MSc PROGRAMME SOIL AND WATER

THESIS

# USING "SALTMOD" TO PREDICT DESALINIZATION IN THE LEZIRIA GRANDE POLDER, PORTUGAL

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# 3. DESCRIPTION OF THE STUDY AREA

## 3.1 The study area

Leziria Grande is an island bordered to the west by the Tagus river and to the east by the Sorraia and Risco rivers. The Tagus and Sorraia are subject to tidal movement. The island is located about 25 km from Lisbon, figure 4. It covers an area of approximately 13000 ha. The ground level varies from 0 to 2.5 m above mean Tagus level. The area is protected against flooding by a 60 km long dike. The dike was constructed in the mid fifties. In February 1979 dike breaches occurred and a large part of the Leziria Grande was flooded for a period of two months. The dike was rehabilitated.

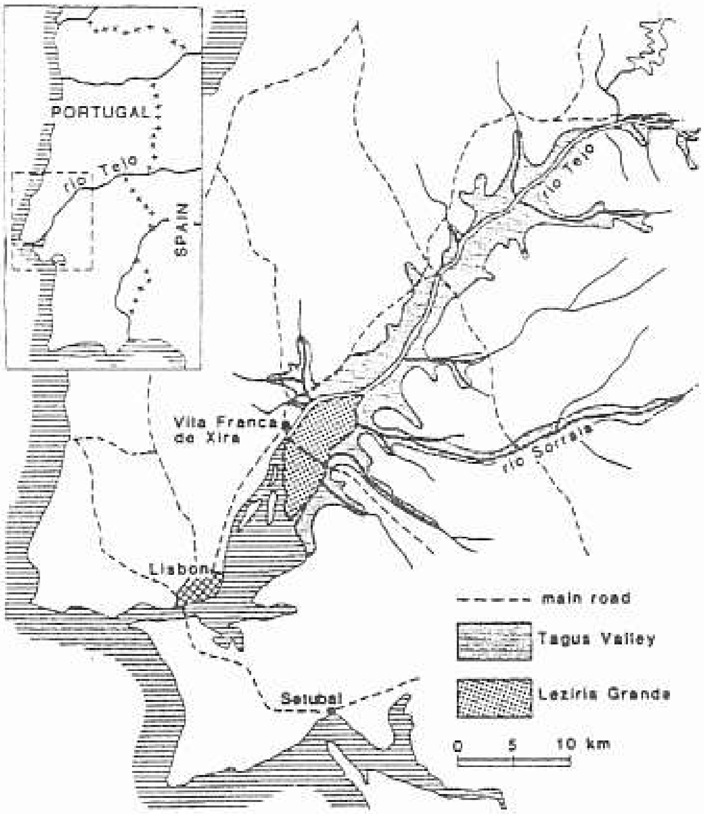



Figure 4. Location of the project area (van Alphen and Pisarra, 1988).

The climate is Mediterranean. Average annual rainfall is around 670 mm with a variation from 350 to 980 mm. Rainfall occurs mainly between October and March. Temperature varies from a monthly average of about 9.0°C in December to 21.5 °C in July. The annual average is about 15 °C. The potential evapotranspiration (on the basis of the Thornthwaite equation) ranges from 20 mm in December to 210 mm in July. The annual average comes to 1220 mm (van Alphen and Pisarra, 1988).

The soils consist of fluvial deposits in the northern part and marine deposits in the central and southern parts. In between there is a transition zone where fluvial deposits area overlying marine sediments, figure 5. The marine deposits are fine-textured and more or less homogeneous in texture. The calcium carbonate content varies from 4% to nil. A high content of soluble salts is common and exchangeable sodium is often present in large amounts. In winter, waterlogging is a common phenomenon, due to the flat topography, the low position with respect to the water level in the Tagus river and the often low soil permeability. Especially the southern part of the island is affected by the twin problem of waterlogging and salinity.

A surface drainage system was constructed in the late fifties. Excess water (from rainfall) is drained off by gravity through a system of 460 km of open water courses and 18 sluices. Because of tidal movement, discharge is possible during relatively short intervals only (van Alphen and Pisarra, 1988). The system, in essence, is a surface drainage system designed to carry off excess rain water. Nevertheless, desalinization can only be enhanced by installing a field drainage system, thus facilitating infiltration and percolation of excess rain water. Since no experience existed with this type of drainage, three experimental plots with subsurface field drains were installed in 1976, which cover the soil condition in the southern part of the Leziria Grande, see also figure 5.

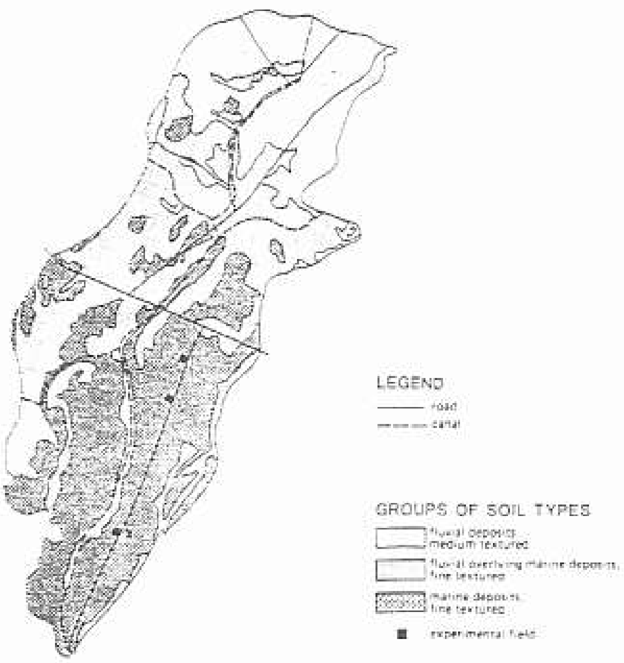



Figure 5. Simplified soil map of the Leziria Grande and location of the experimental plots (van Alphen and Pisarra, 1988).

Whereas winters (months of October-March), in general, show conditions of excess water, the summers (months of April-September) are dry. Irrigation water is required for summer cropping. Water is let in from the Tagus and Sorraia rivers through about 20 sluices and is conveyed and distributed through the system of open water courses that serves the drainage of the area.

The land is owned by a small number of farmers and by a nationalized "Companhia das Lezirias". Amongst the cultivated crops winter grains (wheat, barley and oats) and summer crops like melons and tomatoes predominate. About 3000 ha of land, located in the salt-affected southern part, is left as natural pasture. Tomatoes and melons are mainly cultivated by "seareiros" farmers who rent land on an annual basis.

The acreage of irrigated crops measures about 300 ha. Irrigation water of good quality is in short supply. Major bottlenecks are the total intake capacity (by gravity) of the sluices and of the poor maintenance of the system of open water courses. Ditch cleaning machinery was purchased and a crash program of canal cleaning was implemented. Despite impeded drainage conditions and the restricted supply of irrigation water, crop yields in the Leziria Grande are above the national average.

### 3.2 The experimental plots

Poor drainage conditions and high levels of salinity and exchangeable sodium in soils prevail in the southern part of the Leziria. The traditional field drainage system consists of a network of 40-60 cm deep ditches at a spacing of 10-20 m. This system often fails to arrive at an effective control of the water-table and at a rapid removal or surface water after a heavy downpour. Reasons for this poor functioning are the improper connection to the system of open water courses, too high water levels in the open water courses and insufficient land levelling. Field drainage conditions may be improved considerably by implementing a set of rehabilitation measures. Whether an improved traditional drainage system contributes much to overcome the problem of high salinity was much doubted.

Therefore, three experimental plots with subsurface field drains were laid out on the fine-texture and highly saline soils in the souther part of the Leziria, to find out whether tile drainage can be used effectively for lowering the groundwater table, improving the desalinization of the soils, and increasing yields in the affected area.

### 3.2.1 Soil properties

According to the soil survey (Constantino, 1976). Table 6, shows the main characteristics of the soil of these tree experimental plots. As it can be seen the experimental plots number 1 and 2 are situated on fine-textured homogeneous soils of marine origin. No $CaCO_3$ is present in the top 0.5 m. Experimental plot number 3 is located on similar soils but $CaCO_3$ is present in the topsoil. In all cases the subsoil below a depth of 1.2 m is soft and unripened.

Table 6. Characteristics of the three experimental plots (Constantino, 1976).

| Plot number | Soil type | Permeability cm/day | Groundwater level cm Winter | Summer |
|---|---|---|---|---|
| 1 | MTg 1 | < 10 | Above 30 | Above 120 |
| 2 | MTg 1/2 | < 10 | Above 30 | Beneath 120 |
| 3 | MCg 1 | 10-15 | Above 30-50 | Beneath 120 |

**Legend of the soil classification:**

M: Fine and homogeneous textured soil from sediments deposited in water with high salt content.

T: Without $CaCO_3$ above 50 cm.

C: With $CaCO_3$ above 50 cm.

g: Silty clay topsoil.

1: High salinity level from 0-30 cm downwards.

2: High salinity level from 30 cm downwards.

#### 3.2.1.1 Physical characteristics

The fine soil texture did not vary much between the experimental plots or between the different soil layers. The soil are silty clays, the bulk density in the top 0.75 m varies from 1.2 to 1.35 g/cm3, indicating a porosity of 49-55%. At greater depth, the bulk density decreases to values varying from 1.0 to 1.1 g/cm$^3$. The amount of soil moisture retained between field capacity and wilting point was about 17.5% by volume. The drainable pore space was estimated to be 3 to 4%. The hydraulic conductivity of the soft subsoil did not vary much between experimental plots. The average hydraulic conductivity of the layer of 1.0 to 2.0 m measured 0.12, 0.60 and 0.33 m/d on the experimental plots 1, 2 and 3, respectively.

0.07 m/d. In the 0.25 to 0.75 m layer the average hydraulic conductivity measured

#### 3.2.1.2 Chemical characteristics

The cation exchange capacity did not vary much in the layer of 0.0 to 0.5 m. Measured values were 26 to 30 meq/100g of dry soil. The exchangeable sodium percentage in the topsoil (0.0 to 0.25 m) was 25 on experimental plots 1 and 2, and 15 on experimental plot 3. Higher values were found at greater depth. The salt content was high in all layers on all plots. The $EC_{1:2}$ values in the layers of 0.0 to 0.5 m were 8.6, 7.1 and 4.3 dS/m on the experimental plots 1, 2 and 3, respectively. Considering ESP (exchangeable sodium percentage) and salinity the soils were classified as saline-sodic.

### 3.2.2 Lay-out of the experimental plots

Subsurface field drains of corrugated PVC pipes (diameter 0.05 m) were installed at a depth of 1.1 m. Drain length varied from 130 to 150 m. Drain spacings were 10, 15 and 20 m, these values were based on estimated hydraulic conductivity and experience gained in the Marismas, Spain (as reported by Mann, 1979).

On experimental plot 1, only spacing of 10 and 15 m were used. On experimental plots 2 and 3 surface drains were also installed, these surface drains have an average depth of 60 cm and the spacing is 20 m. The gross area of experimental plots 1, 2 and 3 measured 3.6, 8.7 and 8.0 ha.

The lay-out of the experimental plot 2 is presented as an example in figure 6, from this, is possible to discuss: that the field drainage system discharged into open collector drains. The bottom width measured 1.0 m, the depths measured 2.0 m at the upper and 2.2 m at the lower end. Drainage water was pumped from the collector drains into the existing open water courses. Installed pump capacity was such as to cope with a discharge of 25 mm/d and 12 hours of pumping/day, i.e., at 5.8 l/sec.ha. The pumps were of a reversible type so as to be used for irrigation of summer crops.

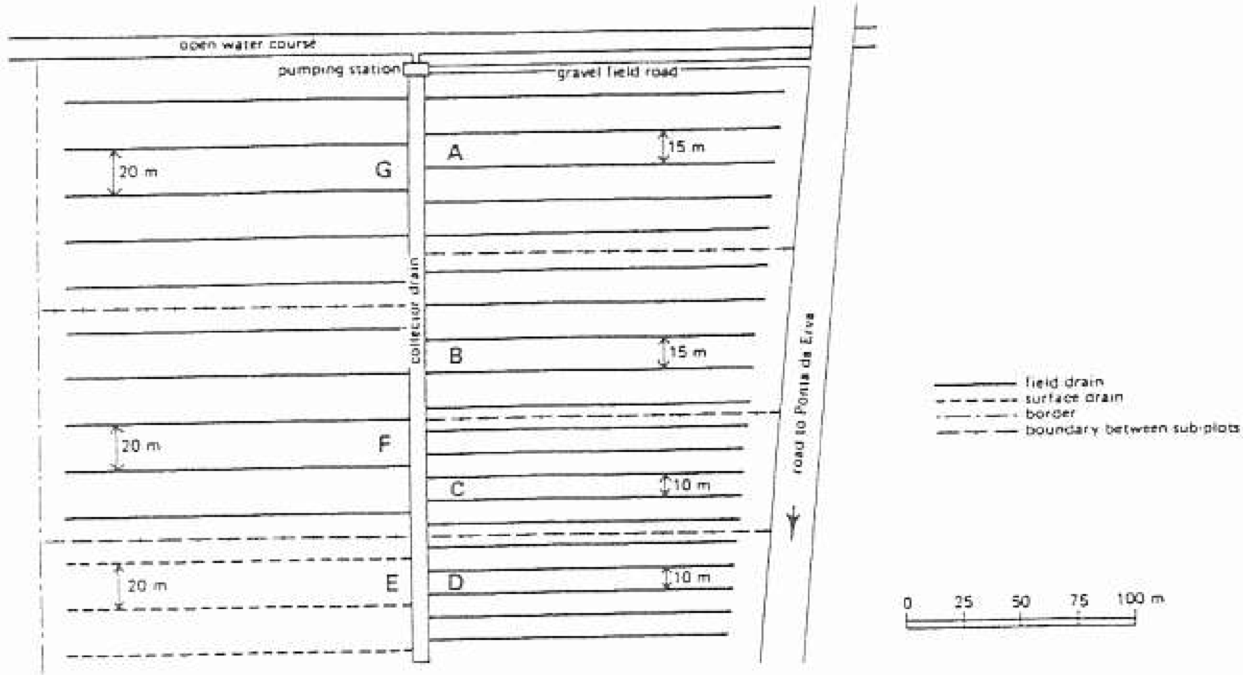



Figure 6. Lay-out of the experimental plot 2 (van Alphen and Pisarra, 1988).

## 4. PRINCIPLES OF SALTMOD

The following paragraphs present a overview of the principles of SALTMOD, as they are reported in the SALTMOD manual (Oosterbaan, 1993).

The computer model SALTMOD is based on seasonal water balance of agricultural lands. Four seasons in one year can be distinguished (e.g. dry, wet, cold and hot). Day to day water balance are not considered for three reasons: a) daily inputs would require a great deal of information, which may not be readily available, b) the method has been especially developed to predict long-term trends and c) future predictions made on a seasonal (long-term) basis are more reliable than those made on a daily (short-term) basis, because of the much higher variability of short term hydrological phenomena.

As input data, the model use water balance components. These are related to the surface hydrology (e.g. rainfall, evaporation, irrigation, reuse of drainage water, run-off) and to the aquifer hydrology (e.g. upward seepage, natural drainage, pumping from wells). The other water balance components (e.g. downward percolation, capillary rise, gravity drainage) are obtained as outputs. The quantity of drainage water is determined by two drainage intensity factors (i.e. for drainage above and below drain level) to be given with the input data and by the height of the water-table, resulting from the computed water balance. By varying the drainage intensity factors, one can simulate the impact of different drainage systems.

The input data of irrigation, evaporation and surface run-off are to be specified for three kinds of agricultural practices: rain fed agriculture or fallow land, irrigation of dry foot crops and irrigation of submerged rice (paddy land), for which areal fractions have to be given with the input data. By varying these fractions, one can simulate the impact of different agricultural practices on the water and salt balance.

SALTMOD accepts four different reservoirs in the soil profile, see figure 7. A surface reservoir, an upper (shallow) soil reservoirs, an intermediate soil reservoir or transition zone, and a depth reservoir or aquifer. If a horizontal subsurface drainage system is present, the transition zone is divided into two parts: an upper transition zone above drain level and a lower transition zone below it. Water balance are calculated for each reservoir separately. The excess water leaving one reservoir is converted into incoming water for the next reservoir. The three soil reservoirs is converted into incoming water for the next reservoir. The three soil reservoirs can be assigned different thicknesses and storage coefficients, to be given as input data. In a particular situation, the transition zone or the aquifer need not be present. They must then be given a minimum thickness. Appendix 1, defines the symbols used in SALTMOD.

The upper soil reservoir is defined by the soil depth from which water can evaporate or be taken up by plant roots. It can be saturated, unsaturated, or partly saturated, depending on the water balance. All water movements in this zone are vertical, either upward or downward, also depending on the water balance. The transition zone, too, can be saturated, unsaturated, or partly saturated. All flows in this zone are vertical, except the flow to subsurface drains, if present. The aquifer has horizontal and vertical flow. Pumped wells, if present, receive their water from the aquifer only.

The salt balance are calculated for each reservoir separately. They are based on water balances and on the salt concentrations of the incoming and outgoing water. Some concentrations (e.g. the initial salt concentrations of the water in the different soil reservoirs, in the irrigation water, and in the incoming groundwater in the aquifer) must be given as input data. The concentrations can be expressed in any consistent units (e.g. mmho/cm or mg/l).

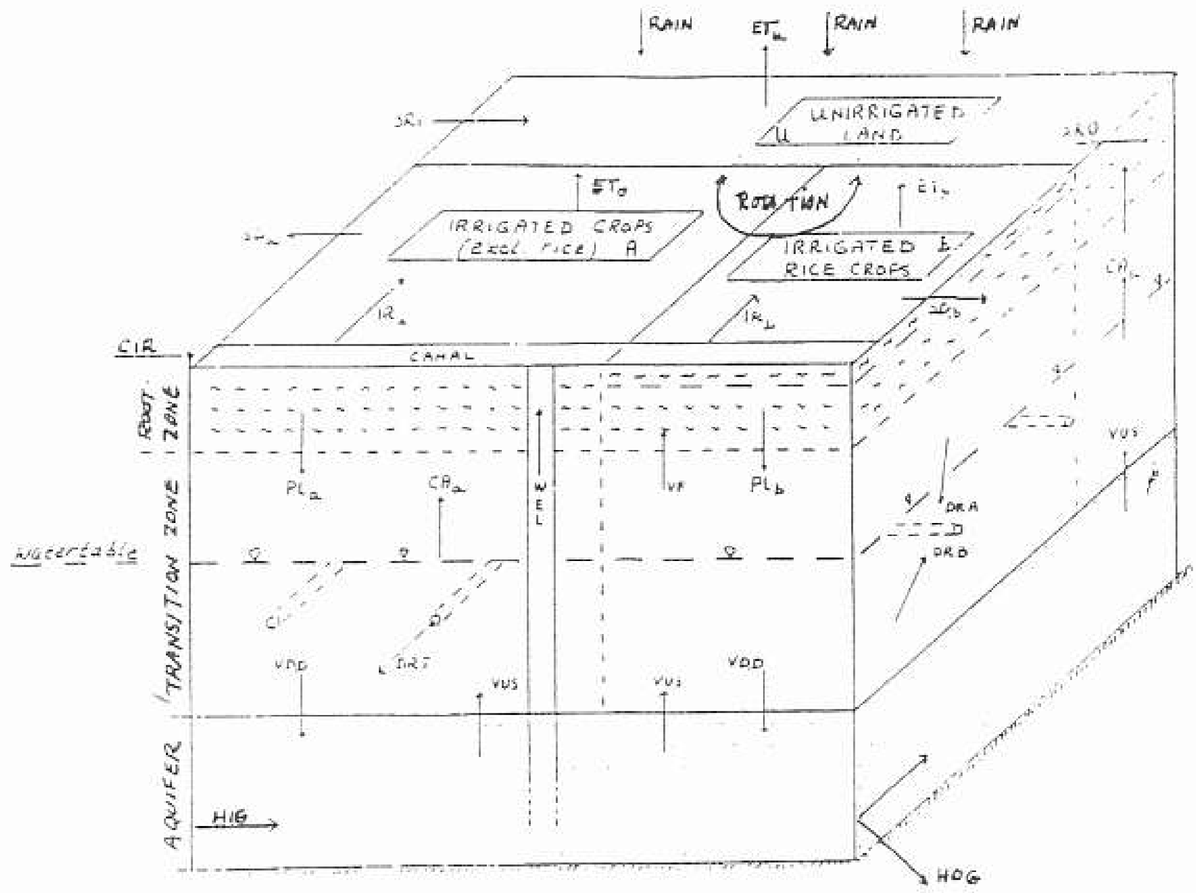



Figure 7. Different soil reservoirs accepted by SALTMOD (Oosterbaan, 1993).

Salt concentrations of outgoing water either from one reservoir into the other or by drainage are computed on the basis of the salt balance, with different leaching or salt mixing efficiencies to be given with the input data. The amount of salt removed during a season is based on the weighted average salt concentration during the season. The weight factor is introduced to take into account an exponential leaching function with time. Since the average concentration depends on initial and final salt concentrations, and since the final salt concentration depends on the leaching, which, again, depends on the average concentration, a trial and error procedure has to be applied to calculate the correct salt balance.

The effects of different leaching efficiencies can be simulated by varying their input value. If drain or well water is reused for irrigation, the method computes the salt concentration of the mixed irrigation water in the course of time and the subsequent impact on the soil and groundwater salinities, which again influences the salt concentration of the reused drainage water. By varying the fraction of reused drain or well water (to be given in the input data), one can simulate the long term impact of different reuse policies.

The output of SALTMOD is given for each season of any year for any number of years, as specified with the input data. The output consist of the seasonal volumes of drainage water and capillary rise, the seasonal average depth of the water-table, the salt concentration of the different soil reservoirs at the end of the season, and the season average salt concentration of the drainage water and the mixed irrigation water, as well as some indicators of irrigation efficiency and sufficiency. If required, farmer's responses to waterlogging and salinity can be taken into account. When the water-table becomes shallower, for example, the method can gradually increase the fraction of paddy land; or, with a shallow water-table or increasing soil salinity, it can gradually reduce the fraction of cultivated land and the amount of irrigation water applied. These adjustments influence the water and salt balances, which in turn slow down the process of waterlogging and salinization. Ultimately, an equilibrium situation will arise.

Some of the input data are inter-dependent, notably the irrigation data. These data can not, therefore, be indiscriminately varied. In very obvious illogical combinations of data, the program will give a warning but no more than that. The correctness of the input data remains the responsibility of the user.

The selection of the area to be analyzed by SALTMOD should be governed by the uniformity of the distribution of the cropping, irrigation, and drainage characteristics over the area. If these characteristics are randomly varied, it is advisable to use a larger area. If, on the other hand, the spatial distribution can lead to the designation of more uniform subareas, it is advisable to analyze the sub areas separately. It is also possible to use first the larger area approach and then use some of the outputs as inputs in the sub area approach. For example, an area may have fallow un irrigated land next to irrigation land. The resulting capillary rise in the fallow land can be obtained as output from the larger area approach. This can then be used either as a groundwater input in a separate approach for the fallow land or as a groundwater output in a separate approach for the irrigated land.

The output data are filed in the form of tables. Their interpretations is left entirely to the user. The program offers the possibility of developing a multitude of relations between varied input data, resulting outputs, and time. Different users may wish to establish different cause-effect or correlational relationships. The program, therefore, offers no standard graphics.

# 5. METHODOLOGY

The main work described in this thesis is an application of the computer model SALTMOD, which was developed at the International Institute for Land Reclamation and Improvement /ILRI by Oosterbaan and Pedroso de Lima in 1986 and which was revised in 1993 by Oosterbaan. The principles were described in Chapter 4. Existing data from the Leziria Grande polder in Portugal were used for calibration, validation, and predictions with the model, as described below.

## 5.1 Input data

SALTMOD requires as input: water balance components related to the surface hydrology (e.g. rainfall, evaporation, irrigation and run-off), physical and chemical soil characteristics, water-table behaviour, and crop and drainage data. The inputs are given as averages per season, i.e. for a wet winter season (from October to March) and a dry summer season (from April to September). These data were obtained from the results of the investigations at the drainage experimental plots in the Leziria Grande, as reported by Mann (1979) and van Alphen & Pisarra (1988). Data were available for the period 1977-1986.

### 5.1.1 Input constants

A set of input constants regarding to the different reservoirs in the soil profile and their porosity, water-table behaviour and drainage data, are presented in table 7. They are valid for each one of the three experimental plots during the study period 1977-1986, because they refer to general characteristics of the Leziria area.

As was explained in Chapter 3, section 3.1, the soils in the southern part of the Leziria consist of marine deposits, and they are not fully developed.

Two reservoirs in the soil profile are defined: a root zone of 0.75 m, and a transition zone of 1.25. Because SALTMOD also assumes the presence of an aquifer, it was set at a very low level. Based on measured data, total porosity was set at 50 % in the root zone, and 60 % in the transition zone and the aquifer, while drainable porosity was 4 % in root zone, and 3 % in the transition zone.

Depth of 0.5 m was taken to characterize water table behaviour.

According to the depth of the ripened soil, a critical depth of the water-table for capillary rise of 1.5 m was assumed.

Since the permeability of the unripened soil is negligible, drain depth is limited to the depth of the overlaying layer (1.1 m), and the drainage flow below drain level was assumed negligible.

In the heavy clay soils of the Leziria Grande polder, the hydraulic conductivity decreases with depth (Oosterbaan et al., 1988). A geometric mean of the hydraulic conductivity values for the layers 0.25-0.75 m, and 1.0-1.20 m was used to calculate the ratio between drain discharge and square value of the elevation of the water-table above drain level (QHS). The QHS values refer to the drainage flow above drain level, and they were calculated using the Hooghoudt equation, as reported by Wesseling (1974). A tentative initial QHS value of 0.003 was taken to characterize the area.

### 5.1.2 Rainfall data

Meteorological data of the area are obtained at the "Estacao Meteorologica da Leziria Grande". This station is situated in the middle of the study area. Seasonal average values of rainfall data for this station are presented in table 8. Separate data were collected for each experimental plot as well, but were not used in the model.

These data have been divided in three periods. The first period from 1977 to 1979, was extremely wet, and, consequently, during this period the study area was flooded (Mann, 1979). The second period from 1979 to 1984 was a dry one, which is more normal. The third period from 1984 to 1986 was relatively dry, the summer average value being a bit smaller than during the two previous periods and the winter average value being a bit higher than in the dry period 1979-1984. An outgoing surface run-off of 0.03 m/wet season was recorded.

Regarding the storage efficiency of rain-water, defined as the fraction of rain-water stored in the root zone of unirrigated lands as an average of all the rainstorms (STU). A value of 0.7 was assumed initially.

Table 7. Input constants

| Soil reservoirs and their porosity | Symbol | Value |
| --- | --- | --- |
| Thickness of the root zone layer (m) | ROO | 0.75 |
| Porosity of the soil in the root zone (m/m) | POR | 0.50 |
| Thickness of the transition zone (m) | TRA | 1.25 |
| Porosity of the transition zone (m/m) | POT | 0.60 |
| Thickness of the aquifer (m) | AQU | 0.15 |
| Porosity of aquifer (m/m) | POA | 0.60 |
| Effective (drainable or refillable) porosity of the soil in ROO (cub.m porespace/cub.m soil) | PR | 0.04 |
| Effective (drainable or refillable) porosity of the soil in TRA (cub.m porespace/cub. m soil) | PA | 0.03 |
| **Water table behaviour** | **Symbol** | **Value** |
| Initial depth of the water table (m). | DWTo | 0.3 |
| Critical depth of the water table for capillary rise (m) | CDW | 1.5 |
| **Drainage data** | **Symbol** | **Value** |
| Presence of subsurface drainage system, 1 = yes | DRAI | 1 |
| Reclamation experiment, 1 = yes | RECL | 1 |
| Depth of the subsurface drains (m) | DRD | 1.1 |
| Ratio between drain discharge and square value of the elevation of the water table above drain level to determine the drainage flow above drain level | QHS | 0.003 |

Table 8. Rainfall data

| Seasonal average | Symbol | 1977-1979 | 1979-1984 | 1984-1986 |
|---|---|---|---|---|
| Summer rainfall (m/season) | RAI 1 | 0.13 | 0.13 | 0.11 |
| Winter rainfall (m/season) | RAI 2 | 0.89 | 0.45 | 0.50 |

### 5.1.3 Irrigation practices

Regarding irrigation, two periods are distinguished: an unirrigated period from 1977 to 1984 and an irrigated one from 1984 to 1986. Irrigation practices were mainly carried out on experimental plot 3. Irrigation was practiced only during summer seasons, the irrigation water was taken by pumping from a nearby drainage cum irrigation canal. The depth of water applied is calculated from the data on pump discharge and pumping hours. The water was applied by furrow method, an average amount of water entering the area through the irrigation furrow of 0.22 m/dry season was recorded, and losses of 10% are assumed. The salt content of the irrigation water was measured frequently, and if found too high, irrigation was delayed. $EC_w$ values of 0.8, 0.9 and 1.0 dS/m were registered.

### 5.1.4 Crop practices

In the Leziria Grande, two kinds of crop practices have been utilized: rain-fed agriculture or fallow land and irrigation of foot-dry crops. During the period 1977-1984, cereals (e.g. wheat, barley) were grown during the wet season, and no crop was grown during the dry season. During the period 1984-1986, cereals were grown during the wet season and melons were grown during the dry season. So far, no rotation of crops is used (crops are planted each year in the same area).

### 5.1.5 Evapotranspiration

The values used to determinate the reference crop evapotranspiration (ETo) are 20 years' averages calculated on the basis of the Thornthwaite equation. Average values of 0.2 m/wet season and 0.97 m/dry season were calculated (Mann M.A.M., 1979). To determine the crop evapotranspiration (ETcrop), crop coefficients (kc) of 1 for winter cereals, and 0.22

for uncovered land are used (Doorenbos & Pruitt, 1977). It is important to remark that variations in the crop evapotranspiration during the dry season are included to contribute to achieving a better match between observed and computed values. A value of 0.2 for the period 1977-1979, a value of 0.4 for the period of 1979-1984, and an average value of 0.3 m/dry season for the period of 1984-1986 are used.

### 5.1.6 **Salt concentration of the different soil reservoirs**

Considering the behaviour of the rainfall during the study period, the salt concentration of the soil moisture when saturated, expressed as EC (dS/m) for the root zone and transition zone, is presented in three chronological periods too. Table 9 shows these values for experimental plot 3, which are averages of data per layer of 0.25 m., from the soil surface to a depth of 1.5 m, and of a layer of 0.5 m between 1.5 to 2.0 m deep (Pedroso de Lima and Oosterbaan, 1987). There is one value for the root zone, and there are two for the transition zone.

To describe the salt balance in the transition zone, SALTMOD utilizes values of the salt concentrations above and below drain level. If irrigation is practised, the salt balance of the root zone is analyzed apart for the unirrigated and the irrigated area. Because aquifer is present, as explained in section 5.1.1, in this particular case it is not necessary to assign it a salinity value.

Table 9. Salt concentration of the soil reservoirs, expressed as EC (dS/m)

| **Experimental plot 3** | **Symbol** | **1977-79** | **1979-84** | **1984-86** |
|---|---|---|---|---|
| Root zone in the unirrigated area | SCRU | 8.6 | 7.7 | 7.5 |
| Root zone in the irrigated area | SCRA | ---- | ---- | 7.5 |
| Transition zone above drainage level | SCu | 31.0 | 13.1 | 10.4 |
| Transition zone below drainage level | SCl | 54.0 | 54.0 | 54.0 |

### 5.1.7 The leaching efficiency

As described in Chapter 2, section 2.7.2, clay soils are characterized by a low leaching efficiency (LE), and since the soils of the Leziria Grande polder are heavy clays, a value of 0.15 was assumed initially.

Appendix 2, shows an example of the input file required for SALTMOD, once it has been filled with the different data described in this section.

## 5.2 Output file

Using an input and after running the computer program, SALTMOD delivers an output in tabular form, which mainly consists of: the seasonal volumes of drainage water and capillary rise, the seasonal average depth of the water-table, the salt concentration of the different soil reservoirs at the end of the season, and the seasonal average salt concentration of the drainage water and the mixed irrigation water, as well as some indicators of irrigation efficiency and sufficiency. Appendix 3 shows the definition of the different symbols used in SALTMOD output (Oosterbaan, 1993), and Appendix 4 shows as an illustration the output of the input file shown in Appendix 2.

## 5.3 Calibration procedure

For each one of the three experimental plots the computer model is calibrated for the unirrigated period 1977-1984, using observed data on soil salinity in the root zone expressed as EC (dS/m), depth of the water table (m) and drain discharge (mm/season). Because during the study period the distributions of rainfall, evaporation, irrigation and cropping patterns were not uniform, it was not considered wise to use one set of input data to characterize the area. Therefore, the model calibration is done in two periods, one from 1977 to 1979 (wet period) and an other from 1979 to 1984 (dry period), in which the output of one does not correspond to the input of the other.

In both periods, the match between observed and computed values is obtained by varying the uncertain input parameters LE, STU and QHS. To check the outcome in case different values of such input parameters would have been chosen, the following combinations are tested: LE values of 0.10, 0.15 and 0.20, STU values of 0.50, 0.70 and 0.90, and QHS values of 0.002, 003 and 0.004.

## 5.4 Validation procedure

After calibration, a validation is done for the irrigated period 1984-1986, maintaining the LE, and QHS values, which were determined during the calibration of the model, and using an average value of $EC_w$ equal to 0.9 dS/m. This average value of $EC_w$ is based on field experiences in the Leziria area (van Alphen and Pisarra, 1988), as mentioned in section 5.1.3.

## 5.5 Simulation runs

With the objective to predict future behaviour of desalinization in the Leziria area, the simulation of a few different scenarios is done for the period 1986-1994. Using average meteorological data of 1985-1987 (van Alphen and Pisarra, 1988).

### 5.5.1 Varying the amount of irrigation water

SALTMOD is used to predict desalinization by varying the amount of irrigation water (CIR) from 0.22 to 0.77 m/dry season, in two different situations:

**Case 1:** Using a fraction of 0.5 of the total area occupied by irrigated crop during the dry season (melons), only one type of land use (irrigation of dry-foot crop), and no rotation during the summer seasons (the irrigated crops are planted each year in the same area, Rota 1). Predictions on desalinization are done in the area with mixed irrigation (SCj) and in the permanently unirrigated area (SCn).

**Case 2:** Using an hypothetical scenario, with only one type of land use (irrigation of dry-foot crops), and full rotation during the summer seasons (the irrigated crops are planted each year in a different area, Rota 4). Prediction of desalinization is done in the total area with mixed irrigation (SCm).

### 5.5.2 Varying the drain depth

As described in Chapter 2, section 2.9, determining a desirable drain depth has quite a number of benefits. SALTMOD is applied to determine to what extent the drain depth in the pilot area of Leziria (which is currently 1.1 m on the average) can be reduced without causing serious waterlogging and salinity. Prediction runs for drain depths of 1.1, 0.9 and 0.7 m are made. It is important to remark that the parameter reclamation experiment (RECL) is changed from 1 to 0 to simulate farmer's response.

Furthermore, due to the fact that the hydraulic conductivity (K) decreases with depth in the Leziria area, the QHS values differ too. For the depth of 1.1 m, the QHS value determined in the calibration of the model is maintained. For the depths of 0.7 and 0.9 m, QHS values were set at 0.01 and 0.006 respectively, to reflect the increasing K-value higher in the profile (Oosterbaan et al., 1988). In the prediction of drain depth of 0.7 m, the thickness of the root zone layer (ROO) which was 0.75 m is changed to 0.6 m.

# 6. RESULTS AND DISCUSSION

## 6.1 Calibration of the model

Figure 8 shows the simulated effects of different leaching efficiencies (LE) of the root zone on soil salinity in experimental plot 3. In the same figure, collected field data have also been plotted. As can be seen, a LE value of 0.10 characterizes the period 1977-1979. For the period 1979-1984, the value of LE 0.15 seems to produce the best agreement between observed and computed values. Figure 9 shows the simulated effects of different storage efficiencies on soil salinity in experimental plot 3. As can be seen, a STU value of 0.70 characterizes the period 1977-1979. For the period 1979-1984, a value between 0.50 and 0.70 seems to produce a good match between observed and computed values.

The general conclusion to be drawn is that the root zone of the heavy clay soils of the Leziria Grande are characterized by a very low leaching efficiency, apparently only 15 %. This means that these soils have a low capacity to be leached. Therefore, care must be taken with the water management and with using relatively saline irrigation water so as to avoid resalinization. A storage efficiency of rainwater of 0.60 and a QHS value of 0.004 seem to characterize the area.

The data of experimental plots 1 and 2, show similar features (not shown).

Figure 8. The simulated effects of different leaching efficiency of the root zone on soil salinity. Experimental plot 3.

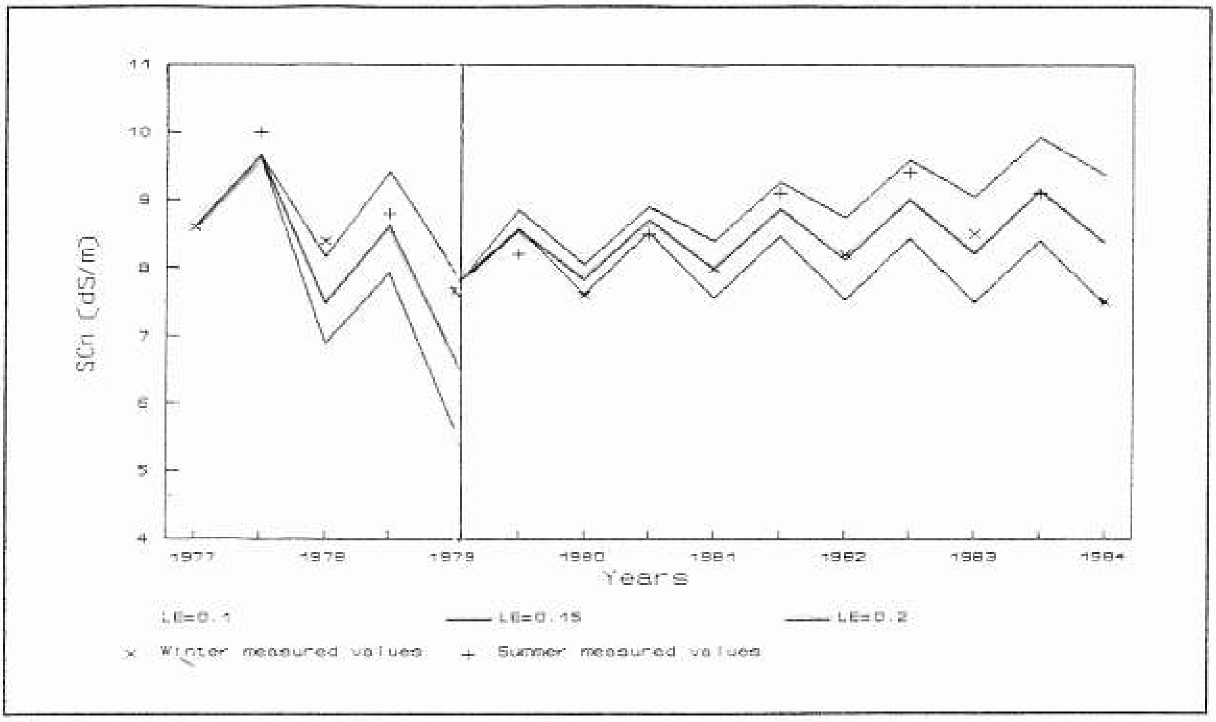



Figure 9. The simulated effects of different storage efficiency of rainwater on soil salinity. Experimental plot 3.

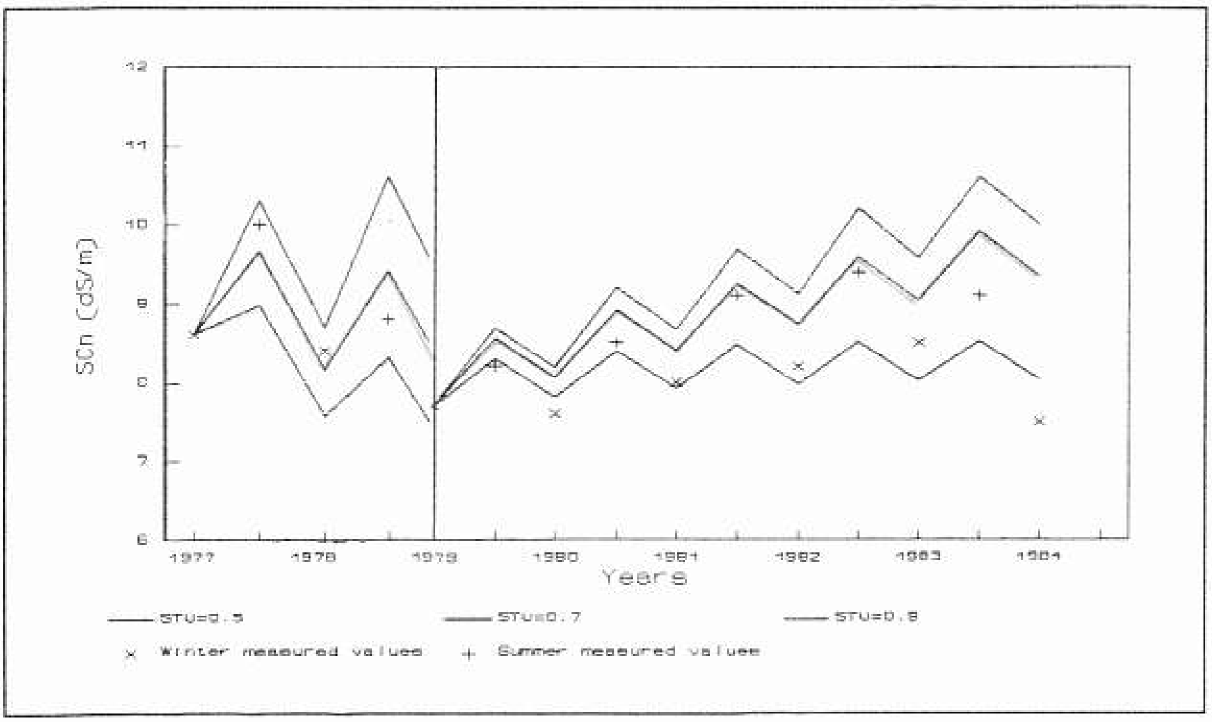


Table 10 shows the different observed and computed values of water-table depths (DWT) and drain discharge (DRT), as a general overview of the situation in the Leziria area. Averages for the three experimental areas are given, because input data between experimental plots only differ in area and salinity level. It is possible to see an overestimate of computer values, during the wet season of the period 1977-1979 for both water-table and drain discharge. It can be explained due to the low leaching efficiency of the soils and the big amount of rainfall registered during this period. For 1979-1984, a general good agreement between observed and computer values is seen.

The high water-tables in the wet seasons of 1977-1979 also show that at high discharge, the groundwater flows mainly through the topsoil (between soil surface and about 0.2 m depth). Furthermore, due to the fact that the hydraulic conductivity decreases with depth, a flow resistance in the vicinity of the drain-pipe is supposedly developed. Such a remark is in agreement with what was reported by Oosterbaan et al., in 1988 regarding hydraulic head and discharge relations of pipe drainage systems with entrance resistance in the Leziria Grande polder, Portugal.

The above mentioned flow resistance would be strongly reduced, if the field drains were placed at shallower depth. This is discussed in section 6.3.2.

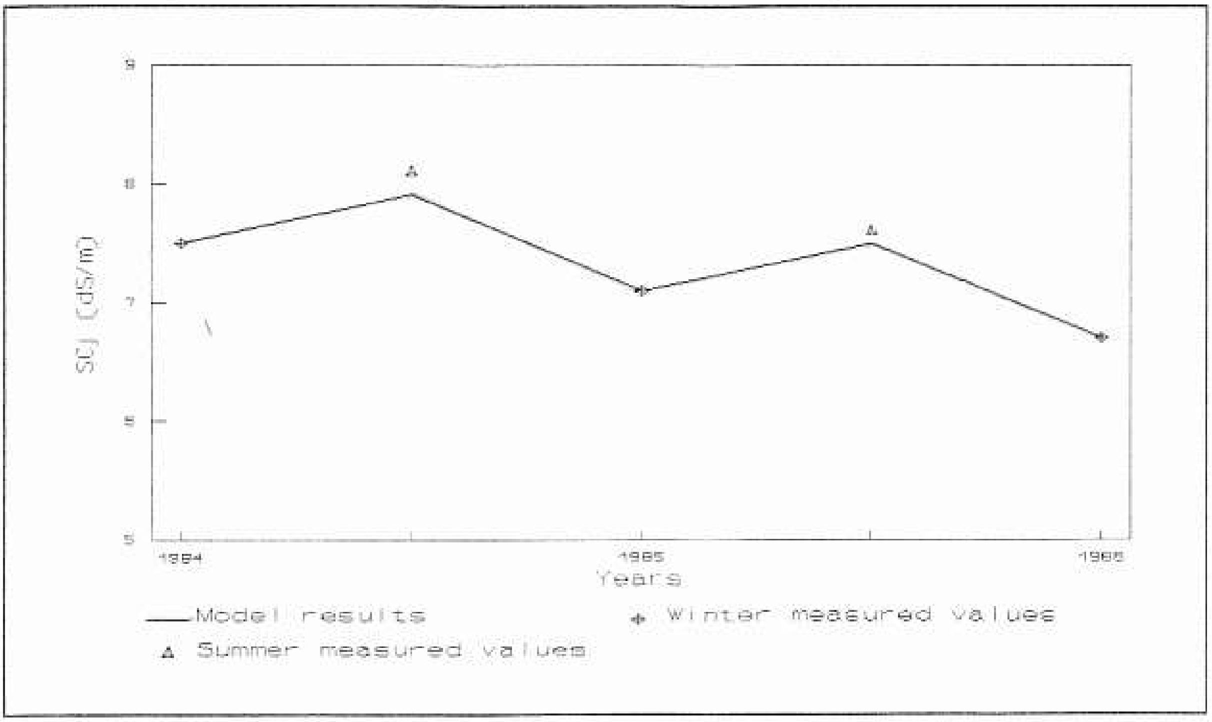
Table 10. Observed and computer water-table depths and drain discharges

| Period | 1977-1979 | | 1979-1984 | |
|---|---|---|---|---|
| Season | wet | dry | wet | dry |
| Observed value of water-table depth (m) | 0.50 | > 1.20 | 0.50 | > 1.20 |
| Computer value of water-table depth (m) | 0.20 | 1.00 | 0.55 | 1.15 |
| Observed value of drain discharge (mm/season) | 270 | 0 | 150 | 0 |
| Computer value of drain discharge (mm/season) | 600 | 10 | 200 | 0 |

### 6.2 Validation of the model

Figure 10 shows observed and computed values of soil salinity in the root zone of experimental plot 3, for the irrigated period 1984-1986. The validation was done using the LE value of 0.15, the STU value of 0.60 and the QHS value of 0.004 determined during the calibration of the model. As it can be seen, again a good agreement exists between observed and computed values.

Figure 10. Soil salinity in root zone, Experimental plot 3 (1984-1986)




## 6.3 Simulation runs

### 6.3.1 Predicting desalinization under varying amounts of irrigation water

**Case 1**: Figures 11 and 12 show the predicted simulated process of desalinization in the Leziria area under the same conditions as described in section 5.5.1 for the so-called case 1. Based on them, it is possible to see that increasing the amount of irrigation water (CIR) from 0.22 to 0.77 m/dry season, the salinity increases too: see figure 12. Furthermore, both amounts of irrigation cause an extremely high salinity in the unirrigated area, see figure 13. It can be explained by seepage from the irrigated to the unirrigated area.

Figure 11. The simulated effects of different amounts of irrigation water (CIR) on soil salinity in the irrigated area, SCj.

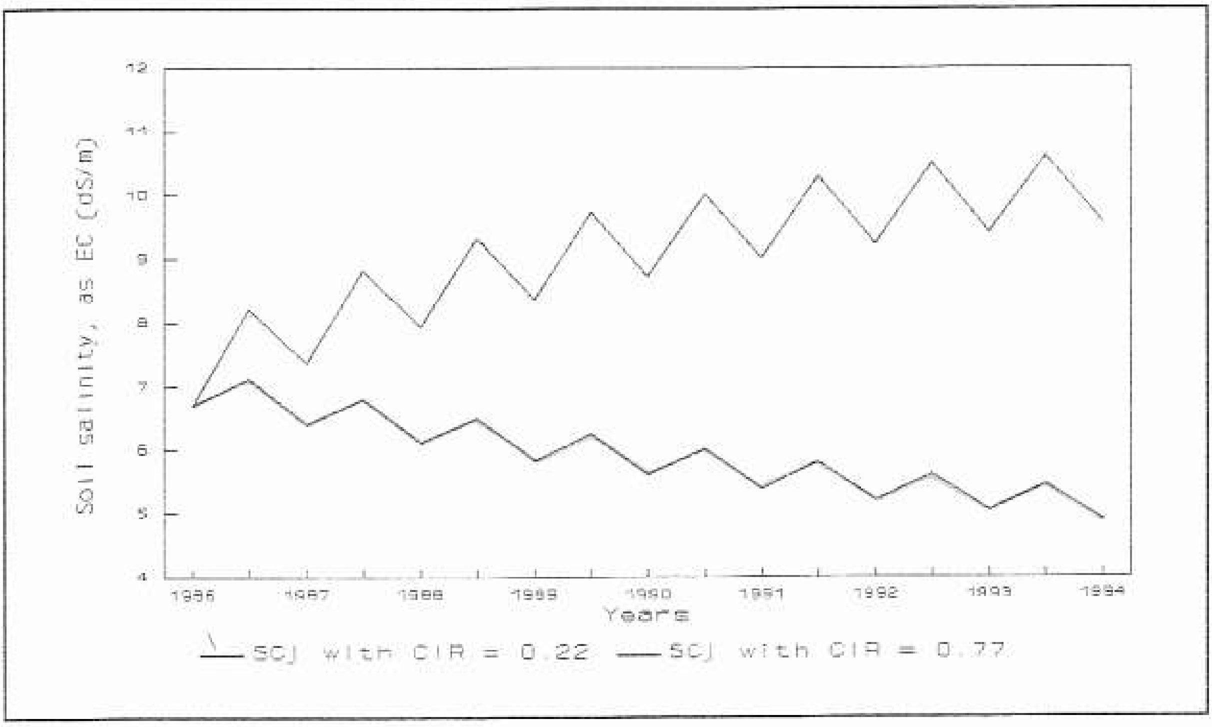
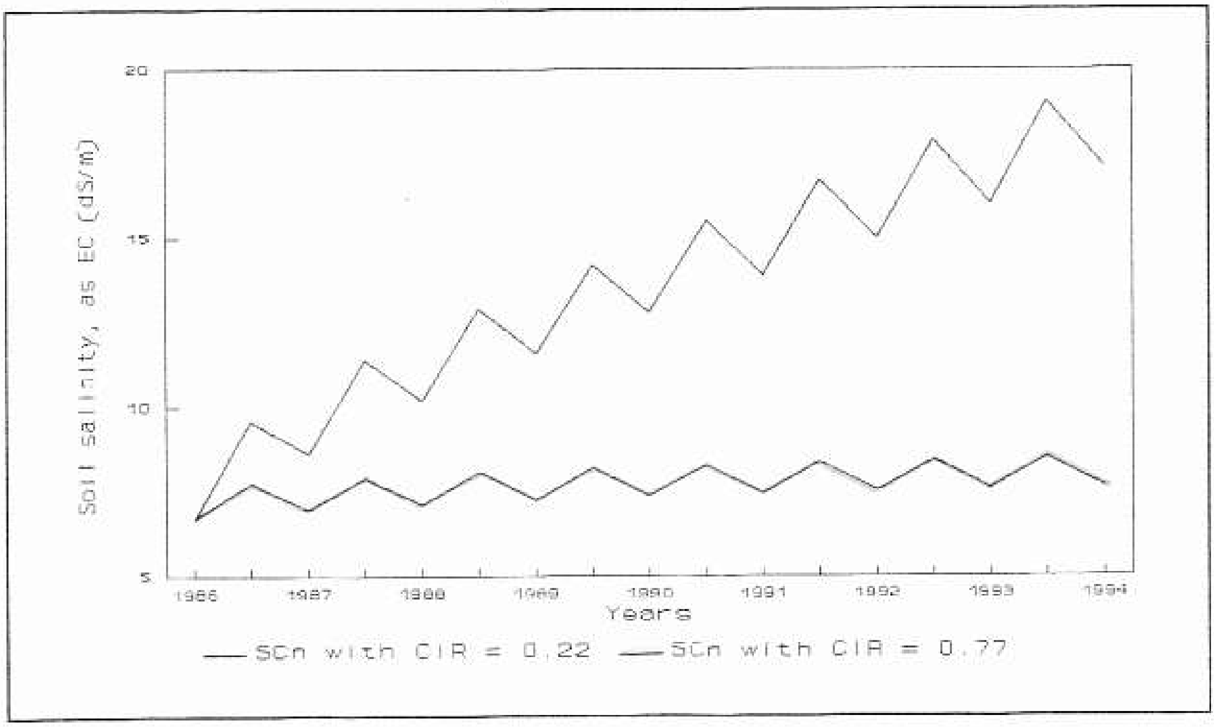



Figure 12. The simulated effects of different amounts of irrigation water (CIR) on soil salinity in the unirrigated area, SCn.



The general conclusion to be drawn is that the quality of the irrigation water plays an important role in the water management of the area, and that as little irrigation water as possible should be used. A poor quality has influence on salinity and permeability of the soil, as was explained in section 2.6. Likewise, saline irrigation water it self (see table 3), low soil permeability, inadequate drainage, and poor irrigation management all contribute to the tendency of salt to accumulate in soils, which affects crop growth and yield levels.

**Case 2**: Figure 13 shows the behaviour of the soil salinity in the total irrigated area (SCm), for the conditions described in section 5.5.1, for the so-called case 2.

It is possible to see that full crop rotation produces resalinization of the soil. Nevertheless, this increment in salinity is smaller when less irrigation water (of $EC_w$ 0.9 dS/m) is used (0.22 in stead of 0.77 m/dry season).

Apparently, full crop rotation requires a larger amount of irrigation water of a better quality than 0.9 dS/m to produce desalinization. After some simulation varying the quality of irrigation water (Zic) expressed as $EC_w$, the value of $EC_w$ 0.3 dS/m is found as the right one to produce desalinization in the area when full crop rotation is used with 0.22 m/dry season. See figure 14.

Such a situation gives an extra reason to consider again the quality of irrigation water as an important factor to achieve desalinization in the heavy clay soils of the Leziria (due to their low leaching efficiency).

### 6.3.2 Varying the drain depth

Simulation runs with different drain depths were done, according to the conditions described in section 5.5.2. The result of such predictions for the summer and winter season, once an equilibrium was achieved (after 8 years, period 1986-1994), are presented in tables 11 and 12 respectively.

Table 11 shows that a drain depth of 0.9 m is acceptable. During the summer season, it does not lead to an excessively high value of the soil salinity of the root zone in the irrigated area (SCj), although the value of the soil salinity of the root zone in the unirrigated area (SCn) is relatively high. Furthermore, it does not lead to any drain discharge (DRT), and its seasonal irrigation sufficiency (SUa) and irrigation efficiency (EFa) are higher than

Figure 13. The simulated effects of different amount of irrigation water (CIR) on soil salinity in the total irrigated area, SCm.

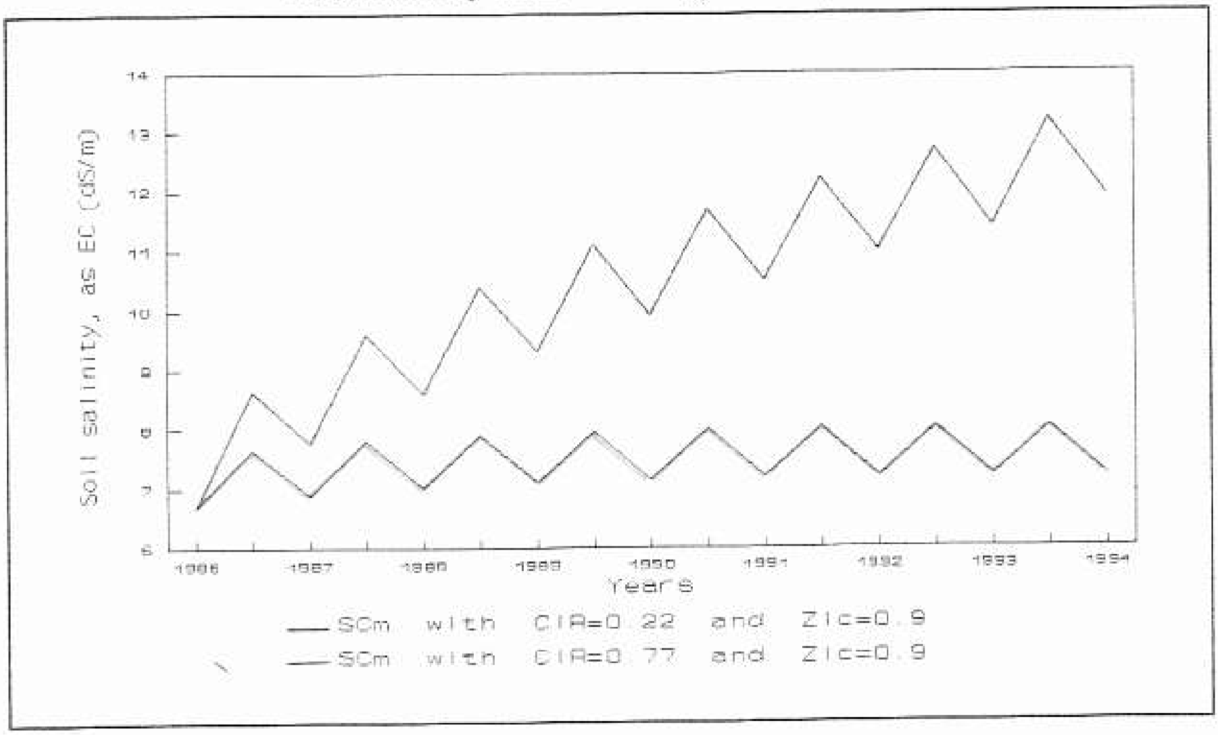
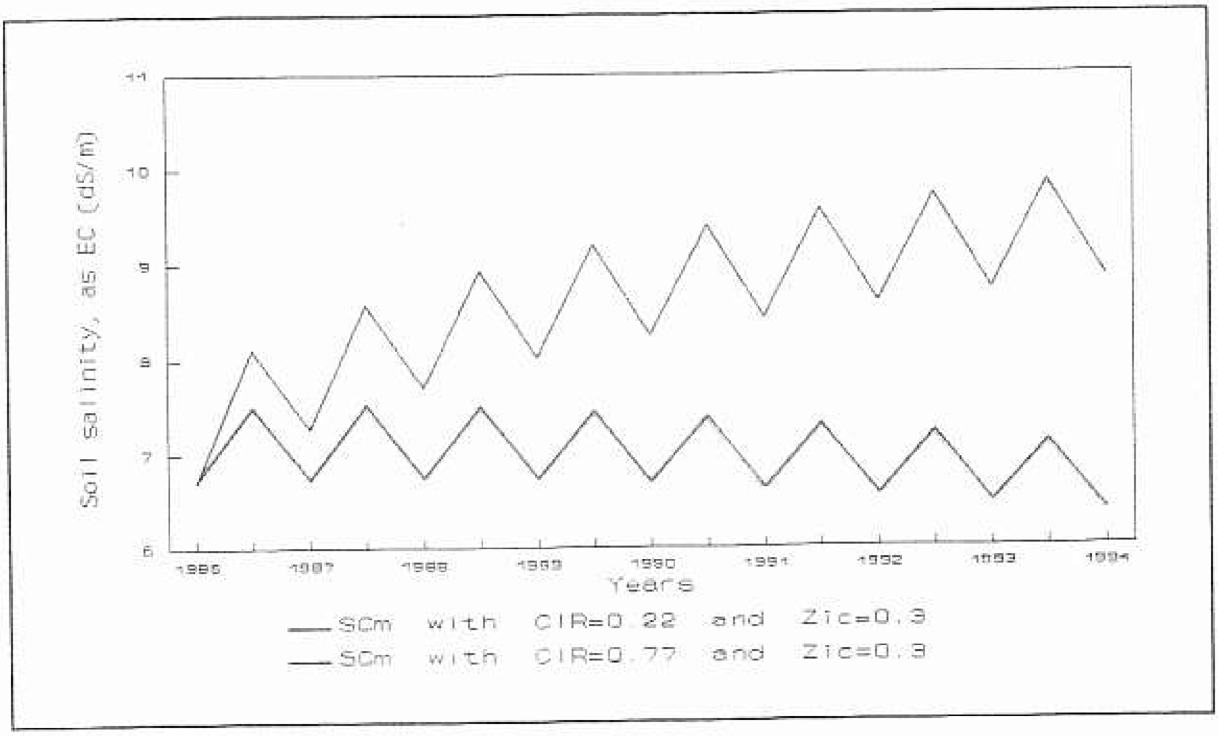



Figure 14. The simulated effects of different amount of irrigation water (CIR) on soil salinity in the total irrigated area, SCm.



the values which belong to the actual drain depth of 1.1 m. As well, it is possible to see that there is no risk of increasing the soil salinity of the root zone in the irrigated area by capillary rise (CAj). However, the small value of capillary rise in the permanently unirrigated area (CAn) originates from irrigation losses from the cropped land, which, in turn, contribute to produce salinization in the fallow land in summer seasons.

Table 12 shows that a drain depth of 0.9 m is acceptable in winter too. It does not lead to an excessively high value of the soil salinity of the root zone in the summer irrigated area (SCj), and in the permanently unirrigated area (SCn). Likewise, it does not lead to a too shallow water-table depth, and the value of the drain discharge is smaller than the value which belongs to the actual drain depth of 1.1 m.

A conclusion from this particular application of SALTMOD is that based on hydraulic conductivity and soil salinity considerations, the drain depth in the Leziria Polder could have been reduced from 1.1 to 0.9 m while maintaining the same drain spacings (10, 15 and 20 m). Likewise, the depth to the water table midway between the drains would not be much shallower compared to the situation with deeper drains (see also van Alphen and Pissarra, 1988). Therefore, the flow resistance in the vicinity of the drain pipe caused by the hydraulic conductivity decreasing with depth, will be reduced.

Regarding salinity in the unirrigated area, it can be avoided if the quality of irrigation water and irrigation practices are improved.

Table 11. Simulation of the effects of various drain depths DRD in m. Summer season.

| DRD | SCj | SCn | EFa | SUa | DWT | DRT | CAj | CAn |
|---|---|---|---|---|---|---|---|---|
| 0.7 | 6.0 | 30 | 0.99 | 0.73 | 0.88 | 0 | 0 | 0.08 |
| 0.9 | 5.6 | 14 | 0.99 | 0.73 | 0.92 | 0 | 0 | 0.08 |
| 1.1 | 5.4 | 11 | 0.95 | 0.69 | 0.99 | 10 | 0 | 0.06 |

Table 12. Simulation of the effects of various drain depths DRD in m. Winter season.

| DRD | SCj | SCn | DWT | DRT |
|---|---|---|---|---|
| 0.7 | 4.9 | 26 | 0.34 | 246 |
| 0.9 | 5.1 | 13 | 0.43 | 249 |
| 1.1 | 4.9 | 9.5 | 0.51 | 259 |

# 7. CONCLUSIONS

Although SALTMOD limits itself to simple solute transport and does not address sodicity problems (which occur in the Leziria area), we can still formulate a number of conclusions as a result of the application of the model.

Applying existing data, the calibration of SALTMOD showed that the soils of the Leziria Grande have a low leaching efficiency, in the order of 15 % only.

It was shown that during the unirrigated period 1977-1984, the salinity levels were in equilibrium with the average rainfall pattern. It means that soil salinity does not decrease further because the amount of salt leached from the top soil in winter season accumulates again in the following summer season as a result of capillary transport. Consequently irrigation during summer seasons was implemented.

Due to the low leaching efficiency of the soils, the introduction of irrigation during summer seasons has shown that irrigation itself does not contribute, in the long run, to reach desalinization (predicting desalinization under varying amounts of irrigation water, section 6.3.1, case 1). Therefore, as little irrigation water as possible should be used and the quality of irrigation water must be carefully monitored to avoid an increase of salinity.

The introduction of irrigation produces salinity in the unirrigated area. It can be avoided if the quality of irrigation water and irrigation practices are improved.

It seems that full crop rotation is not advisable because it requires more irrigation water of very good quality, which is not available from the river Tagus, to maintain safe salinity levels than a fixed cropped area (predicting desalinization under varying amounts of irrigation water, section 6.3.1, case 2) .

It was shown that at high discharge, the groundwater flows mainly through the topsoil (between soil surface and about 0.2 m depth). Therefore a high entrance resistance in the vicinity of the drain-pipe is developed, due to the fact the hydraulic conductivity decreases with depth.

The above mentioned flow resistance would be reduced, if the field drains were placed at shallower depth, e.g. 0.70 m instead of 1.1 m as suggested by van Alphen and Pisarra, 1988, and Oosterbaan et al., 1988. However, it was shown that the depth of the water-table would then become so high that the fallow land salinizes in summer due to capillary rise originating from irrigation losses from the cropped area. It shows that recommendations for the drain depth should not be based only on hydraulic conductivity considerations, but also on salinity aspects. From this study it follows that the drain depth in the Leziria area could have been reduced from 1.1 to 0.9 m while maintaining the same drain spacings.

SALTMOD is a powerful computer model to predict long-term effects of several drainage design and water management scenarios. Preparation of input data is somewhat tedious. It is still being developed further. An user-friendly version which provides easier input and output screens and standard graphics, would contribute to making interpretation of the output data easier and quicker (by the time this thesis work was finalized, a more user-friendly version became available).