heavy soil might be watered for 10 to 16 hours, light soils for 6 to 10 hours (Ghassemi *et al.*, 1995).

According to EUROCONSULT (1989), advantages of drip irrigation consist of multiple things. Management is easier, since drip irrigation does not impede other farm operations and access to the field is possible at all times. Control of pests and weeds is easier as foliage and soil surface are not wetted and fields are accessible at all times. The application of drip irrigation avoids leaf burn. The use of water of higher salt concentration than with conventional systems is possible, when soil water tension is kept low. Applying drip irrigation ensures a better use of poor soils, since heavy soils are difficult to irrigate by sprinkling and very light textured soils cannot be irrigated properly by surface methods. Because of high efficiency and the low working pressure, pumping costs are relatively low.

The second type of localised irrigation, *microjet or microspray irrigation* is an under-tree method of irrigation. The main difference from mini-sprinkler is the absence of a moving spinner to distribute the water droplets. Instead a fine jet of water is directed onto a fixed irrigation surface. Microjets tend to be used on new plantings and young trees (Ghassemi *et al.*, 1995).

Another method of under-tree irrigation is *mini-sprinkler irrigation*. Because mini-sprinklers deliver more water over a greater area than microjet irrigation methods and because some sprinklers have a pressure compensation valve, they are often used on mature plantings in place of microjets. (Ghassemi *et al.*, 1995).

Selection of irrigation methods

The division in three main groups as localized irrigation, sprinkler irrigation and drip irrigation is made by EUROCONSULT (1989) as well, but the subdivision of these groups is dealt with more extensively. For further reading one is referred to the Agricultural Compendium For Rural Development in the Tropics and Subtropics.

The selection of irrigation methods is influenced by factors such as nature of the soil, relief as in place of microjets. (Ghassemi et al., 1995). Selection of irrigation methods The division in three main groups as localized irrigation, sprinkler irrigation and drip irrigation is made by EUROCONSULT (1989) as well, but the subdivision of these groups is dealt with more extensively. For further reading one is referred to the Agricultural Compendium For Rural Development in the Tropics and Subtropics. The selection of irrigation methods is influenced by factors such as nature of the soil, relief and considerable damage caused by saline water on leaves when the concentration exceeds a certain value (Ghassemi *et al.*, 1995).

The possibilities of farm irrigation and water supplies do not only depend on physical characteristics of the irrigated area, such as climate, topography and soil type, but also on socioeconomic conditions. Available information is needed. If this is not available, the lack of sufficient knowledge of water use efficiency has several serious drawbacks. Investments might be too high and limited water resources might not be optimally distributed and used. Harmful side effects such as rising water tables and soil salinisation might occur. See appendix III for a number of efficiencies of irrigation water use, defined by Bos & Nugteren (1990). Appendix IV shows information concerning labour requirements for various field irrigation systems.

The United Arab Emirates

The United Arab Emirates faced a number of problems when developing their national irrigation programme. These problems included a scarcity of water, moderate to high salinity in most water supplies, lack of labour and poor farming practices. Several practices have been identified to improve yields while using the high salinity water. Drip irrigation appeared to improve the general growth of tomatoes as compared to furrow irrigated tomatoes. No differences were found between field seeded or transplanted tomatoes. Further, new lemon plantings showed that sprinkling reduced growth during the first 16 months as compared to drip and basin irrigation. Extensive leaf burn and defoliation were caused by the concentrations of sodium and chloride in the irrigation water. 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. A comparison of sprinkler irrigated potatoes showed 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 (FAO, 1985).

Spain

In Spain traditionally the available water supply has been distributed by a preestablished and equitably scheduled utilization. In large irrigation districts this ensures a nearly constant flow of water circulating in the main canals during the periods of time when consumption varies little. In order not to lose any water, some water users have to irrigate by day and some by night. Particularly in southern Spain and other areas with a strong tradition of irrigation, this system of operation was an accepted practice for centuries. In the late sixties difficulties began to be encountered, particularly in the new development areas set up by the government, since users refused to irrigate at night.

The need arose to repair old irrigation networks to incorporate them in the new water works systems which are entirely different from the traditional ones. In addition, the designing, laying out and bringing into use of new irrigation districts had to meet the new criteria. The conversion of irrigation systems raised very serious difficulties in the old systems and for new ones required principles of design to which up to then relatively little importance had been attached. Not only should attention be paid to the need of adjusting the operation of water works to the workday, but also to diminish loss of water through the operation of irrigation networks not flexible enough to meet fluctuations in consumption, since at certain times almost the complete water supply is utilized. The improvement of existing irrigation networks and the better designing of future ones is therefore a fundamental goal, if only from the viewpoint of the economics of water consumption. The need to improve the functioning of these irrigation systems arises almost exclusively in the large areas that can be irrigated for community-wide use, since in small community areas or in those where private landowners exist, it is much easier to equate water consumption to supplies.

Water conduction through closed pipes or tubes with water under pressure has advantages over open ditches, not only in immediate response to fluctuations in demand, but also because they are a better guarantee against wastage of water. In the Montijo district, the entire Bajo Ter zone, totalling 12.000 ha, is a vast irrigation district, completely brought under sprinkler irrigation. Water is supplied upon demand. The best kind of irrigation network would consist of pipelines. Many engineers consider the best solution to be that of overhead tanks despite their higher cost, in view of their greater guarantee of usefulness. For economic reasons, instead of pipelines, water measuring devices have been introduced widely. These devices regulate sets of pumps already in operation according to requirements. Whenever the pressure of the network falls below a set level, the devices start functioning. For canals with great streamflow capacity the cost of piping is prohibitive compared with the cost of open ditches and may involve difficulties in the construction of large diameter piping with water under pressure. In addition, in already existing irrigation networks it may be advisable to improve installations by introducing a certain amount of automation without substantially altering existing channels.

Untill the late sixties, in Spain no electrically controlled automatic systems have ever been used except in very special cases. There is a great future for electronic computers to improve regulation of water

use. The shorter the normal irrigation workday, which is gradually coming into effect in the countryside, results often in insufficient capacity of the networks already constructed. So it is of utmost importance that the water utilization be improved through certain programmes that will, with the help of electronic calculations, maximize flow capacity of existing networks by means of the most appropriate manipulation at different times (Montañes, 1970).

Chapter 3

SOIL AND WATER INTERACTIONS

Precipitation characteristics

In the majority of catchments, unless outcropping rock is dominant, precipitation interacts to an important degree with soil. The pathway precipitation follows through or over soil to a drain, stream or lake, depends upon the physical characteristics of the soil, the quality, duration and intensity of precipitation, prior climatic conditions, surface and subsurface topography and the form of the precipitation. During this period of soil-water contact, chemical reactions take place which regulate the chemical composition of the obtained freshwater. Precipitation itself contains a solute which also interacts with the soil solid components as the water drains through or over the soil. Origins of the solute may be natural or may result from human activities.

The stage of soil evolution determines the extent to which soil modifies solutes in water. Either the hydrological pathway followed by the water may change with the degree of soil development or changes may occur over decades and centuries in the soil physicochemical characteristics. Soil functions as a buffer regulating the quality of surface water and, to some extent, groundwater. Contribution of individual catchment characteristics to the overall process may be associated with precipitation characteristics, other climatic factors, soil characteristics, general catchment characteristics or vegetation characteristics.

The relative amounts of precipitation and evapotranspiration play an important role in soil formation. When evapotranspiration exceeds precipitation, alkaline soils with calcium carbonate accumulation are likely to develop. In drier areas less water has contacted the mineral soils, whereby less mineral weathering has occurred and less base cations have leached from the ecosystem. A prolonged and heavy rainstorm, occurring in a flat region with freely drained soils, will flush out soluble salts previously present in the soil solution when the water drains to the water table. The soluble salts composition will be the net result of previous wet and dry deposition inputs, geochemical weathering, microbial activity, plant uptake, soluble fertiliser, climate prior to precipitation and the precipitation composition. Initially a small increase in soluble salts may occur in river water through the flushing effect. The extent of this will depend upon catchment size and the degree of mixing with groundwater. Generally the evolution of acid soils from the same parent material over the same timescale will be more advanced in an area with higher annual precipitation.

In arid climates considerable natural organic matter accumulation is not likely to occur, so that organic matter concentration in solution is prone to be low. Nevertheless, when sodic soils are irrigated and drained, the very high pH will cause dissociation of phenolic and carboxyl groups on the organic matter, rendering it much more soluble.

The changes which occur in precipitation chemistry from storm to storm or even within individual storms are of little consequence of water quality when soils in agricultural drainage basins are regularly

fertilised and limed. An other climatic factor is temperature, which is important in regulating soil-water interactions. The higher the temperature, the greater the evapotranspiration and the less probability of surface runoff, return flow or throughflow occurring. Biological activity also increases at higher temperatures, so soil formation processes will be modified (Cresser *et al.*, 1993).

Soil, catchment and vegetation characteristics

Both chemical and physical characteristics of soils influence the solute composition of drainage waters and they are interactive to a large degree. The most important physical parameter is hydraulic conductivity and its change with depth down the soil profile. Hydraulic conductivity, together with slope, controls the hydrological pathway and determines what soils the drainage waters equilibrate with.

Unless the mineral soil is very old or shallow or the soil was formed from highly weathered, acid rocks or associated tills, the base status and pH of drainage water are likely to be high and the dissolved aluminium concentrations very low. The soil parent material is important since the soil pH depends upon the capacity of soil mineral geochemical weathering to replace cations depleted in drainage water or by erosion or crop or animal removal. The soil base saturation depends upon the current state of soil evolution, which depends, other formation factors being equal, upon the nature of the soil parent material.

The catchment characteristics, such as slope, other surface and subsurface characteristics, aspect and altitude, are related to the soil and precipitation characteristics. All these factors influence soil thickness and other soil formation factors. Slope influences the probability of physical erosion and hence soil thickness. It directly and indirectly influences water retention in the soil and hydrological pathway.

The type of vegetation growing in a catchment may significantly influence water quality in a natural ecosystem. Several interacting mechanisms regulate the changes observed. They include change in water loss by evapotranspiration and associated modifications to hydrological pathways, differences in the trapping efficiency of water and atmospheric nutrient inputs, modifications to the soil profile, including the extent of litter accumulation, the degree of microbial activity and alterations in the extent of erosion. Changes in throughfall solute chemistry may also be important (Cresser *et al.*, 1993).

Drainage

Soils which are too wet for healthy plant growth need to be drained. Improved aeration resulting from drainage lowers the solubility of iron and manganese, reduces the extent of denitrification losses of gaseous nitrogen species, encourages nitrification and encourages oxidation of reduced sulphur species to sulphate. Furthermore, drainage may be used to overcome salinity problems. These may arise in arid climates as a negative consequence of irrigation schemes. The drainage water chemistry in arid climates depends upon the soil alkalinity, calcium carbonate content and the irrigation water quality (Cresser *et al.*, 1993).

Most soils in agricultural use, especially if the agriculture is intensive, are treated with one or more agrochemicals from time to time. These include fertilisers, liming materials and pesticides. Care should be taken in order that agrochemicals and their degradation products are not transferred at unacceptable concentrations to potable water supplies. (Cresser *et al.*, 1993).

Iraq

The Tigris-Euphrates River Plain in Iraq is one of the oldest known irrigated areas of the world. Both salinity and high water tables became and still are a problem, although river water salinity for most of the irrigated area is low ($EC_w = 0.3 - 0.7$ dS / m). Since the natural water quality has been excellent, salinity should normally not be a problem. However, with inadequate drainage and resulting high water tables, it was impossible to control and permanently leach any significant portion of the salts being applied in the irrigation water. Salts slowly accumulated and productivity declined. Records indicate that salinity problems were present in some areas by 2400 BC and farmers were turning from wheat to the more salt tolerant barley. Drainage and reclamation projects are now being implemented and the area will again become a very productive agricultural area (FAO, 1985).

Fertilisers and pesticides

A link exists between nitrate concentrations in streamwater and intensity of agricultural activity. This is caused by nitrogenous fertilisers and manures. Liming and crop removal produce conditions which favour mineralisation of organic nitrogen and nitrification. Concentrations of nitrate in rainfall tend to be higher in drier, lowland areas better suited to agriculture. Both in the atmosphere and in soils the dilution effect is reduced in such areas. In the soil, the bulk of the applied ammonium is retained on cation-exchange sites. Manures are often applied as a method of disposal and to increase soil organic matter and contents of nitrogen and phosphorous. Mineralisation and nitrification of organic nitrogen may contribute substantially to total pollutant load of adjacent drainage waters.

Unlike nitrates, phosphates are generally relatively insoluble. When they do dissolve, most of the phosphate is fixed by adsorption by soil mineral components. This minimizes the probability of serious pollution of freshwaters from normal use of phosphate fertilisers. Pollution from sludge disposal or sewage outlets is more significant. The growth of algal blooms may be a consequence. Phosphate and nitrate are often the key nutrients limiting plant growth in oligotrophic lakes. When the two pollutants occur together, growth may become very rapid and eutrophication takes place.

Mobilisation of potassium from potassium fertilisers is rarely a source of pollution. Most of the element is retained on cation-exchange sites or fixed by clay minerals as it moves down the soil profile. In most agricultural soils, liming is of no consequence to water quality. In uncultivated upland catchments it may have beneficial effects by reducing water acidity and increasing its calcium content.

The fraction of any applied pesticide dose or its degradation products that eventually reaches groundwater or a stream is the net result of a number of interactive processes. These include the rates of chemical transformations in the soil, uptake by plants and soil organisms, the distribution between soil gas, liquid and solid phases and transport rates through the soil in the gas and liquid phases. Transport rates in soil solution depend upon adsorption coefficients on soil solid components, the excess of precipitation over evapotranspiration, crop cover and growth stage (Cresser *et al.*, 1993).

Chapter 4

WATER QUALITY

Groundwater

Irrigation water is obtained from groundwater, surface streams, artificial and natural sources. Groundwater may be extracted by shallow or deep wells, open or closed tube wells and vertical or horizontal wells. Traditional wells consist of an open pit dug to below the phreatic water table. The water is drawn by hand, by animal traction or by motor-driven pumps. The horizontal well is of importance in some countries. An underground gallery is dug almost horizontally along the sloping land in order to drain groundwater from the above lying areas. These systems are known under different local names, such as rhattaras in Morocco (EUROCONSULT, 1989).

The irrigation potential of groundwater depends on hydrogeological conditions such as the presence and depth of exploitable aquifers, the available groundwater reserve and the natural or artificial recharging conditions. The artificial recharging of groundwater by spreading and infiltration of surface water may be a viable solution to the optimum use of perennial, irregular surface streams in semi-arid regions (EUROCONSULT, 1989).

Some aspects to be considered in evaluating groundwater development are suitability for small-scale development, suitability for step-wise development of large schemes composed of independent smaller units, whether the development capacity can be adapted to the available funds and the absorption capacity of the area and whether wells can y spreading and infiltration of surface water may be a viable solution to the optimum use of perennial, irregular surface streams in semi-arid regions (EUROCONSULT, 1989). Some aspects to be considered in evaluating groundwater development are suitability for small-scale development, suitability for step-wise development of large schemes composed of independent smaller units, whether the development capacity can be adapted to the available funds and the absorption capacity of the area and whether wells can r table and an increasing groundwater salinity (EUROCONSULT, 1989).

Groundwater is an important source for industry and agriculture and it sustains rivers experiencing low flows. Groundwater is not only abstracted for supply or river regulation purposes, it also naturally feeds surface waters through springs and seepages to rivers and is often important in supporting wetlands and their ecosystems. Removal or diversion of groundwater can affect total river flow. A reduction in either quantity or quality of the discharging groundwater can significantly influence surface-water quality. Surface-water and groundwater are therefore closely linked in the water cycle (Hiscock, 1995).

The slow rates of groundwater flow and low microbiological activity limit any self-purification. Processes which take place in days or weeks in surface-water systems are likely to take decades in groundwater. The causes of groundwater pollution depend much on the spread of toxic and persistent

chemicals from agricultural intensification the world over, from salt extrusion in disturbed dryland soils, nitrate pollution from excessive or inappropriate fertilizer use and sedimentation of rivers and estuaries (Hiscock, 1995).

Jordan

Groundwater degradation is a major problem in the Wadi Dhuleil irrigation scheme, the largest groundwater irrigation project in Eastern Jordan, comprising 1560 ha. The irrigation water supply comes entirely from the groundwater. Water pumped from the Dhuleil - Halabot aquifer was initially of good quality with EC_W in the range of 0.4 to 0.6 dS / m. In the northeastern part of the project lower quality water was found with EC_W ranging between 1.05 and 1.35 dS / m. Since irrigation began in 1971 there has been a slow deterioration in water quality. Salts are thought to be the source of degradation, leaching down to the groundwater by deep percolation of irrigation water, although the main sources of salt consist of lenses deeper in the soil profile. 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 supply water in sufficient amounts to meet both crop evapotranspiration 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 (FAO, 1985).

Surface streams

River water can be drawn either by gravity offtake, with or without a diversion dam, or by pumping. Rivers with a regular discharge and a stable base flow are appropriate for irrigation. The feasibility of using a river can be determined by statistical analysis of long-term daily river discharges and by irrigation water requirements. To achieve optimum crop production, crop patterns must be adapted to the available irrigation water. Other aspects to be remembered when evaluating surface stream possibilities are whether the offtake or pumping station is far away from the irrigation area, whether the development costs are relatively low, the adaptability to small-scale and large-scale development and the efficiency with which the river flow is used (EUROCONSULT, 1989).

Yemen Arab Republic

In the Yemen Arab Republic surface water quality deteriorates due to sequential use and re-use of a single water supply for irrigation. The upper reach of the Wadi Al Hama, near Taiz, is of excellent quality

($EC_W = 0.5$ 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 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 $EC_W = 0.5$ to near 8.0 dS / m. 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 irrigation of maize or sorghum using runoff from nearby rocky hillsides. A similar degradation pattern can be seen for other rivers, such as the Euphrates River and the Tigris River in Iraq (FAO, 1985).

Reservoirs

Artificial reservoirs are constructed by closing off the river valley at a suitable site by a dam. The dam is equipped with a spillway to evacuate excess flood water. Water for irrigation is released through an intake tower and conveyed to the area by a main canal or to a diversion dam via the river-bed. The mobilization of water from natural lakes for irrigation usually requires pumping. The storage in a reservoir equals the storage at the beginning of the month, minus the change in storage, being the difference between outflow and inflow during the month. The outflow is equal to the sum of irrigation requirements, reservoir seepage, evaporation losses and the water requirements for other uses (EUROCONSULT, 1989).

The main advantage of an irrigation reservoir is that it provides a regular water supply. Secondary benefits are the possibility for hydro-electric power production, the prevention of flooding in downstream areas and the possibilities for recreation and fish production. Some potential problems of a reservoir are listed below. As a rule it is located in a narrow upstream valley, at a fair distance from the downstream irrigation area. This implies the need for an expensive long supply canal. It is not suitable for small-scale or step-by-step implementation. It requires careful studying and planning of all related aspects, especially agricultural development. It requires careful staffing for operation and maintenance. It involves high initial investments and low revenues during the first years after implementation. The land to be used for a reservoir sometimes necessitates the evacuation of the rural population (EUROCONSULT, 1989). Furthermore, the ecological impact should be studied and risks of vector-borne diseases and pests should be taken into account.

Irrigation water quality

The quality of irrigation water is determined by various chemical and physical characteristics, whereby aspects like temperature and oxygen content are usually of minor importance. The salinity or total concentration of soluble salts is the most important parameter, since growth of the majority of crops is

affected by total concentration of ions rather than by any specific ion. Although dissolved salts may contain valuable plant nutrients, irrigation with salty water may lead to soil salinization, which will impede the water uptake of the plant (EUROCONSULT 1989).

Water used for irrigation can vary greatly in quality depending upon type and quantity of dissolved salts. Salts are present in irrigation water in relatively small but significant amounts. They originate from dissolution or weathering of the rocks and soil, including dissolution of lime, gypsum and other slowly dissolved soil minerals. These salts are carried with the water to where it is used. In the case of irrigation, the salts are applied with the water and remain behind in the soil as water evaporates or is used by the crop. The suitability of a water for irrigation is determined not only by the total amount of salt present, but also by the kind of salt. Various soil and cropping problems develop as the total salt content increases and special management practises may be required to maintain acceptable crop yields. Water quality or suitability for use is judged on the potential severity of problems that can be expected to develop during long-term use. The problems that result vary both in kind and degree and are modified by soil, climate and crop, as well as by the skill and knowledge of the water user. As a result, there is no set limit on water quality; rather, its suitability for use is determined by the conditions of use which affect the accumulation of the water constituents and which may restrict crop yield. The soil problems most commonly encountered and used as a basis to evaluate water quality are those related to salinity, water infiltration rate, toxicity and a group of miscellaneous problems (FAO, 1985). When analysing irrigation water, care should be taken to obtain a representative sample. The depth of sampling will influence salinity, as fresh water will flow on top of more saline water. The period of sampling is also of importance, since most river waters are characterized by seasonal changes in chemical composition (EUROCONSULT, 1989).

Generally an increase in the salt content of irrigation water will result in an increase in the salinity of the soil water. The rate and extent of the increase will depend on a number of factors including the leaching fraction, the ionic composition of the irrigation water and physical properties of the soil. The leaching fraction refers to the amount of water supplied by irrigation or rainfall in excess of that required to satisfy consumptive use of crops and leaching efficiency. Physical properties of the soil comprise infiltration, moisture characteristics, drainage and water application (Ghassemi *et al.*, 1995).

The total salts content or specific cations and anions content may be expressed as weight ratio, weight per unit volume or electrical conductivity (EC) at 25 ° C. The weight ratio is often expressed as mg / kg or parts per million (ppm), weight per unit volume is commonly given as mg / l or meq / l and electrical conductivity is usually referred to in dS / m, which is equivalent to mmhos / cm or mS / cm (EUROCONSULT 1989).

The sodicity or sodium hazard of irrigation and soil waters can negatively affect crop production. Sodicity refers to the concentration of sodium relative to other cations. Unlike salinity hazard, excessive sodium does not impair the uptake of water by plants but impedes the infiltration of water into the soil. The growth of a plant is thus affected by an unavailability of soil water (Ghassemi *et al.*, 1995).

Toxicity normally results when certain ions are taken up with the soil water and accumulate in the leaves during water transpiration to an extent that results in damage to the plant. The usual toxic ions in irrigation water are chloride, sodium and boron. Some trace elements that occur in water and soil are essential for plant growth, but become toxic at an elevated concentration (Ghassemi *et al.*, 1995).

The quality of irrigation water is also determined by the quantity and quality of suspended solids like sand and silt. Silts may supply plant nutrients to irrigated top soils and the soil texture and soil structure may improve. This in turn will have a favourable effect on the available soil water and on soil permeability. Nevertheless, silt may also cause deterioration of the soil texture and soil structure, depending on quality and quantity of the amount of silt and the type of soil. Disadvantages of silt comprise the siltation of reservoirs, siltation of canals and structures, excessive wear of sprinklers, pipes and pumps, clogging of sprinkler and dripping nipples and a reduced lifetime of works. This results in high maintenance costs. Silt content is expressed as a weight ratio or as a weight per unit volume of water, such as mg / kg and mg / l respectively (EUROCONSULT, 1989).

The actual suitability of a given water for irrigation depends very much upon the specific conditions of use and on the relative economic benefits that can be derived from irrigating with that water compared to others (Ghassemi *et al.*, 1995). Marginal and poor quality water is being used in several places in the world. Careful management is required to prevent or cope with the related potential problems. Although crop yields may not be at a maximum, they continue to provide an economical return when using marginal and poor quality water, since often it is the only supply available. In other cases, re-use of wastewater from both agricultural and urban sources may be required. Awareness is growing that this wastewater must be treated and returned to supplement the main water supplies. Most of this degraded wastewater is still usable and its utilization often reduces the total volume of wastewater that must be disposed of ultimately. As competition for existing supplies increases, many irrigation projects will be faced with this re-use problem (FAO, 1985).

Tunisia

Soil conditions and high salinity of the irrigation water make the lower Medjerda Valley of Tunisia difficult to farm. West of the town of Tunis the Medjerda River enters a wide coastal plain characterized by heavy clay soils with a lime (CaCO₃) 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 develop and water quickly enters the soil through the cracks until they swell and close. The quality of the river water varies considerably during the year, with salinity (EC_w) ranging from 1.3 to 4.7 dS / m. During much of the year, the river water can be used for irrigation of medium to high salt tolerant crops. The soil conditions in summer make efficient leaching difficult, while in winter the rainfall only partially leaches salts from the top 15 cm of the clayey soils. This leaves the soil surface with such poor structure and low infiltration rate (high ESP and low EC_e) that leaching the entire profile during this winter period becomes nearly impossible. The

main recommendation of a field research programme, performed by the Gouvernement of Tunisia and Unesco, 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 this study are transferable to other similar areas (FAO, 1985).

Water quality evaluation

Irrigation water classification schemes aimed at defining the salinity hazard for a given water are all based on generalisations regarding crop growth, climate, irrigation management and soil properties (Ghassemi *et al.*, 1995). According to Frenkel (1984, in: Ghassemi *et al.*, 1995) these classifications are rigid and often fail to recognise certain specific factors which are critical in determining the potential use of a given water. Therefore, any assessment of the suitability of water for irrigation must be made in relation to three main subjects. These are crop tolerance to salinity, how much leaching will be achieved and what level of soil water salinity will be obtained when a certain type of irrigation water is used. More recent and presently used guidelines for evaluating irrigation water are those recommended by FAO (1985). They differ from the previous ones with respect to the judgment of the sodium effects. The guidelines can indicate potential problems and possible restrictions on use of the water but the true suitability of a given water depends on the specific conditions of use and on the management capability of the user.

Water quality problems comprise salinity, water infiltration rate, specific ion toxicity and miscellaneous problems. The FAO Water Quality Guidelines (see appendix V, table 14) take these four categories into account when evaluating water quality. *Salinity* is considered from the perspective of a reduction in soil-water availability to the crop. Salinity problems develop when salts accumulate in soil or water and reduce the water availability to such an extent that yield is affected. A water infiltration problem related to water quality is associated with both the salinity and sodium content of the water. *Water infiltration rate* is affected by a relatively high sodium or low calcium content of soil or water. This reduces the rate at which irrigation water enters the soil to such an extent that insufficient water can be infiltrated to supply the crop adequately from one irrigation to the next. An evaluation of the potential of a water to cause an infiltration problem is possible by combining salinity with the sodium adsorption ratio. *Specific ion toxicity* refers to the concentration of boron, sodium or chloride and their effect on yield of sensitive crops. These ions accumulate from soil or water in a sensitive crop to concentrations high enough to cause crop damage and reduce yields. *Miscellaneous problems* comprise excessive nutrients reducing yield or quality and excessive corrosion of equipment increasing maintenance and repairs.

Water quality refers to what extent the quality of a water supply is suitable for a specific use. In irrigation water evaluation, emphasis is placed on the chemical and physical characteristics of the water and seldom are any other factors, such as biological characteristics, considered important. Specific uses have different quality needs and one water supply is considered more acceptable if it produces better results or causes fewer problems than an alternative water supply (FAO, 1985).

When evaluating water quality, emphasis should focus on relating the potential problem to the field situation since solutions to water quality problems usually must be implemented at the farm level rather than at the project level. The four problem categories previously discussed are used for evaluation. Water quality problems are often complex and a combination of problems may affect crop production more severely than a single problem in isolation. The more complex the problem, the more difficult it is to formulate an economical management programme for solution. If problems do occur in combination, they are more easily understood and solved if each factor is considered individually (FAO, 1985).

A complete evaluation takes the following matter into account:

- the type and concentration of salts causing the problem
- the soil-water-plant interactions that may cause the loss in crop yield
- the expected severity of the problem following long-term use of the water
- the management options that are available to prevent, correct or delay the onset of the problem (FAO, 1985).

Detailed analysis of the water quality for irrigation requires the determination of the chemical parameters given in table 1 (see page 27). Determination of most of these parameters need laboratory facilities, but the electrical conductivity (EC) and pH can be determined in the field. The sodium adsorption ratio (SAR) is a parameter to evaluate irrigation water with respect to possible sodic effects on soil. If cation concentrations are expressed in meq / l, then:

$$SAR = Na / [0.5(Ca + Mg)]^{0.5}$$

Adj. R_{Na} refers to an adjusted SAR value for which in the above equation a corrected value (Ca_x) is used for the Ca concentration in irrigation water. The Ca_x value (in meq / l) can be found with the following empirical formula:

$$Ca_x = [0.34(EC_i - 0.1)^{0.5} + 1.7] / [(CO_3 + HCO_3) / Ca]^{0.672}$$

where: EC_i in dS / m,
 CO_3, HCO_3, Ca in meq / l

The adj. R_{Na} is a better measure than SAR for evaluating the sodium hazard of irrigation water. But for assessing the exchangeable sodium percentage (ESP) in equilibrium with the ionic composition of soil water, the SAR value should be used (EUROCONSULT, 1989).

Appendix V shows guidelines for the interpretation of water quality for irrigation. Another criterion to judge the sodium hazard, the Residual Sodium Carbonate and Bicarbonates (RSC) classification, is given as well in this appendix. Figure 1 in appendix V presents a diagram for the classification of irrigation waters with respect to salinity hazard in 6 EC_i classes and to sodium hazard in 4 SAR classes.

Limits of trace element concentrations for normal irrigation water are given in table 16, appendix V. Salinity and trace element drinking water limitations for livestock are given in table 17 and table 18, appendix VI. Water quality for livestock and poultry will be dealt with in chapter 8.

parameter	symbol	usual range in irrigation water
salt content		
electrical conductivity	EC _i	0 - 3 dS / m
total dissolved salts	TDS	0 - 2000 mg / l
cations and anions		
calcium	Ca ²⁺	0 - 20 meq / l
magnesium	Mg ²⁺	0 - 20 meq / l
sodium	Na ⁺	0 - 5 meq / l
carbonate	CO ₃ ²⁻	0 - 40 meq / l
bicarbonate	HCO ₃ ⁻	0 - 1 meq / l
chloride	Cl ⁻	0 - 10 meq / l
sulphate	SO ₄ ²⁻	0 - 30 meq / l
boron	B	0 - 20 meq / l
sodium adsorption ratio	SAR	0 - 2 meq / l
adj. sodium adsorption ratio	adj. R _{Na}	0 - 15
acidity / basicity	pH	5 - 8.5
nutrients		
nitrate	NO ₃	0 - 10 mg / l (N)
ammonium	NH ₄	0 - 5 mg / l (N)
phosphate	PO ₄	0 - 2 mg / l (P)
potassium	K	0 - 2 mg / l

Table 1: Parameters to evaluate irrigation water quality (source: FAO, 1985)

Chapter 5

WATER QUALITY PROBLEMS

Salinity

A salinity problem exists if salt accumulates in the crop root zone to a concentration that causes a loss in yield. In irrigated areas, these salts often originate from a saline, high water table or from salts in the applied water. Yield reductions occur when the salts accumulate in the root zone to such an extent that the crop is no longer able to extract sufficient water from the salty soil solution. This results in a water stress for a significant period of time. If water uptake is appreciably reduced, the plant slows its rate of growth. The plant symptoms are similar in appearance to those of drought. The plant wilts, obtains a darker, bluish-green colour and sometimes thicker, waxier leaves. Symptoms vary with the growth stage, being more marked if plants are affected during the early stages of growth. At times mild salt effects may go unobserved because of a uniform reduction in growth across an entire field.

Salts that contribute to a salinity problem are water soluble and readily transported by water. The from prior irrigations accumulated salts can be partly leached below the rooting depth if more irrigation water infiltrates the soil than is used by the crop during the crop season. Leaching is the most important factor in controlling a water quality-related salinity problem. Over a period of time, salt removal by leaching must equal or exceed the salt additions from the applied water to prevent salt building up to a damaging concentration. The amount of leaching required is dependent upon the irrigation water quality and the salinity tolerance of the crop grown.

Salt content of the root zone varies with depth. Near the soil surface it equals more or less that of irrigation water, whereas at the bottom of the rooting depth the salt content increases to many times that of the applied water. This increase in salt concentration is due to plants extracting water but leaving salts behind in a greatly reduced volume of soil water. Each succeeding irrigation leaches the salts deeper into the root zone where they continue to accumulate until leached. The salinity in the lower root zone will depend upon the leaching that has occurred. The most readily available water is in the upper root zone, where salt concentrations are low. As the crop uses water, the upper root zone becomes depleted and the zone of most readily available water changes toward the deeper parts as the time interval between irrigations is extended. These lower depths are generally more salty.

The crop does not respond to the extremes of low or high salinity in the rooting depth but integrates water availability and takes water from wherever it is most readily available. A high soil-water availability is maintained with good timing of irrigation, which reduces the problems caused when the crop must draw a significant portion of its water from the less available, higher salinity soil-water deeper in the root zone. For good crop production, equal importance must be given to maintaining a high soil-water availability and to

leaching accumulated salts from the rooting depth before the salt concentration exceeds the tolerance of the plant.

For crops irrigated infrequently, as is normal when using surface methods and conventional irrigation management, crop yield is best correlated with the average root zone salinity, but for crops irrigated on a daily, or near daily basis, such as localized or drip irrigation, crop yields are better correlated with the water-uptake weighted root zone salinity. The differences are not remarkable but may become important in the higher range of salinity.

In irrigated agriculture, many salinity problems are associated with or strongly influenced by a shallow water table (within 2 metres of the surface). Salts accumulate in this water table and frequently become an important additional source of salt that moves upward into the crop root zone. Control of an existing shallow water table is thus essential to salinity control and to successful long-term irrigated agriculture. Higher salinity water requires extra water for leaching, which aggravates a potential drainage problem and makes long-term irrigated agriculture nearly impossible without sufficient drainage. If drainage is adequate, good management ensures that the crop is adequately supplied with water at all times and that enough leaching water is applied to control salts within the tolerance of the crop (FAO, 1985).

Turkey

A survey of all available data on saline and / or waterlogged soils indicates that the cause of salinity in Turkey is related to as well climate, drainage, farming practices as soil characteristics. The importance of each is difficult to determine when considering the effects of these factors on the present state of salinity. Apart from the north-eastern Black Sea coast of Turkey, the climate can be considered to be arid to semi-arid.

With increasing population and mechanisation of agriculture, the tendency towards irrigation has caused major changes in land use, particularly the last 25 years. The forest land has been depleted fast, resulting in more runoff from the highlands to the lowlands. The rangelands, high- and low-lying, were ploughed and opened up for agricultural use, resulting in an increase of the amount of runoff from higher areas. The lowlying natural pastures lost the water and salt balance under farming and, due to the arid and semi-arid climate, the salts moved to the upper zone of the profile. The establishment of irrigation systems without providing adequate drainage on the lowlying alluvial coastal plains also led to waterlogging problems. The coastal plains are hydromorphic alluvial soils, while on the central plateau ancient Lacustrine deposits cover fairly large areas. The hydromorphic soils include alluvial soils with inadequate drainage and with excess salts. They occur in all parts in Turkey in stream valleys, deltas and basins in association with other alluvial soils. The main causes of salt accumulation are irrigation without adequate drainage and seepage from irrigation canals. The principal areas of Solonchak soils found in Turkey are large tracts of old lake basins and in valleys where groundwater rises to or near the surface temporarily or for long periods.

Because of the geographical and seasonal distribution of precipitation approximately 90 percent of the agricultural lands do not receive adequate rainfall during the vegetation periods of crops. Apart from maybe the main lakes Van, Tuz and Burdur and some tributaries of the Kizilirmak river, the quality of the major rivers in Turkey from the point of view of irrigation seems to be fairly safe.

The damage caused by salinity was first recognized in areas where irrigation systems were established. The first modern irrigation system was constructed during 1908 in the Konya-Çumra plain to irrigate 53.360 ha. Another large system was on the right bank of the Seyhan in 1944 to irrigate 17.000 ha in the Adana-Tarsus plain. Both these locations as well as other irrigation project sites on the Aegean coast and in Central Anatolia had drainage problems following irrigation that led to salinity. The problems arising led to the establishment of irrigation research stations to deal with the local problems of irrigated farming.

In 1952 the first field experiments were started on heavy saline soils in Alifaki. The initial field experiments consisted of opening drainage canals about 1.5 m deep at intervals of 120 m. The first results indicated that rice could be grown on these soils and that with deep drainage the soluble salts could be leached.

The leaching trial at Tarsus indicated that the effect of 460 kg / dec of gypsum was significant in the removal of exchangeable Na and the leaching of soluble salts after the second year, but these still remained at unsafe levels especially below the first 30 cm. The impossibility of draining the drainage ditches for certain periods of time due to outlet problems is thought to be the cause.

At Menemen drainage canals were constructed in lighter but highly saline and sodic soils. One year after leaching had been started, plots were seeded with alfalfa. Due to the lightness of the soil texture the leaching of soluble salts was satisfactory both with and without gypsum. The removal of exchangeable Na was similar in the first 30 cm in both treatments, but below that depth it was in favour of gypsum treatment.

At Eskisehir-Kizildiken, again on heavy textured highly saline and sodic soils, leaching without gypsum and with various rates of gypsum application gave encouraging results at 350 and 400 kg / dec gypsum application, but the ineffectiveness of higher rates in the removal of exchangeable Na is rather difficult to explain.

At Kayseri-Karasaz an experiment was conducted on deep peat soils. To control salinity and boron problems, various leaching methods, such as continuous ponding, intermittent ponding and intermittent sprinkling, were compared. The soil was sampled after each 10 cm of water application down to 1 m profile depth. After application of 170 cm leaching water the average salt content of the soil profile decreased to 20 % of the initial value. The average boron content of the 1 m soil profile was about 8 ppm before leaching. After the application of 150 cm of leaching water it was lowered to 4 ppm.

On the Çukurova plain and the Gediz plain gross project areas were provided with field subsurface drainage. Most of the area covered by field drainage in these two project areas had salinity or alkalinity problems to varying degrees. Areas that had lost their productivity prior to drainage have been cultivated within a few years after installation of drainage systems.

In a way the preceding examples support the assumption that the main cause of salinity in Turkey is directly related to inadequate drainage. With the exception of some small local areas where the parent material is very rich in sodium salts, all saline soils in Turkey have drainage or waterlogging problems. When artificial drainage is provided in these areas and when annual precipitation is around 500 mm, salinity in the upper soil profile diminishes very fast. When the water table is lowered by drainage salts are leached from the soil profile under natural conditions. Wherever possible, if such land can be put under rice crop or pasture after drainage is provided, the removal of salt is significant (Beyce, 1973).

Water infiltration rate

An infiltration problem related to water quality occurs when the normal infiltration rate for the applied water or rainfall is reduced and water remains on the soil surface too long or infiltrates too slowly to supply the crop with sufficient water to maintain acceptable yields. Although the infiltration rate of water into soil varies widely and can be greatly influenced by the quality of the irrigation water, soil factors such as structure, degree of compaction, organic matter content and chemical make-up can also greatly influence the infiltration rate.

The two most common water quality factors which influence the normal infiltration rate are the total quantity of salts in the water and its sodium content relative to the calcium and magnesium content. A high salinity of the water increases infiltration. A low salinity water or a water with a high sodium to calcium ratio decreases infiltration. Both factors may operate at the same time. Secondary problems may develop if irrigations must be lengthened for an extended period of time to achieve adequate infiltration. These include crusting of seedbeds, excessive weeds, nutritional disorders and drowning of the crop, rotting of seeds and poor crop stands in low-lying wet spots. One serious side effect of an infiltration problem is the potential to develop disease and vector (mosquito) problems.

An infiltration problem related to water quality occurs usually in the surface few centimetres of soil and is linked to the structural stability of this surface soil and its low calcium content relative to that of sodium. When a soil is irrigated with a high sodium water, a high sodium surface soil develops which weakens the soil structure. The surface soil aggregates disperse to much smaller particles which clog soil pores. The problem may also be caused by an extremely low calcium content of the soil. In some cases, water with a low salt content causes a similar problem. This is related to the corrosive nature of the low salt water in stead of to the sodium content of the water or soil. The low salt water dissolves and leaches most of the soluble minerals, including calcium, from the surface soil (FAO, 1985).

Spain

In the south-west of the Iberian peninsula a large plain with an altitude approximately the same as the maximum high tide of the sea is found. This plain is formed by the silting up of suspended matter originating from the upper catchment of the Guadalquivir river. The deposits of fine matter clays and loams have been in contact with salt or brackish waters at times of low river discharge. This has made the soils rich in salts with a predominance of sodium chloride. In this area Fluvisols in the saline-alkaline phase and Solonchaks in the alkaline phase are found. Due to the fine clayey texture of the soils, permeability is slow and infiltration rate is low.

The climate is defined as sub-humid-dry according to Thornwaite's classification; according to Mayer's classification, this area is a semi-arid zone. Variability in precipitation is extremely marked and distribution of rainfall over the year causes a water shortage in the period June - October. The discharge of the Guadalquivir river consequently shows considerable variation. This creates serious problems for agriculture, so supplementary irrigation is required for normal plant growth in summer. The lack of precipitation in summer causes capillary rising of the water table. Water evaporates at the surface, depositing salt. Even standing pools evaporate causing the formation of large sodic crusts. The water of the groundwater table is saline, both because of its original marine origin and due to leaching caused by its movement through the soils. The concentration of salts is influenced by the level of the groundwater table and time of the year. The depth of the water table is closely related to the topography and causes natural vegetation to be halophilous on soils not subject to waterlogging and paludous on those where the water is standing or flows through runoff channels.

Studies made in the forties showed that soils in this area could be reclaimed. In order to achieve that goal, entry of water from outside into the area of reclamation should be prevented. The soil should be provided with an adequate drainage network which would enable rain or irrigation water to pass through it, washing out the toxifying salts. The water table should be maintained at a level that is not damaging crop plant development and, at the same time, does not cause capillary rising. Furthermore, drainage of rain should be used for leaching. By loosening the ground the permeability is maintained. With addition of lime, gypsum, etc. sodium is helped to release from the surfaces of the soil particle. In this way, these operations contribute to the desired change into a normal soil.

The first phase of reclamation was carried out using winter precipitation. Open drains were installed in the interest of economy. The slope and depth of the drains were depended on evacuation of the water by gravity to avoid the expense of pumping. At the most unfavourable circumstances the drainage network was to ensure that the water table would at any time remain 40 cm below ground surface. During a period of nine years the results were studied. The water level appeared to remain below the theoretical depth. Furthermore, it was observed that the amount of salt extracted was considerable. In nine years 72 percent of existing salts were leached, whereas in the first three years 47 percent were leached. Desalinization was marked in the first years and decreased as the salt content of the environment became lower. The salt

content of the groundwater decreased also, confirming that its variation in salinity is substantially the same as that of the soil. This change was also observed through the natural development of the vegetation. In the following years dry crops were planted and production increased yearly. Throughout the work, the risk existed that alkalinity would develop, due to leaching of soluble salts in the presence of the relatively high proportion of sodium. Nevertheless, when work started the ESP was 24.2 at a depth of 15 cm, while at the end it was 4.0 at the same depth. The nine year period resulted in the transformation of saline-alkaline soils into salt- and alkali-free soils in the first 40 cm of the soil profile.

During the second phase of reclamation disadvantages encountered with the implication of an open ditch scheme were dealt with. Open drains were replaced by buried drains, with a view to both quicker desalinization and higher crop yields. First, clay pipes were used, but later plastic pipes became usual. Large quantities of water had to be applied since part of the water was intended for leaching of salts and only a small part for supplementing crop water requirements. The application of irrigation had to be timed at intervals so that the moisturizing and cracking process should continue. Very frequent irrigation would cause the soil surface to become a pasty mass with no permeability, obstructing leaching. For better aeration periodic subsoiling was recommended. Fertilizers were recommended to help eliminating sodium.

Irrigation began in 1968 and after three years the results of cropping in the area were satisfactory. Crop production of barley, oats and wheat doubled in the period from 1961 to 1971, production of forage beans even tripled. The introduction of irrigation clearly assisted soil improvement and made it possible to obtain higher crop yields (Grande Covián, 1973).

Toxicity

With regard to toxicity three ions are of importance. These are chloride, sodium and boron. *Chloride* in irrigation water may be toxic. It is not absorbed by the soil and readily taken up by the plant where it accumulates in the leaves. If the chloride concentration in the leaves exceeds the tolerance of the crop, injury symptoms develop such as leaf burn or drying of leaf tissue. Many tree crops are sensitive to chloride. They may show injury above 0.3 % chloride in the dry weight leaf tissue. *Sodium* toxicity has as typical symptoms leaf burn, scorch and dead tissue along the outside edges of leaves, whereas symptoms of chloride normally start at the extreme leaf tip. *Boron* is needed in relatively small quantities, but becomes toxic in amounts significant greater than those required. Boron toxicity normally shows first in older leaves by yellowing, spotting or drying of leaf tissue at drips and edges (FAO, 1985). The toxicity of aluminium becomes a problem with very low pH, since this increases the solubility of aluminium. In appendix VII the relative tolerance of selected crops to exchangeable sodium and to boron are shown.

The fertilizing value of irrigation water depends on the amount of dissolved and suspended nutrients. Toxicity problems occur if certain ions in the soil or water are taken up by the plant and accumulate to concentrations high enough to cause crop damage or reduced yields. The degree of damage depends on the uptake and the crop sensitivity. The permanent, perennial-type crops like tree crops are the

more sensitive. Damage often occurs at relatively low ion concentrations for sensitive crops. It is usually first evident by marginal leaf burn and interveinal chlorosis. If the accumulation is great enough, reduced yields result. The more tolerant annual crops are not sensitive at low concentrations but almost all crops will be damaged or killed if concentrations are sufficiently high (FAO, 1985).

Although toxicity problems may occur even when the toxic ions are in low concentrations, toxicity often accompanies and complicates a salinity or water infiltration problem. Damage results when the potentially toxic ions are absorbed in the significant amounts with the water taken up by the roots. The absorbed ions are transported to the leaves where they accumulate during transpiration. The ions accumulate to the greatest extent in the areas where the water loss is greatest, usually the leaf tips and leaf edges. Accumulation to toxic concentrations takes time and visual damage depends upon the duration of exposure, concentration by the toxic ion, crop sensitivity and the volume of water transpired by the crop. In a hot climate or hot part of the year, accumulation is more rapid than if the same crop were grown in a cooler climate or cooler season when it might show little or no damage. Toxicity can also occur from direct adsorption of the toxic ions through leaves wet by overhead sprinklers. Sodium and chloride are the primary ions adsorbed through leaves, and toxicity to one or both can be a problem with certain sensitive crops such as citrus. As concentrations increase in the applied water, damage develops more rapidly and becomes progressively more severe (FAO, 1985).

Miscellaneous problems

Frequently encountered other problems related to irrigation water quality include high nitrogen concentrations, unsightly deposits on fruit or leaves, various abnormalities often associated with an unusual pH of the water and vector-borne diseases. High nitrogen concentrations in the water may cause excessive vegetative growth, lodging and delayed crop maturity, whereas deposits on fruit or leaves are caused by overhead sprinkler irrigation with high bicarbonate water, water containing gypsum or water high in iron. The development of vector-borne diseases will be discussed below. A problem faced by some farmers practising irrigation is deterioration of equipment due to water induced corrosion or encrustation. Wells and pumps are the most seriously affected, but in some areas a poor quality water may also damage irrigation equipment and canals.

Suspended organic as well as inorganic sediments cause problems in irrigation systems through clogging of gates, sprinkler heads and drippers. They cause damage to pumps if screens are not used to exclude them. Sediments tend to fill canals and ditches and cause costly dredging and maintenance problems. Sediment also tends to reduce further the water infiltration rate of an already slowly permeable soil (FAO, 1985).

Vector problems associated with water quality

In areas where there is a potential risk from diseases such as malaria and insects such as mosquitoes, vector problems must be considered along with other water-quality related problems. Vector problems often originate as a secondary trouble related to a low water infiltration rate, to the use of wastewater for irrigation or to poor drainage.

Irrigation schemes and other water development projects may have an impact on vector populations and human health, which increases opportunities for human-water-vector contact and creates habitats well suited to vector production. Similar conditions may arise in relation to nuisance species of insects which cause personal discomfort and can be notably disruptive of community life, work and leisure activities. Several ways exist in which water quality may affect the size and species composition of the populations of disease vectors and nuisance insects. These include soil conditions and irrigation practices which change the extent of water surfaces in area or in duration and modification of the aquatic flora or fauna. Furthermore, direct influence on the vector may affect vector disease populations. The relation between water quality and vector-borne diseases is both complex and specific to the site and the human population.

The ideal conditions for good irrigation management are similar to those which discourage vector production in irrigated agriculture or they at least assist in vector control. A minimum of unnecessary water surface is needed, as well as constructed and maintained supply channels, effective, unimpeded drainage of excess water and efficient, economical water application. When irrigation water quality causes a deterioration of these conditions, there is increased risk of vector production.

Excess nitrogen from fertilizers may change the composition of aquatic flora and stimulate the growth of aquatic weeds. Wastewater for domestic or food-processing sources may also have this effect. It also may provoke algae growth. Presence of dense aquatic weeds and algae introduces conditions which are suited to the development of some insect vectors, pest insects and snails. Domestic wastewater in irrigation is an attractive way to raise crop yields, but it results in a dramatic increase in the breeding of mosquitoes (FAO, 1985).

Chapter 6

WATER QUALITY FOR LIVESTOCK

Livestock water quality

Irrigation canals frequently serve as sources for livestock drinking water but other sources, including poor quality supplies, are often used. Salinity requirements for irrigation are more restrictive than those for animals but highly saline water or water containing toxic elements may be hazardous to animal health and may even render the milk or meat unfit for consumption.

In the arid and semi-arid regions of the world, livestock commonly use poor or marginal quality drinking water for several months of the year. These supplies originate from small wells, canals, streams or water holes. Only the better of these are also used for irrigation. Occasionally such water is high in salt which may cause physiological upset or even death in livestock. The main reported effect is depression of appetite, which is usually caused by a water imbalance rather than related to any specific ion. Nevertheless, water containing a high level of magnesium is known to cause scouring and diarrhea. Animals drink little, if any, highly saline water if low salt content water is available to them, but they can consume moderate amounts of highly saline water for a few days without being harmed. Abrupt changes from water of low salinity to highly saline water cause more problems than a gradual change.

Table 17 (see appendix VI) gives a water quality guide for livestock and poultry uses, based on a salinity standpoint. Livestock drinking water with an electrical conductivity less than 5 dS / m should be satisfactory under almost any circumstances. It is often necessary in arid and semi-arid regions to use water which exceeds this recommended limit. In table 18 (see appendix VI) suggested limits for magnesium in drinking water for livestock have been given. These two tables are the basic guides for determining the suitability of a particular water supply for drinking water for animals, but local factors, especially effects of evaporation and concentration, must be considered.

In evaluating the usability of any particular water, local conditions and availability of alternate supplies play an important role and a number of factors should be considered, such as the kind of water source, seasonal changes, age and condition of the animal, feed composition and species. With regard to *water source*, it should be noticed that small shallow wells and streams are more likely to become contaminated or produce poor quality water than are the larger wells and flowing streams. Also groundwater is likely to be more chemically imbalanced than surface water. In particular marginal quality water is affected by *seasonal changes*. It may become unsuitable in hot dry periods because of increase in natural salinity, when evaporation from stock watering ponds or tanks is very high with a resulting higher salt concentration. Water temperature increases during these periods. Furthermore, water or dry feed consumption by the animal increases due to the heat. *Age and condition of the animal* make the lactating, young and weak animals normally more susceptible. Furthermore, *feed composition* affects the salinity tolerance of an

animal. Dry pastures and high protein supplementary feed may reduce the salinity tolerance of the animal due to the lower moisture content of feed and higher salt content. Additionally, variation in tolerance to water salinity is considerable between animal *species*.

Animals can subsist for short periods with very poor water. Longer periods will require more careful monitoring. To minimize the problems, drains or overflows may be provided on troughs and tanks to flush them occasionally. This will prevent poor water concentrating further by evaporation. Additionally, dilution water should be provided if available, rainfall collection for dilution purposes should be increased, evaporation losses should be reduced, high water-using vegetation along streams and around holding ponds or spring sources of water should be controlled and settling basins to remove sediment should be provided (FAO, 1985).

Toxic substances in livestock water

There are a number of substances or toxic ions which cause toxicity in animals. These sometimes occur naturally in water, but more frequently they result from man's activities, including waste disposal. Toxic substances in natural water are usually at concentrations well below toxic levels. If unusually high and toxic levels are found, this often implies the existence of some outside contaminating source such as a wastewater. The common toxicants include many inorganic elements, organic wastes, pathogenic organisms, herbicides and pesticides and their residues. These may be directly toxic to the animal. They also may cause the water to be distasteful or may accumulate in the animal making its edible product unsafe or unfit for human consumption.

The most common management problems are related to fluoride, nitrate, hydrogen sulphide and iron. *Fluoride* causes tooth mottling and bone problems. Toxicity problems are amplified when the forage used is also irrigated with the same potentially toxic water. The plants take up the salts, thus raising the toxicity risk to the animal when both the sources of feed and water combine to exceed the critical levels. *Nitrate* levels over 100.0 mg / l for combined nitrate and nitrite in drinking water are toxic to livestock. A high nitrate level may cause heavy growth of algae in watering points, which might produce circumstances favorable to the development of botulism. *Hydrogen sulphide* by itself does not harm the animal, but the odour influences the animals to reject the water. Aeration of the water has proved very effective, because the greater part of the hydrogen sulphide is dissipated before entering the water trough or tank. At watering points, *iron* is rarely present in the water since, on contact with air, the ferrous salts are oxidized and they precipitate, rendering them essentially harmless to animals. However, even with a few milligrams per litre, iron can cause clogging of lines to watering troughs or an undesirable staining or deposit (FAO, 1985).

Chapter 7

CROP TOLERANCES

Crop water requirements

Plants consume water essentially for the two processes of photosynthesis and transpiration. They absorb water through the roots and primarily through the root hairs. Water is transported through the plant and then removed from the leaf surface via transpiration. Transpiration is controlled by the stomatal aperture and by vapour pressure gradient from the leaf to the air. The crop transpires during its growth. At the same time evaporation takes place at the soil surface. The combined quantity of water used under conditions of optimum availability is known as consumptive use or evapotranspiration.

The amount of water required by plants for their growth depends on a number of factors including the type of plant, its stage of development, soil properties and meteorological conditions such as temperature, radiation, humidity and wind. The demand for water is not evenly spread over the growing season. At the beginning of the season, consumptive use is low. It increases as the plant foliage develops and the days become warmer, peaks during flowering and fruit formation and rapidly decreases towards the end of the growing season.

The amount of water in the soil useable by plants lies between field capacity and wilting point (see 'available soil water', chapter 2). This portion is called the useable capacity. The field capacity is the maximum amount of water capable of being held by the soil in opposition to gravity. The wilting point corresponds to that amount of water that opposes the absorptive strength of the plant. The amount of useable capacity depends on the soil type. It is low in sandy soil and high in loam and loess. Optimum plant growth occurs when soil moisture is near field capacity. Wilting of plants occurs when suction exerted by the roots on the moisture in the soil fails to maintain an adequate flow of water to the leaves. If the level of soil water is approaching wilting point, rainwater or irrigation is required to maintain plant growth. At the other limit, when saturation is reached, air is cut off from the roots and the plant growth stops.

Excess water on farm lands may be caused by rain, excessive irrigation or by poor land grading. Excess water should be drained to maintain a healthy soil moisture for crop production. It is important to note that because the amount of salt removed by crops is negligible, salt will accumulate in the root zone and will cause a loss in production. Consequently, salt must be leached by supplying more water than is required by the crops. The amount of leaching water needed depends mainly on the salt content of the irrigation water, soil and groundwater; and the salt tolerance of the crops. The ratio of the depth of drainage water to the depth of applied water (irrigation plus rainfall) is called the leaching fraction (Ghassemi *et al.*, 1995).

Crop tolerance to salinity

Good irrigation practices provide a crop with adequate and timely amounts of water in order to avoid yield loss caused by extended periods of water stress during stages of crop growth that are sensitive to water shortages. During repeated irrigations the salts in the irrigation water can accumulate in the soil, reducing water available to the crop and accelerating the onset of a water shortage (FAO, 1985).

The salt tolerance of a plant can be defined as the plant's capacity to endure the effects of excess salts in the medium of root growth. The salt tolerance of a plant is not an exact value, but depends on many factors. These include environmental factors and biological factors. The first set includes soil fertility, physical condition of the soil, salt distribution in the profile, irrigation method and climate, whereas biological factors include stage of growth, varieties and rootstocks (Ghassemi *et al.*, 1995).

The plant extracts water from the soil by exerting an absorptive force greater than which holds the water to the soil. If the plant cannot make sufficient internal adjustment and exert enough force, it is not able to extract sufficient water and will suffer stress. This happens when the soil becomes too dry. Salt in the soil-water increases the force the plant must exert to extract water. This additional force is referred to as the osmotic effect or osmotic potential. Salts have an affinity for water. If the water contains salt, more energy per unit of water must be expended by the plant to absorb relatively salt-free water from a relatively salty soil-water solution. This additional energy is required to overcome the osmotic potential of a salty soil-water solution. As salinity increases, an important reduction in water available to the crop takes place. Salinity effects are closely analogous to those of drought since both result in water stress and reduced growth. Effects such as stunting, leaf damage and necrosis or obvious injury to the plant are only noticeable after prolonged exposure to relatively high salinity (FAO, 1985).

The tolerance of a plant with respect to soil salinity can be described by a yield response function which is a plot of the relative yield as a function of soil salinity. Plant growth rate decreases linearly as salinity increases above a critical threshold salinity at which growth rate begins to decrease. Deviations from the linear decrease occur at yields considerably less than 50 percent of potential. At this level yields are commercially unacceptable (FAO, 1985). For soil salinities exceeding the threshold of any given crop, the crop yield can be given by the following linear equation (van Genuchten & Hoffman, 1984 in: Ghassemi *et al.*, 1995):

$$Y = Y_m - Y_m s (c - c_t)$$

where Y = crop yield
 Y_m = the crop yield under non-saline condition
 s = the slope of the line determining the yield decline per unit increase in salinity, beyond the threshold
 c = the average root zone salinity
 c_t = the salinity threshold.

According to FAO (1985), a similar equation from Maas & Hoffman (1977) expresses the straight line salinity effect on yield in percent:

$$Y = 100 - b (EC_e - a)$$

where Y = relative crop yield (percent)
EC_e = salinity of the soil saturation extract in dS / m
a = salinity threshold value
b = yield loss per unit increase in salinity.

Because the linear equation predicts yields so well, it can be used to predict the approximate theoretical soil salinity (EC_e) at which the plant is presumed to be unable to extract water. In this case, growth ceases and yield would be zero.

Table 19 (see appendix VII) presents salt tolerances of selected plants with respect to the electrical conductivity of saturated-soil extract.

Water uptake from the root zone

As the soil dries, the plant is exposed to a continually changing water availability in each portion of the rooting depth since the soil-water content and soil-water salinity are changing as the plant uses water between irrigations. The plant absorbs water but most of the salt is excluded and left behind in the root zone in a shrinking volume of soil-water. Following an irrigation, the soil salinity is not constant with depth. After each irrigation, the soil-water content at each depth in the root zone is near the maximum as is the concentration of dissolved salts. Each changes, however, as water is used by the crop between irrigation.

The plant exerts its absorptive force throughout the rooting depth and takes water from wherever it meets the least resistance to absorption. Usually this is the upper root zone, the area most frequently replenished by irrigation and rainfall. Since more water passes through this upper root zone, it is more thoroughly leached and the osmotic or salinity effects are much less than at greater depths. Between irrigations, the upper root zone dries more rapidly than the lower because of the proliferation of roots in this zone which extract the readily available soil moisture. The plant must then meet more of its water demand from increasingly greater depths as the upper soil-water is depleted. Both the soil moisture at depth and the soil moisture remaining in the upper portions have a higher soil-water salinity and thus a greater osmotic potential.

As the plant depletes the soil-water, a water extraction pattern develops. The extraction pattern of 40, 30, 20 and 10 percent for the upper to lower quarters of the root zone is assumed in the guidelines given in table 14 (see appendix V). This closely fits water extraction patterns under infrequent irrigation practices. The pattern for water uptake is closely related to the frequency of irrigation. For more frequent irrigations, the water uptake pattern is skewed towards greater uptake from the upper root zone and less from the lower. In this case, the crop rooting depth tends to be at shallower depths. A typical extraction pattern might be 60 - 30 - 7 - 3 percent.

Whatever the frequency, irrigations must be timed to supply adequate water and prevent crop moisture stress between irrigations, especially if the soil salinity is also affecting water availability. When the upper rooting depth is well supplied with water, salinity in the lower root zone becomes less important. If periods between irrigation are extended and the crop must extract a significant portion of its water from the lower depths, the deeper root zone salinity becomes important, particularly if in the latter stages of a soil moisture depletion period between irrigations, a high crop water demand should occur. In this case, absorption and water movement toward the roots may not be fast enough to supply the crop and a severe water stress results. Reduced yields or crop damage can be expected for most crops when there is a shortage of water for a significant period of time.

Salinity reduces water availability, but not all crops are equally affected at the same soil salinity. This is because some are better able to make the needed osmotic adjustments enabling them to extract more water from a saline soil. Tolerance data show that there is an 8 to 10-fold range in salt tolerance of agricultural crops. The ability of a crop to adjust to salinity is extremely useful. In areas where a build-up of soil salinity cannot be controlled at an acceptable concentration for the crop being grown, a yield loss will result unless an alternate crop more tolerant to the expected salinity is cultivated.

The wide range in tolerance allows for a much greater use of moderately saline water much of which was previously thought to be unusable. It also greatly expands the acceptable range of water salinity (EC_i) considered suitable for irrigation. The relative salt tolerance of most agricultural crops is known well enough to give general salt tolerance guidelines. The guidelines of table 14 indicate that water with salt contents listed in the slight to moderate range, a full yield potential is still possible but care must be taken to achieve the required leaching fraction in order to maintain soil salinity within tolerance of the crop. For higher salinity water and sensitive crops, increasing the leaching to satisfy a leaching requirement greater than 0.25 - 0.30 may not be practical because of the excessive amount of water required. Consideration must then be given to changing to a more tolerant crop that will require less leaching to control salts within crop tolerance. As the water salinity (EC_i) increases within the slight to moderate range, production of the more sensitive crops may be restricted due to an inability to achieve the high leaching fraction needed, especially when grown on the heavier, more clayey soil types. If the salinity of the applied water exceeds 3.0 dS / m, as shown in table 14 for a severe restriction on use, the water may still be usable but its use may need to be restricted to more permeable soils and more salt tolerant crops where the high leaching fractions are more easily achieved. Figure 2 (see appendix V) can also be used to estimate the leaching requirement if crop tolerance grouping and water salinity are known. If the exact cropping patterns or rotations are not known for a new area, the leaching requirement must be based on the least tolerant of the crops adapted to the area. In those instances where soil salinity cannot be maintained within acceptable limits of preferred sensitive crops, changing to more tolerant crops will raise the area's production potential. Figure 3 (see appendix V) presents divisions for relative salt tolerance ratings of agricultural crops, which is

useful for general planning and for comparisons among crops. In table 2 relative crop salinity tolerances are given. This table is based on figure 3.

relative crop salinity tolerance rating	soil salinity (EC _e) at which yield loss begins
sensitive	< 1.3 dS / m
moderately sensitive	1.3 - 3.0 dS / m
moderately tolerant	3.0 - 6.0 dS / m
tolerant	6.0 - 10.0 dS / m
unsuitable for most crops (unless reduced yield is acceptable)	> 10.0 dS / m

Table 2: Relative crop salinity tolerance rating (source: FAO, 1985)

The relation between applied irrigation water salinity (EC_i) and the soil salinity (EC_e) can be found by the use of the following equation:

$$EC_e = 1.5 EC_i .$$

where EC_e = soil salinity
EC_i = water salinity

This concentration factor from water salinity (EC_i) to soil salinity (EC_e) of 1.5 is representative of a 15 - 20 percent leaching fraction. The soil salinity that is expected to develop following several years of use of a water assumes that the water is the primary source of soluble salts. If a water table is present, it is an additional salt source not considered in the above given fixed relationship between soil salinity and water salinity. If conditions of use consistently indicate a leaching fraction other than 0.15 to 0.20, the concentration factor will also be different. Changing the leaching fraction to change the concentration factor is one of the options available for control of salinity (FAO, 1985).

Factors affecting crop tolerance

Crop production potential using a particular irrigation water can range from 100 percent down to zero but there are often factors other than water quality which affect yield. Tolerance during the germination and early seedling stage may be different than the values given in the appendix. In general, if the soil salinity in the surface soil is greater than 4 dS / m, it may inhibit or delay germination and early seedling growth. This slowed germination may then delay emergence, allowing soil crusting and disease problems to reduce the crop stand. Rainfall or pre-plant irrigations will often help to maintain low salinity, delay crusting and promote good emergence.

Rootstocks used for certain tree such as citrus, almond and stone-fruit and vine crops can appreciably influence salinity tolerance. Rootstocks differ in their ability to exclude salt, especially the toxic sodium and chloride ions. With a reduction in the amount absorbed, accumulation is reduced. This characteristic for exclusion has allowed selection of commercially acceptable rootstocks as well as varieties

for improved production under saline conditions of soil and water. Varietal differences also exist among cultivars of annual crops. This is of importance when salinity of applied water makes tolerance critical. Plant breeding and selection for salinity tolerance have only recently been undertaken to any appreciable extent. If successful, plant breeding and gene selection for salinity tolerance may greatly expand the ability to use more saline water supplies, although any new information on tolerance should be used with caution.

Climate also affects crop tolerance to salinity and drought. In general, crops grown in cooler climates or during the cooler time of the year will have higher tolerance to salinity than similar crops grown during warmer, drier periods. Since crop demand for water is less during the cooler periods, the effect of reduced water availability due to salinity is not so critical and a greater proportion of rainfall or applied water may be available to leach accumulated salts. In contrast, during periods of very high evapotranspiration demand under hot, dry conditions, water absorption by the plant roots may not be adequate due to both rapid depletion of soil water and increased salt concentration around the roots. Under these conditions, the plants may show earlier water stress than anticipated from normal bulk soil sampling and water stress may be critical during extended periods of hot dry winds. Climate appears to affect salt sensitive crops to a much greater extent than salt tolerant ones.

Fertilization has little effect on salt tolerances. If fertility is a limiting factor, proper fertilization will increase yields, but if fertilization is not limiting, additional fertilizer will not improve salt tolerance. Since fertilizers are for the most part soluble salts, timing and placement are important, and unless properly applied they may contribute to or cause a salinity problem (FAO, 1985).

CONCLUSION

In arid and semi-arid environment irrigation is practiced to ensure a good crop development. Three types of irrigation methods may be distinguished, which are surface irrigation, sprinkler irrigation and localized irrigation. The selection of irrigation methods is influenced by physical factors and socioeconomic conditions.

Both chemical and physical characteristics of soils influence the solute composition of drainage waters and they are interactive to a large degree. Hydraulic conductivity, together with slope, controls the hydrological pathway and determines what soils the drainage waters equilibrate with. When evapotranspiration exceeds precipitation, alkaline soils with calcium carbonate accumulation are likely to develop.

Soils which are too wet for healthy plant growth need to be drained. Drainage may be used to overcome salinity problems. These may arise in arid climates as a negative consequence of irrigation schemes. The drainage water chemistry in arid climates depends upon the soil alkalinity, calcium carbonate content and the irrigation water quality.

Irrigation water is obtained from groundwater, surface streams, artificial and natural sources. The quality of irrigation water is determined by various chemical and physical characteristics. The soil problems used as a basis to evaluate water quality are those related to salinity, water infiltration rate, toxicity and a group of miscellaneous problems. Assessment of the suitability of water for irrigation must be made in relation to three main subjects. These are crop tolerance to salinity, how much leaching will be achieved and what level of soil water salinity will be obtained when a certain type of irrigation water is used. The true suitability of a given water depends on the specific conditions of use and on the management capability of the user.

Salinity or total concentration of soluble salts is the most important parameter, since growth of the majority of crops is affected by total concentration of ions rather than by any specific ion. Irrigation with salty water may lead to soil salinization, which will impede the water uptake of the plant. The rate and extent of the increase will depend on a number of factors including the leaching fraction, the ionic composition of the irrigation water and physical properties of the soil. Leaching is the most important factor in controlling a water quality-related salinity problem.

Salt content of the root zone varies with depth. Near the soil surface it equals more or less that of irrigation water, whereas at the bottom of the rooting depth the salt content increases to many times that of the applied water. The crop does not respond to the extremes of low or high salinity in the rooting depth but integrates water availability and takes water from wherever it is most readily available. Maintaining a high soil-water availability and leaching accumulated salts from the rooting depth are both very important measures.

Salinity reduces water availability, but not all crops are equally affected at the same soil salinity. Some are better able to make the needed osmotic adjustments enabling them to extract more water from a saline soil. Tolerance during stage of growth and between varieties may be significant. Plant breeding and selection for salinity tolerance have only recently been undertaken to any appreciable extent.

Climate also affects crop tolerance to salinity and drought. Under hot, dry conditions, water absorption by the plant roots may not be adequate due to both rapid depletion of soil water and increased salt concentration around the roots. Climate appears to affect salt sensitive crops to a much greater extent than salt tolerant ones.

Excessive sodium does not impair the uptake of water by plants but impedes the infiltration of water into the soil. The growth of a plant is thus affected by an unavailability of soil water. Although the infiltration rate of water into soil varies widely and can be greatly influenced by the quality of the irrigation water, soil factors such as structure, degree of compaction, organic matter content and chemical make-up can also greatly influence the infiltration rate.

The usual toxic ions in irrigation water are chloride, sodium and boron. Although toxicity problems may occur even when the toxic ions are in low concentrations, toxicity often accompanies and complicates a salinity or water infiltration problem. Damage results when the potentially toxic ions are absorbed in the significant amounts with the water taken up by the roots.

The quality of irrigation water is also determined by the quantity and quality of suspended solids like sand and silt. Suspended organic as well as inorganic sediments cause problems in irrigation systems through clogging and sediments tend to fill canals and ditches. Sediment also tends to reduce further the water infiltration rate of an already slowly permeable soil.

Vector problems often originate as a secondary trouble related to a low water infiltration rate, to the use of wastewater for irrigation or to poor drainage. Ideal conditions for good irrigation management are similar to those which discourage vector production in irrigated agriculture.

The actual suitability of a given water for irrigation depends very much upon the specific conditions of use and on the relative economic benefits that can be derived from irrigating with that water compared to others

Irrigation canals frequently serve as sources for livestock drinking water but other sources, including poor quality supplies, are often used. Salinity requirements for irrigation are more restrictive than those for animals but highly saline water or water containing toxic elements may be hazardous to animal health and may even render the milk or meat unfit for consumption.

Here physical and chemical parameters concerning irrigation have been discussed. Socioeconomic conditions such as land and water rights are of equal importance, as are the capabilities of the user. Therefore, developing irrigation schemes is only useful within the context of both the physical as well as the socioeconomical factors.

Recommended literature in developing irrigation schemes and managing relative problems is the Agricultural Compendium For Rural Development in the Tropics and Subtropics, edited by EUROCONSULT (1989).

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Appendix I

SURFACE IRRIGATION: CRITERIA AND SUGGESTIONS IN DESIGNING THE FIELD LENGTH

Soils with similar infiltration characteristics can be grouped into infiltration families. The infiltration family is one of the criteria used in determining the design length of fields in level and graded surface irrigation. The infiltration families are given a name and code number; the numerical code indicates the nearly constant infiltration rate in mm / h (1 or 2 h after initial water application to a soil of which the moisture status is such that an irrigation application is needed). Table 1 only presents the main infiltration families. The designations low, medium and high correspond with the qualifications fine, medium and coarse texture and with clay, silt or loam, and sand, respectively. Infiltration rates may change in the growing season, due to crop development and effects of irrigation on the soil (e.g. crusting).

Family name	code	infiltration time for various application depths			
		25 mm	50 mm	75 mm	100 mm
low	< 12.5	> 40 min	> 2 h	> 3 h 40 min	> 5 h 30 min
medium	12.5 - 37.5				
high	> 37.5	< 13 min	< 40 min	< 70 min	< 100 min

Table 3: Main infiltration families

slope (%)	heavy-textured (clay) soils	medium-textured (loamy) soils	light-textured (sandy) soils
2	180	130	70
4	120	90	45
6	90	75	40
8	85	60	30
10	75	50	

Table 4: Length of corrugation (in metres) for deep-rooted crops on deep soils. For shallow-rooted crops the length should be reduced by 30 %.

flow rate l / s	m ³ / h	area (ha)			
		sand	sandy loam	clay loam	clay
30	108	0.02	0.06	0.12	0.20
60	216	0.04	0.12	0.24	0.40
90	324	0.06	0.18	0.36	0.60

Table 5: Basin areas for different soil textures and flow rates.

Sand	0.75
loam	1.00
clay	1.25

Table 6: Maximum furrow spacing (m)

soil type	irrigation depth (mm)	slope (%)	width (m)	length (m)	unit stream * (l / s)
sand	100	0.2	12 - 30	60 - 100	10 - 15
		0.4	10 - 12	60 - 100	8 - 10
		0.8	5 - 10	75	5 - 7
loam	150	0.2	15 - 30	90 - 300	4 - 6
		0.4	10 - 12	90 - 180	3 - 5
		0.8	5 - 10	90	2 - 4
clay	200	0.2	15 - 30	350 +	3 - 6
		0.4	10 - 12	180 - 300	2 - 4

Table 7: Suggested border sizes (source: Kay (1986) in: EUROCONSULT, 1989)

* Unit stream is the flow for each meter width of border. The irrigation stream size is the unit stream multiplied by the width of the border

soil type		sand	clay
humid areas	bare soil	0.3	0.5
	good crop cover	1.0	2.0
arid areas	bare soil	1.0	2.0
	good crop cover	2.0	5.0

Table 8: Maximum land slopes for borders (%) (source: Kay (1986) in: EUROCONSULT, 1989)

slope (%)	maximum stream size (l / s)	average irrigation depth (mm)							
		clay		loam			sand		
		75	150	50	100	150	50	75	100
0.05	3.0	300	400	120	270	400	60	90	150
0.1	3.0	340	440	180	340	440	90	120	190
0.2	2.5	370	470	220	370	470	120	190	250
0.3	2.0	400	500	280	400	500	150	220	280
0.5	1.2	400	500	280	370	470	120	190	250
1.0	0.6	280	400	250	300	370	90	150	220
1.5	0.5	250	340	220	280	340	80	120	190
2.0	0.3	220	270	180	250	300	60	90	150

Table 9: Suggested furrow length (m) (source: Kay (1986) in: EUROCONSULT, 1989)

	minimum	maximum	
humid regions	0.05	0.3	longitudinal slope
arid regions	0.05	2	longitudinal slope
all regions	0	3	cross slope

Table 10: Minimum and maximum slopes for graded furrows (%)

irrigation method	land topography				soil infiltration (mm / h)
	humid regions		arid regions		
	bare soil	good crop cover	bare soil	good crop cover	
basin	level slope or less than 0.1 (steeper slopes need terracing)				up to 30
border	0.5	2.0	2.0	5.0	up to 30
furrow	0.3	-	2.0	-	up to 30
	cross slope		cross slope		
	3.0		3.0		

irrigation method	field shape	crops				labour
		row crops	sown, drilled crops	flooded rice	orchards	
basin	any shape	yes	yes	yes	yes	0.5 - 1.5
border	rectangular	yes	yes	no	yes	1.0 - 3.0
furrow	rows should be of equal length	yes	no	no	yes	2.0 - 4.0
border	rectangular	yes	yes	no	yes	1.0 - 3.0
furrow	rows should be of equal length	yes	no	no	yes	2.0 - 4.0

Table 11: Factors affecting choice of surface method (source: Kay (1986) in: EUROCONSULT, 1989)

Source: EUROCONSULT (1989)

Appendix II
SUGGESTED MAXIMUM WATER APPLICATION RATES

soil texture and profile	maximum water application rates (cm / h)					
	0 % slope		5 % slope		10 % slope	
	with cover	bare	with cover	bare	with cover	bare
deep uniform sandy loam	4.4	2.6	3.5	2.1	2.6	1.6
sandy loams over more compact subsoil	3.1	1.8	2.5	1.4	1.8	1.1
deep uniform silt loams	2.6	1.3	2.1	1.0	1.6	0.8
silt loams over more compact subsoil	1.6	0.8	1.3	0.5	1.1	0.3
clay loams and clays	0.5	0.3	0.4	0.3	0.3	0.2

Table 12: Suggested maximum water application rates (source: ILRI (1972) in: EUROCONSULT, 1989)

Appendix III EFFICIENCIES OF IRRIGATION WATER USE

Conveyance efficiency (e_c) is the efficiency of canal and conduit networks from the reservoir, river diversion or pumping station to the offtakes of the distributary system.

$$e_c = (V_d + V_2) / (V_c + V_1)$$

where V_c = volume diverted or pumped from the river (m^3)
 V_d = volume delivered to the distribution system (m^3)
 V_1 = inflow from other sources to the conveyance system (m^3)
 V_2 = non-irrigation deliveries from the conveyance system (m^3)

Distribution efficiency (e_d) is the efficiency of the water distribution canals and conduits supplying water from the conveyance network to individual fields.

$$e_d = (V_f + V_3) / V_d$$

where V_d = volume delivered to the distribution system (m^3)
 V_f = volume of water furnished to the fields (m^3)
 V_3 = non-irrigated deliveries from the distributary system (m^3)

Field application efficiency (e_a) is a relation between the quantity of water furnished at the field inlet and the quantity of water needed, and made available, for evapotranspiration by the crop to avoid undesirable water stress in the plants throughout the growing cycle.

$$e_a = V_m / V_f$$

where V_f = volume of irrigation water furnished to the fields (m^3)
 V_m = volume of irrigation water needed and made available (m^3)

Tertiary unit efficiency (e_u) is the combined efficiency of the water distribution system and of the water application process. This means the efficiency with which water is distributed and consumptively used within the tertiary unit.

$$e_u = (V_m + V_3) / V_d$$

Irrigation system efficiency (e_s) is the combined efficiency of the systems of water conveyance and distribution.

$$e_s = (V_f + V_2 + V_3) / (V_c + V_1)$$

Overall or project efficiency (e_p)

$$e_p = (V_m + V_2 + V_3) / (V_c + V_1)$$

Source: Bos & Nugteren (1990)

Appendix IV
LABOUR REQUIREMENTS FOR VARIOUS FIELD IRRIGATION SYSTEMS

irrigation method	labour requirements (man-hour per irrigation per ha)
surface	
furrow	1 - 3
border	0.5 - 1.5
basin	0.1 - 1
sprinkler	
hand-moved laterals	1 - 2.5
tractor-moved laterals	0.5 - 1
self-moved systems	0.05 - 0.3
permanent systems	0.05 - 0.2
drip	
orchard	0.1 - 0.3
row crops	0.1 - 0.3

Table 13: Labour requirements for various field irrigation systems (source: Jurriëns & Bos (1980) in: Ghassemi *et al.*, 1995)

Appendix V
WATER QUALITY FOR IRRIGATION

potential irrigation problem	unit	degree of restriction on use		
		none	slight to moderate	severe
salinity				
EC _i (or)	dS / m	< 0.7	0.7 - 3.0	> 3.0
TDS (total dissolved solids)	mg / l	< 450	450 - 2000	> 2000
infiltration				
SAR or adj. R _{Na}	0 - 3 and EC _i	> 0.7	0.7 - 0.2	< 0.2
	3 - 6	> 1.2	1.2 - 0.3	< 0.3
	6 - 12	> 1.9	1.9 - 0.5	< 0.5
	12 - 20	> 2.9	2.9 - 1.3	< 1.3
	20 - 40	> 5.0	5.0 - 2.9	< 2.9
specific ion toxicity *				
sodium (Na)				
surface irrigation	SAR	< 3	3 - 9	> 9
sprinkler irrigation	meq / l	< 3	> 3	
chloride (Cl)				
surface irrigation	meq / l	< 4	4 - 10	> 10
sprinkler irrigation	meq / l	< 3	> 3	
boron (B)	mg / l	< 0.7	0.7 - 3.0	> 3.0
miscellaneous effects **				
nitrate nitrogen (NO ₃ - N) ***	mg / l of N	< 5	5 - 30	> 30
bicarbonate (HCO ₃) (overhead sprinkling only)	meq / l	< 1.5	1.5 - 8.5	> 8.5
pH			normal range 6.5 - 8.4	

Table 14: Guidelines for interpretation of water quality for irrigation (source: FAO (1985))

* For surface irrigation, most tree crops and woody plants are sensitive to sodium and chloride; use the values shown.

Most annual crops are not sensitive; use the tolerance tables given in appendix VI. With overhead sprinkler irrigation and low humidity (< 30 percent), sodium and chloride may be absorbed through the leaves of sensitive crops

** Referring to crops sensitive to the ion concerned

*** NO₃ - N means nitrogen reported in terms of elemental nitrogen (NH₄ - N and organic - N should be included when wastewater is being tested)

Assumptions in the guidelines: The water quality guidelines in table 12 are intended to cover the wide range of conditions encountered in irrigated agriculture. Several basic assumptions have been used to define their range of usability. If the water is used under greatly different conditions, the guidelines may need to be adjusted. Wide deviations from the assumptions might result in wrong judgements on the usability of a particular water supply, especially if it is a borderline case. Where sufficient experience, field trials, research or observations are available, the guidelines may be modified to fit local conditions more closely.

The basic assumptions in the guidelines are:

Yield potential: Full production capability of all crops, without the use of special practices, is assumed when the guidelines indicate no restrictions on use. A 'restriction on use' indicates that there may be a limitation in choice of crop or special management may be needed to maintain full production capability. A 'restriction on use' does not indicate that the water is unsuitable for use.

Site conditions: Soil texture ranges from sandy-loam to clay-loam with good internal drainage. The climate is semi-arid to arid and rainfall is low. Rainfall does not play a significant role in meeting crop water demand or leaching requirement. Drainage is assumed to be good, with no uncontrolled shallow water table present within 2 metres of the surface.

Methods and timing of irrigations: Normal surface or sprinkler irrigation methods are used. Water is applied infrequently, as needed, and the crop utilizes a considerable portion of the available stored soil-water (50 percent or more) before the next

irrigation. At least 15 percent of the applied water percolates below the root zone (leaching fraction LF > 15 percent). The guidelines are too restrictive for specialized irrigation methods, such as localized drip irrigation, which results in near daily or frequent irrigations, but are applicable for subsurface irrigation if surface applied leaching satisfies the leaching requirements.

Water uptake by crops: Different crops have different water uptake patterns, but all take water from wherever it is most readily available within the rooting depth. On average about 40 percent is assumed to be taken from the upper quarter of the rooting depth, 30 percent from the second quarter, 20 percent from the third quarter and 10 percent from the lowest quarter. Each irrigation leaches the upper root zone and maintains it at a relatively low salinity. Salinity increases with depth and is greatest in the lower part of the root zone. The average salinity of the soil-water is three times that of the applied water and is representative of the average root zone salinity to which the crop responds. These conditions result from a leaching fraction of 15 - 20 percent and irrigations that are timed to keep the crop adequately watered at all times.

Salts leached from the upper root zone accumulate to some extent in the lower part but a salt balance is achieved as salts are moved below the root zone by sufficient leaching. The higher salinity in the lower root zone becomes less important if adequate moisture is maintained in the upper, 'more active' part of the root zone and long-term leaching is accomplished.

Restriction on use: The 'restriction on use' shown in Table 12 is divided into three degrees of severity: none, slight to moderate and severe. The divisions are somewhat arbitrary since change occurs gradually and there is no clearcut breaking point. A change of 10 to 20 percent above or below a guideline value has little significance if considered in proper perspective with other factors affecting yield. Field studies, research trials and observations have led to these divisions, but management skill of the water user can alter them. Values shown are applicable under normal field conditions prevailing in most irrigated areas in the arid and semi-arid regions of the world.

Water quality guidelines: The guidelines are practical and have been used successfully in general irrigated agriculture for evaluation of the common constituents in surface water, groundwater, drainage water, sewage effluent and wastewater. They are based on certain assumptions given above. These assumptions must be clearly understood but should not become rigid prerequisites. A modified set of alternative guidelines can be prepared if actual conditions of use differ greatly from those assumed.

No soil or cropping problems are experienced or recognized when using water with values less than those shown for 'no restriction on use'. With restrictions in the 'slight to moderate' range, gradually increasing care in selection of crop and management alternatives is required if full yield potential is to be achieved. On the other hand, if water is used which equals or exceeds the values shown for 'severe' restrictions, the water user should experience soil and cropping problems or reduced yields, but even with cropping management designed especially to cope with poor quality water, a high level of management skill is essential for acceptable production. If water quality values are found which approach or exceed those given for the severe restriction category, it is recommended that before initiating the use of the water in a large project, a series of pilot farming studies be conducted to determine the economics of the farming and cropping techniques that need to be implemented.

Table 12 must guard against drawing unwarranted conclusions based only on the laboratory results and the guideline interpretations as these must be related to field conditions and must be checked, confirmed and tested by field trials or experience. The guidelines are a first step in pointing out the quality limitations of water supply, but this alone is not enough, since methods to overcome or adapt to them are also needed. The guidelines do not evaluate the effect of unusual or special water constituents sometimes found in wastewater, such as pesticides and organics.

RSC*	<1.25	meq / l	harmless
	1.25 - 2.50	meq / l	marginal
	> 2.50	meq / l	harmful

Table 15: Residual Sodium Carbonate and Bicarbonates (RSC) classification (source: EUROCONSULT, 1989)

$$* RSC = (HCO_3 + CO_3) - (Ca + Mg)$$

where: HCO₃, CO₃, Ca, Mg in meq / l

element	recommended maximum concentration (mg / l) *	remarks
Al aluminium	5.0	can cause non-productivity in acid soils (pH < 5.5), but more alkaline soils at pH > 7.0 will precipitate the ion and eliminate any toxicity
As arsenic	0.10	toxicity to plants varies widely, ranging from 12 mg / l for Sudan grass to less than 0.05 mg / l for rice

Be	beryllium	0.10	toxicity to plants varies widely, ranging from 5 mg / l for kale to 0.5 mg / l for bush beans
Cd	cadmium	0.01	toxic to beans, beets and turnips at concentrations as low as 0.1 mg / l in nutrient solutions. Conservative limits recommended due to its potential for accumulation in plants and soils to concentrations that may be harmful to humans
Co	cobalt	0.05	toxic to tomato plants at 0.1 mg / l in nutrient solution. Tends to be inactivated by neutral and alkaline soils
Cr	chromium	0.10	not generally recognized as an essential growth element. Conservative limits recommended due to lack of knowledge on its toxicity to plants
Cu	copper	0.20	toxic to a number of plants at 0.1 to 1.0 mg / l in nutrient solutions
F	fluoride	1.0	inactivated by neutral and alkaline soils
Fe	iron	5.0	not toxic to plants in aerated soils, but can contribute to soil acidification and loss of availability of essential phosphorus and molybdenum. Overhead sprinkling may result in unsightly deposits on plants, equipment and buildings.
Li	lithium	2.5	tolerated by most crops up to 5 mg / l; mobile in soil. Toxic to citrus at low concentrations (<0.075 mg / l). Acts similarly to boron
Mn	manganese	0.20	toxic to a number of crops at a few-tenths to a few mg / l, but usually only in acid soils
Mo	molybdenum	0.01	not toxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high concentrations of available molybdenum.
Ni	nickel	0.20	toxic to a number of plants at 0.55 mg / l to 1.0 mg / l; reduced toxicity at neutral or alkaline pH.
Pd	lead	5.0	can inhibit plant cell growth at very high concentrations
Se	selenium	0.02	toxic to plants at concentrations as low as 0.025 mg / l and toxic to livestock if forage is grown in soils with relatively high levels of added selenium. An essential element to animals but in very low concentrations.
Sn	tin		
Ti	titanium		effectively excluded by plants; specific tolerance unknown
W	tungsten		
V	vanadium	0.10	toxic to many plants at relatively low concentrations
Zn	zinc	2.0	toxic to many plants at widely varying concentrations; reduced toxicity at pH > 6.0 and in fine textured or organic soils

Table 16: Recommended maximum concentrations of trace elements in irrigation water (source: FAO, 1985)

* The maximum concentration is based on a water application rate which is consistent with good irrigation practices (10,000 m³ per hectare per year). If the water application rate greatly exceeds this, the maximum concentrations should be adjusted downward accordingly. No adjustment should be made for application rates less than 10,000 m³ per hectare per year. The values given are for water used on a continuous basis at one site.

Figure 1: Diagram for the classification of irrigation waters (source: Thorne & Peterson (1964) in EUROCONSULT, 1989)

Figure 2: Effect of applied water salinity (EC_i) upon root zone soil salinity (EC_e) at various leaching fractions (LF)

Source: FAO (1985)

Figure 3: Divisions for relative salt tolerance ratings of agricultural crops (source: Maas (1984) in FAO, 1985)

Appendix VI
WATER QUALITY FOR LIVESTOCK AND POULTRY

water salinity (EC_i) (dS / m)	rating	remarks
< 1.5	excellent	usable for all classes of livestock and poultry
1.5 - 5.0	very satisfactory	usable for all classes of livestock and poultry. May cause temporary diarrhoea in livestock not accustomed to such water; watery droppings in poultry
5.0 - 8.0	satisfactory for livestock unfit for poultry	may cause temporary diarrhoea or be refused at first by animals not accustomed to such water often causes watery faeces, increased mortality and decreased growth, especially in turkeys
8.0 - 11.0	limited use for livestock	usable with reasonable safety for dairy and beef cattle, sheep, swine and horses. Avoid use for pregnant or lactating animals
11.0 - 16.0	unfit for poultry very limited use	not acceptable for poultry unfit for poultry and probably unfit for swine. Considerable risk in using for pregnant or lactating cows, horses or sheep, or for the young of these species. In general, use should be avoided although older ruminants, horses, poultry and swine may subsist on waters such as these under certain conditions
> 16.0	not recommended	risks with such highly saline water are so great that it cannot be recommended for use under any conditions

Table 17: Water quality guide for livestock and poultry uses

livestock	magnesium (mg / l)	concentration (meq / l)
poultry*	< 250	< 21
swine*	< 250	< 21
horses	250	< 21
cows (lactating)	250	< 21
ewes with lambs	250	< 21
beef cattle	400	33
adult sheep on dry feed	500	41

Table 18: Suggested limits for magnesium in drinking water for livestock

* The tolerance of swine and poultry for magnesium is unknown but could well be less than 250 mg / l

Source: FAO (1985)

Appendix VII
RELATIVE TOLERANCES OF CROPS

plant	threshold ($\mu\text{S} / \text{cm}$)	yield decrease per 1000 $\mu\text{S} / \text{cm}$ increase in salinity (per cent)
sensitive		
apricot	1600	24.0
bean	1000	19.0
carrot	1000	14.0
grapefruit	1800	16.0
orange	1700	16.0
onion	1200	16.0
peach	1700	21.0
strawberry	1000	33.0
moderately sensitive		
alfalfa	2000	7.3
broad bean	1600	9.6
corn (grain)	1700	12.0
cucumber	2500	13.0
lettuce	1300	13.0
potato	1700	12.0
rice	3000	12.0
sugarcane	1700	5.9
tomato	2500	9.9
moderately tolerant		
barley (forage)	6000	7.1
sorghum	6800	16.0
soy bean	5000	20.0
wheat	6000	7.1
tolerant		
barley (grain)	8000	5.0
cotton	7700	5.2
sugar beet	7000	5.9
wheat (semidwarf)	8600	3.0

Table 19: Salt tolerance of selected plants with respect to the electrical conductivity of saturated-soil extract (Source: Maas (1990) in: Ghassemi *et al.*, 1995)

sensitive (ESP* < 15)	semi-tolerant (ESP 15 - 40)	tolerant (ESP > 40)
avocado (<i>Persea americana</i>)	carrot (<i>Daucus carota</i>)	alfalfa (<i>Medicago sativa</i>)
deciduous fruits	clover, ladino (<i>Trifolium repens</i>)	barley (<i>Hordeum vulgare</i>)
nuts	dallisgrass (<i>Paspalum dilatatum</i>)	beet, garden (<i>Beta vulgaris</i>)
bean, green (<i>Phaseolus vulgaris</i>)	fescue, tall (<i>Festuca arundinacea</i>)	beet, sugar (<i>Beta vulgaris</i>)
cotton (at germination)	lettuce (<i>Lactuca sativa</i>)	bermuda grass (<i>Cynodon dactylon</i>)
(<i>Gossypium hirsutum</i>)	bajara (<i>Pennisetum typhoides</i>)	cotton (<i>Gossypium hirsutum</i>)
maize (<i>Zea mays</i>)	sugarcane (<i>Saccharum officinarum</i>)	paragrass (<i>Brachiaria mutica</i>)
peas (<i>Pisum sativum</i>)	berseem (<i>Trifolium alexandrinum</i>)	rhodes grass (<i>Chloris gayana</i>)
grapefruit (<i>Citrus paradisi</i>)	benji (<i>Melilotus parviflora</i>)	wheatgrass, crested (<i>Agropyron cristatum</i>)
orange (<i>Citrus sinensis</i>)	raya (<i>Brassica juncea</i>)	wheatgrass, fairway (<i>Agropyron cristatum</i>)
peach (<i>Prunus persica</i>)	oat (<i>Avena sativa</i>)	wheatgrass, tall (<i>Agropyron elongatum</i>)
tangerine (<i>Citrus reticulata</i>)	onion (<i>Allium cepa</i>)	karnal grass (<i>Diplachna fusca</i>)
mung (<i>Phaseolus aureus</i>)	radish (<i>Raphanus sativus</i>)	
mash (<i>Phaseolus mungo</i>)	rice (<i>Oryza sativa</i>)	
lentil (<i>Lens culinaris</i>)	rye (<i>Secale cereale</i>)	
groundnut (<i>Arachis hypogaea</i>)	ryegrass, Italian (<i>Lolium multiflorum</i>)	
gram (<i>Cicer arietinum</i>)	sorghum (<i>Sorghum vulgare</i>)	
cowpeas (<i>Vigna sinensis</i>)	spinach (<i>Spinacia oleracea</i>)	
	tomato (<i>Lycopersicon esculentum</i>)	
	vetch (<i>Vicia sativa</i>)	
	wheat (<i>Triticum vulgare</i>)	

Table 20: Relative tolerance of selected crops to exchangeable sodium. Tolerance decreases from top to bottom (source: FAO, 1985)

* ESP stands for exchangeable sodium percentage

very sensitive (< 0.5 mg / l)

lemon

Citrus limon

blackberry

Rubus spp.**sensitive (0.5 - 0.75 mg / l)**

avocado

Persea americana

grapefruit

Citrus X paradisi

orange

Citrus sinensis

apricot

Prunus armeniaca

peach

Prunus persica

cherry

Prunus avium

plum

Prunus domestica

persimmon

Diospyros kaki

fig, kadota

Ficus carica

grape

Vitis vinifera

walnut

Juglans regia

pecan

Carya illinoensis

cowpea

Vigna unguiculata

onion

*Allium cepa***sensitive (0.75 - 1.0 mg / l)**

garlic

Allium sativum

sweet potato

Ipomoea batatas

wheat

Triticum aestivum

barley

Hordeum vulgare

sunflower

Helianthus annuus

bean, mung

Vigna radiata

sesame

Sesamum indicum

lupine

Lupinus hartwegii

strawberry

Fragaria spp.

artichoke, Jerusalem

Helianthus tuberosus

bean, kidney

Phaseolus vulgaris

bean, lima

Phaseolus lunatus

groundnut / peanut

*Arachis hypogaea***moderately sensitive (1.0 - 2.0 mg / l)**

pepper, red

Capsicum annum

pea

Pisum sativa

carrot

Daucus carota

radish

Raphanus sativus

potato

Solanum tuberosum

cucumber

*Cucumis sativus***moderately tolerant (2.0 - 4.0 mg / l)**

lettuce

Lactuca sativa

cabbage

Brassica oleracea capitata

celery

Apium graveolens

turnip

Brassica rapa

bluegrass, Kentucky

Poa pratensis

oats

Avena sativa

maize

Zea mays

artichoke

Cynara scolymus

tobacco

Nicotiana tabacum

mustard

Brassica juncea

clover, sweet

Melilotus indica

squash

Cucurbita pepo

muskmelon

*Cucumis melo***tolerant (4.0 - 6.0 mg / l)**

sorghum

Sorghum bicolor

tomato	<i>Lycopersicon lycopersicum</i>
alfalfa	<i>Medicago sativa</i>
vetch, purple	<i>Vicia benghalensis</i>
parsley	<i>Petroselinum crispum</i>
beet, red	<i>Beta vulgaris</i>
sugarbeet	<i>Beta vulgaris</i>
very tolerant (6.0 - 15.0 mg / l)	
cotton	<i>Gossypium hirsutum</i>
asparagus	<i>Asparagus officinalis</i>

Table 21: Relative boron tolerance of agricultural crops. Values given represent the maximum concentrations tolerated in soil water without yield or vegetative growth reductions. Maximum concentrations in the irrigation water are approximately equal to these values or slightly less (source: FAO, 1985)