

ASSESSING SALINE WATER IRRIGATION OPTIONS WITH THE USE OF SOIL-WATER- ATMOSPHERE- PLANT (SWAP) MODEL

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ABSTRACT

Assessing some of the parameters for the use of high salinity water in agriculture with the aid of a well-tested simulation model like SWAP (Soil-Water-Atmosphere-Plant) is the subject of this paper. SWAP is an agricultural model that simulates the transport of water, heat and dissolved solids in unsaturated-saturated soils. Simulations were executed for the Agoulinitza network, which is part of Alfeios river irrigation system in western Peloponnese (Greece). Drainage water of the region could potentially be used for irrigation purposes. The results of water and soil classification tests were used as input data in combination with meteorological and crop data.

Two scenarios were examined: Firstly, irrigations with water of increasing salinity were simulated and secondly, a leaching treatment after increasing the application water depth. The impact on the soil profile from the accumulation of salts under these practices was estimated. The results showed that the use of saline water is suitable but should be adapted to the crop pattern of the region, since salt tolerance varies with crop. Finally, SWAP can be used for the estimation of the leaching fraction in order to control the concentration of salts in the soil profile.

1 INTRODUCTION

The sustainable agricultural development is strongly related to saving important quantities of irrigation water. Indelicato et al. (1993) showed that in arid and semi-arid regions as most of the Mediterranean countries, an effective method of water saving is the use of non-conventional water resources such as drainage water, ground water or treated wastewater. The use of such water resources contributes to the reduction of the gap between supply and demand, the control of underground level and finally the

minimization of temporal changes in the supply of water (months with water shortage) that causes crop stress.

According to FAO (2002), one of the critical problems of using such resources is the lower quality of the water involved. Salinity, infiltration problems and toxicity, mainly affect the quality and restrict the use of these water resources for agricultural purposes. Beltran (1999) showed that when such water resources are available a detailed analysis of the problem is required, since it is possible to use saline waters for irrigation under proper land use and water management conditions. Tsakiris et al. (2009) also showed that the useful potential of a water source is strongly related to the quality requirements of the use.

Environmental modelling is a useful tool for the control of the impacts of the use of this low quality water in irrigation, provided that it involves simulation options for the whole soil-plant-atmosphere-plant system. Willardson et al. (1997) showed that simulation models are excellent tools to analyze actual situations and predict the effects of water management decisions. SWAP is such an environmental model and it is used in this paper for assessing options of using saline water for irrigation. Su et al. (2005) used this model to simulate water and salts movement in tile-drained fields irrigated with saline water.

SWAP requires a considerable number of input data, such as drainage, soil and climatic data. The model has been applied using data from the Agoulinitza region in south-western Greece for the control of the accumulation of salts in the soil profile below the critical levels that affect crops yield according to Ayers and Westcot (1985). Input data such as soil salinity, were obtained from experiments conducted at the Laboratory of Reclamation Works and Water Resources Management in the National Technical University of Athens.

2 SITE DESCRIPTION

The network of Agoulinitza (Figure 1) constitutes a part of irrigation network of the valley of Alfeios River. The irrigated area of Agoulinitza is 2400 ha which is irrigated from 3 pump stations. The area was in the past a part of technically drained lagoon of Agoulinitza, with altitudes ranging from -0.5 to -1.5 m. For this reason a pump station was built, that collects all the drainage water from the network and discharge it to the sea in order to control the rise of water table. The drainage network consists also of surface drains up to 3rd class. The spacing between the 3rd class drains is set to 200m and their average length is 1000 m.

The supply of irrigation water comes from the river Alfeios through a diversion dam. The rainfall imbalances between winter and summer season combined with regional losses from the network, result in water deficit in dry summers. For this reason, it is necessary to consider a secondary resource of water for irrigation. Since there is no reservoir available in the network, a non-conventional resource could be the water collected from the drain ditches that comes mainly from capillary and percolation water. Alexakis et al. (2011) showed that the concentration of the Total Dissolved Solids (TDS) of drainage water during the irrigation period ranged between 300 and 12000 mgL⁻¹. The TDS concentration of irrigation water was measured up to 280 mgL⁻¹.

Minhas et al. (2006) gathered some of the special conditions that should be met in a region, that contribute to an effective application of the technique of drainage water reuse. For example the irrigation network must be in low altitudes, even below the level

of the sea and also, the groundwater level should be shallow, which means low cost of pumping (Bouarfa et al. 2003). These conditions are met in the Agoulinitza network and furthermore, the high rainfalls during winter can contribute to the leaching of the salts accumulated during dry season.

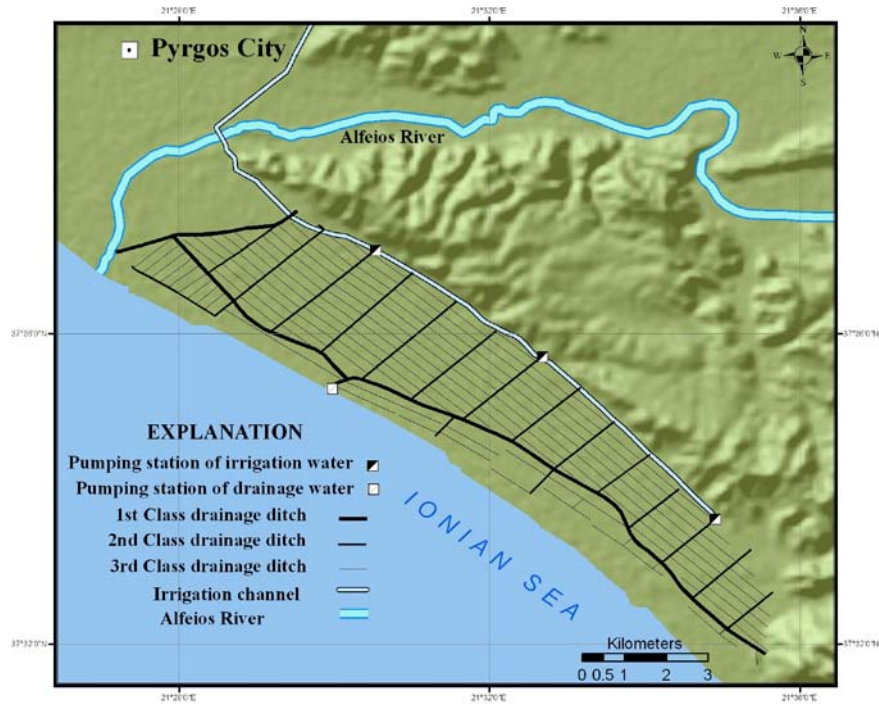


Figure 1. Drainage network of Agoulinitza region.

3 THEORY

SWAP is a one dimensional, physically based simulation model of water, solute (and heat) transport and crop growth in the saturated–unsaturated zone. Detailed specifications of SWAP can be acquired in the technical documentation of the model and especially in: “Theory of SWAP 2.0” by van Dam et al. (1997).

The model has been used by Sarwar et al. (2000) for the evaluation of drainage systems and the optimization of drainage efficiency. The model uses integrated subroutines for the simulation of soil water flow, solute transport, heat flow, evaporation and crop transpiration and finally, the crop growth.

Specifically, in the model the vertical flow of water is described by the Richard’s equation:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z} \left[K(\theta) \left(\frac{\partial h}{\partial z} + 1 \right) - S(h) \right] \quad (1)$$

where θ denotes the volumetric water content (%), t is time (d), h the soil matrix head (cm), z the vertical coordinate, taken positive upwards (cm), K the hydraulic conductivity as a function of water content (cm d^{-1}) and S , represents the water uptake by plant roots (cm d^{-1}).

Regarding the solute transport, which is mainly considered in the paper in the form of the salts, SWAP is focused on the transport of salts, pesticides and other solutes that can be described with relatively simple kinetics.

The transport equation applied in SWAP is valid for dynamic, one-dimensional, convective, dispersive mass transport, including non-linear adsorption, linear decay and proportional root uptake in unsaturated/saturated soil. Processes that are not considered in SWAP are: gas transport, transport of non-mixing or immiscible fluids, chemical equilibria of various solutes (e.g. between Na^+ , Ca^{2+} and Mg^{2+}), chemical and biological chain reactions (e.g. nitrification).

4 MODEL INPUT DATA

As described above, SWAP is a sophisticated model that uses various input files that extend from climatic data and soil texture to irrigation and drainage specifications. For the estimation of daily evapotranspiration, detailed data of rainfall, temperature (min and max), wind speed and relative humidity for a period of one year, were obtained from the meteorological station of Pyrgos (Fig. 1), that is the nearest to the site.

For simulation purposes subsurface drains were considered in addition to the drain ditches of the network. This was essential to control the rise of the underwater table and ensure sufficient drainage and leaching of salts. Other input data involved in the simulations are briefly described below:

4.1 Soil data

The model requires detailed soil parameters as input data. Some of the soil properties derived from previous studies on the soil characteristics of the region (Gotsis, 2007) were added to the default values of the library of soils included in SWAP. A typical top-soil profile of the region is basically consisted of silty sands and loams, the basic characteristics of which can be grouped in Table 1. Since no further analysis was available, the simulated soil profile was considered homogenous with total depth of 200 cm.

Table 1. Basic soil properties.

Soil depth (cm)	Saturated conductivity (cm/day)	Field capacity (%)	Permanent wilting point (%)	Dry bulk density (gr/cm^3)	Porosity (%)
200	4.0	22	16	1.29	50

4.2 Irrigation data

Maize was selected for simulation as the prevailing cultivation in the region (over 40%). The growth cycle of maize was simulated with the use of SWAP's simple crop model. The start of the irrigation period was set at the 1st of May and harvest day at the 15th of October. SWAP also uses an irrigation scheduling table for the user in order to import the irrigation data. The table includes the exact dates of field irrigation, the depth

of irrigation water (mm), the method of irrigation used (sprinkling or surface) and finally, the concentration of salts in the water.

In this paper, the irrigation schedule was conducted according to the water needs during the growing season (Gotsis and Giakoumakis, 2006) as shown in Table 2. Application depth was set to 40 mm per irrigation with 6 days irrigation interval during the months of high evapotranspiration rates.

Table 2. Irrigation schedule.

Month	May	June	July	August	September	October
Application Depth (mm)	80	120	200	200	120	40

4.3 Soil salinity data

A total of 15 soils (0-40 cm) were sampled in Agoulinitza cultivated area at the beginning of the irrigation period. Soil samples were collected using a polypropylene tool and stored into clean polypropylene bags. The soil samples were dried at room temperature (25 °C) for several days and then sieved through 2.00 mm sieve.

The evaluation of the conductivity was performed in duplicates according to the method proposed by Al-Mustafa and Al-Omran (1990). About 30 g of the soil sample were mixed with 60 ml of ultrapure water (18.3MΩ) in polyethylene tubes. The tubes were capped and the mixtures were shaken for 2h on a mechanical shatter at 150 motions per minute. Then the supernatants were filtered through 0.45 μm pore size membrane filters. The electrodes were immersed in the upper part of the supernatant and the conductivity was measured by a precalibrated conductivity meter using a 4071 Jenway model. The conductivity of saturated soil-paste (EC_e) is related to the $EC_{1:2}$ according to eq. (2):

$$EC_e = 5.526 \cdot EC_{1:2} - 0.940 \quad (2)$$

The EC_e values of the soils were calculated by using eq.(2). The conductivity values ranged from 0.16 dS/m to 5.13 dS/m with a mean value of 1.94 dS/m. The mean EC_e value was used in the model as input of the initial salinity in the soil profile (expressed in TDS concentration).

5 SIMULATED SCENARIOS

The goal of the simulation was to examine the potential of the use of saline water for irrigation. The following scenarios were examined for drain spacing $L = 30$ m and $2L = 60$ m:

- The variation of the salt concentration on irrigation water and the effect on the salinity buildup of drainage and soil water.
- The variation of the leaching fraction (increase of the depth of the irrigation water) and the effect on the decomposition of salts in the soil profile.

By simulating the above parameters, it is possible to estimate the accumulation of salts in the soil profile after the use of saline water as well as the leaching requirements.

5.1 Irrigation with saline water

The accumulation of salts in the soil profile was simulated with SWAP after

increasing the salinity (expressed in TDS concentration) of the application water from 600 mgL^{-1} to 2400 mgL^{-1} . At the end of the irrigation period a snapshot of the salinity of the soil profile was taken from the output file. The simulated salinity values were compared with the crop tolerance limits proposed by Ayers and Westcot (1985).

In Figure 2a,b the build-up of salts in the soil profile in relation to the application water is shown. Apparently, applying water with concentration higher than 600 mgL^{-1} can result in salts accumulation that will potentially cause salt stress to some crops. Maize which is mainly cultivated in the region, sustains yield reduction when soil salinity rises over 1100 mgL^{-1} . When using water of such salinity it would be reasonable to consider a change in the crops pattern in favor of more tolerant crops. Cotton and barley also cultivated in the region, can sustain no considerable loss in yield, if TDS concentration in the soil profile is below 4000 mgL^{-1} . From Figure 2a,b. it is shown that water with TDS concentration up to 1800 mgL^{-1} could be used for the irrigation of cotton.

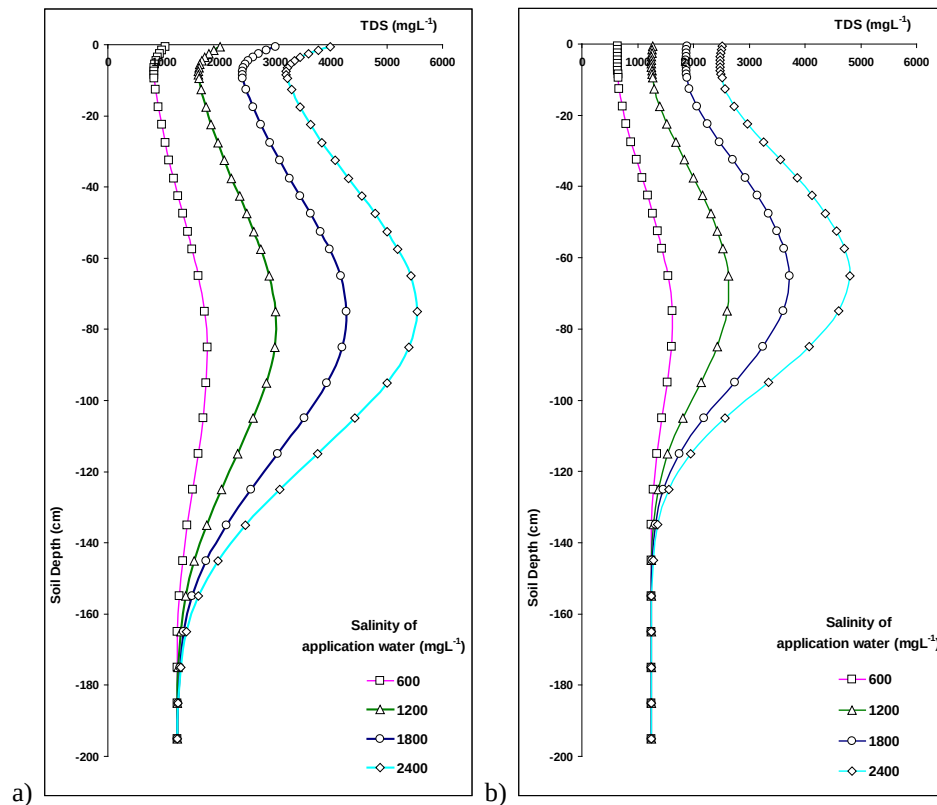


Figure 2a,b. Simulated salinity in the soil profile after application of high saline water for drain spacing: (a) $L=30 \text{ m}$, and (b) $2L=60 \text{ m}$.

Drain spacing seems not to affect significantly the accumulation of salts in the soil profile. Figure 2b shows the built up of salts for drain spacing $2L=60 \text{ m}$. The slight reduction of the maximum concentration of TDS is inconsiderable. It seems that by

reducing the drainage efficiency a part of the applied saline water was not infiltrated into the soil profile.

5.2 Salts leaching

Leaching is required in order to control the accumulation of salts in the soil after irrigating with saline water. If natural conditions in the region of Agoulinita (such as rainfall, capillary rise and drainage sufficiency) could not result in appropriate salt leaching, then a special treatment should be applied. SWAP simulations used in this paper can be a useful tool for designing this treatment.

Leaching can be performed by increasing the depth of the water which is applied for irrigation over the limit required for the crops development (Antonopoulos and Tsakiris, 2006). It is important that the drainage system will be efficiently designed in order to discharge the extra water and control the water table.

In this paper, the scenario of leaching was set by increasing the depth of water applied for irrigation from 40 to 50 and sequentially to 60 mm. Application water was simulated with TDS concentration as 1800 mgL^{-1} . Drain spacing was set to $L=30 \text{ m}$ and $2L=60 \text{ m}$.

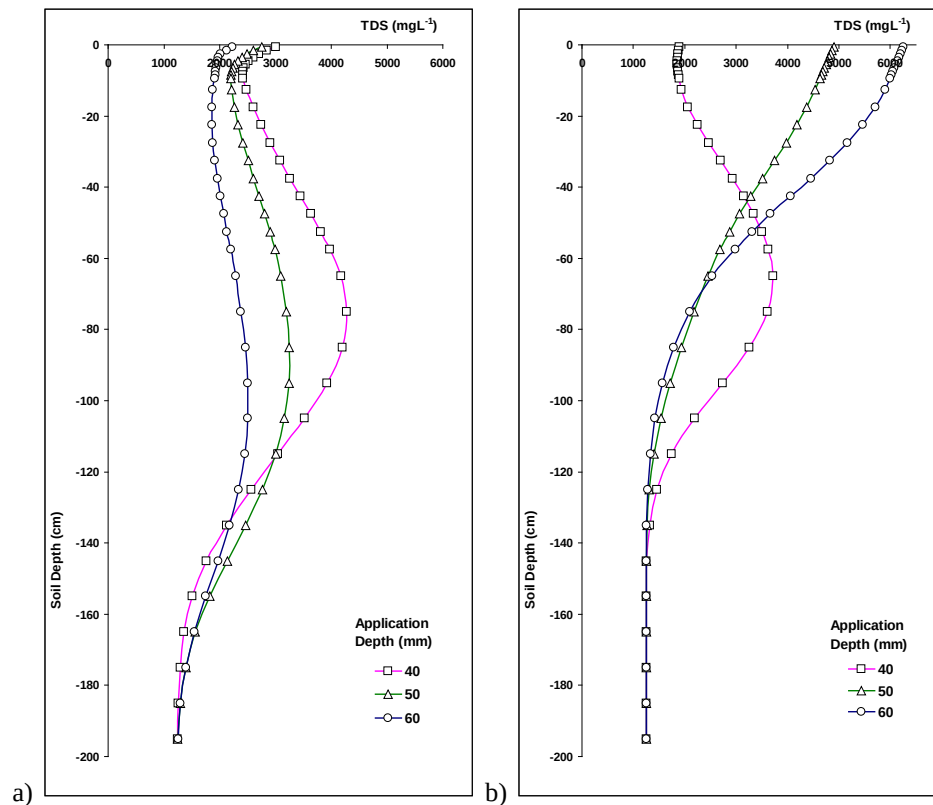


Figure 3a.b. Simulated salinity in the soil profile after increasing application depth for drain spacing: (a) $L=30 \text{ m}$, and (b) $2L=60 \text{ m}$.

Figure 3a shows a snapshot of the soil profile for drain spacing L . It is clear that

leaching can improve the salinity of the soil profile. The TDS concentration reaches up to 4500 mgL^{-1} when applying 40 mm of water. By increasing the application depth of the same saline water to 50 mm and 60 mm, the maximum TDS concentration reduces to 3000 mgL^{-1} and 2500 mgL^{-1} respectively.

When running the simulations for spacing 2L (Figure 3b) the leaching treatment is impracticable. The concentration of salts increases, reaching to over 6000 mgL^{-1} near the surface of the soil profile. The drainage insufficiency prevents the salts from leaving the soil profile so the excess of water applied is inutile.

6 CONCLUSIONS

The use of environmental modelling for the assessment of saline water irrigation options is examined in this paper. SWAP model was used for simulations referring to the irrigation and drainage network of Agoulinita in south-western Greece. As input files, climatic and soil data was used in combination with specifications from the irrigation system in the region. Some of this data were obtained from experiments conducted at the lab.

Two scenarios were examined for drain spacing at $L=30 \text{ m}$ and $2L=60 \text{ m}$. Firstly the use of increasingly saline water was simulated in order to estimate the accumulation of salts in the soil profile after each application. It is shown that cotton and barley could be cultivated when applying saline water with TDS concentration up to 1800 mgL^{-1} , since they show no significant yield loss when TDS concentration in soil water is below 4000 mgL^{-1} . On the other hand water with TDS over 600 mgL^{-1} is unsuitable for crops with limited tolerance to salts such as maize.

The second scenario was a leaching treatment simulated with the use of the model. The depth of the water applied in the crop after every irrigation interval increased from 40 mm to 60 mm. The results showed that the salts are significantly leached from the soil profile for drain spacing L . When the scenario was simulated for drainage spacing $2L$ no leaching occurred. Apparently for the leaching treatment two important conditions must be considered: An appropriate quantity of water must be available for irrigation and also, the drainage system must be able to control the excessive volume and avert waterlogging conditions.

In conclusion, environmental models are useful tools for evaluating the efficiency of irrigation and drainage systems and testing unconventional practices. The potential of simulating scenarios for various applications and treatments regarding irrigation and drainage options is limitless. Nevertheless sophisticated models such as SWAP require a large number of data in order to produce reliable results.

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