

WATER MANAGEMENT AND THE SWAP MODEL

J.G. Kroes

Alterra, Green World Research,
P.O.Box 47, 6700 AA Wageningen, The Netherlands

E-mail: joop.kroes@wur.nl

Phone: +31 317 474372, Fax: +31 317 41900

Abstract

This paper gives a description of the numerical model SWAP and some of its applications like irrigation modelling. The model can be used to simulate transport of water, solutes and heat in the upper (un)saturated part of soils. A description is given of the various processes described by the model. This is followed by results from a sensitivity analyses and a summary of user-limitations. The paper ends with a summary of model use at different scales of applications.

Key words: water management, agro hydrology, model, SWAP

INTRODUCTION

Knowledge of water and solute movement in the variably saturated soil near the earth surface is essential to understand man's impact on the environment. Top soils show the largest concentration of biological activity on earth. Water movement in the upper soil determines the rate of plant transpiration, soil evaporation, runoff and recharge to the groundwater. In this way unsaturated soil water flow is a key factor in the hydrological cycle. Due to the high solubility of water, soil water transports large amounts of solutes, ranging from nutrients to all kind of contaminations. Therefore an accurate description of unsaturated soil water movement is essential to derive proper management conditions for vegetation growth and environmental protection in agricultural and natural systems. A mathematical model which describes this soil water movement is the model SWAP (Soil–Water–Atmosphere–Plant).

SWAP is the successor of the agro hydrological model SWATR (Feddes et al., 1978) and some of its numerous derivatives. The experiences gained with the existing SWATR versions were combined into SWAP, which integrates water flow, solute transport and crop growth according to current modelling concepts and simulation techniques. The model offers a wide range of possibilities to address both research and practical questions in the field of agriculture, water management and environmental protection. Alterra and Wageningen Agricultural University have developed the computer model SWAP in close co-operation.

The theory of the processes simulated by the model is extensively described by Van Dam (2000). A user manual was written by Kroes and Van Dam (2003). Information about the SWAP model can be found on internet: www.swap.alterra.nl

SYSTEM DEFINITION

SWAP is a computer model that simulates transport of water, solutes and heat in variably saturated top soils. The program is designed for integrated modelling of the Soil-Water-Atmosphere-Plant System (figure 1). Transport processes at field scale level and during whole growing seasons are considered.

System boundaries at the top are defined by the soil surface with or without a crop and the atmospheric conditions. The lateral boundary can be used to simulate interaction with surface water systems. The bottom boundary is located in the unsaturated zone or in the upper part of the groundwater and describes the interaction with a regional groundwater system.

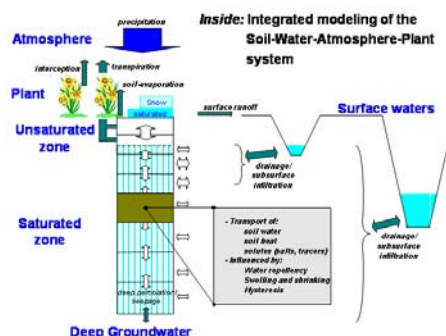


Figure 1. Schematic overview of modelled system

MODEL CONCEPT

The basic equation for soil water flow is the Richards' equation, which allows the use of soil hydraulic data bases. The strong physical base of Richards' equation is important for generalization of field experiments and for analysis of all kind of scenarios. A versatile numerical solution of the non-linear Richards' equation is applied, along with an automatic procedure for the top boundary which accommodates rapidly changing field conditions. Physical and empirical methods determine actual soil evaporation. The soil hydraulic functions are described by the analytical expressions of Van Genuchten and Mualem.

Potential evapotranspiration is calculated with the Penman-Monteith equation, using the method recommended by Allen et al. (1998). SWAP allows direct use of the Penman-Monteith equation, in which case crop specific values of minimum resistance, leaf area index, albedo and crop height are required, or the Penman-Monteith method as applied to reference grass in combination with crop coefficients. Also reference evapotranspiration can be specified as input, which accommodates alternative evapotranspiration formulas. Interception of agricultural crops and forests are modelled as separate processes.

One of the most important outputs of this type of models is the amount of water and salt stress for crops and vegetation. Water stress is a function of soil water pressure head and salt stress is modelled as a function of soil water electrical conductivity. Frost periods are accounted for with a simple module which reduces water flow and accumulates snowfall

(figure 2).

The interaction between soil water and surface water may consist of surface flow (runoff, run-on and inundation) and subsurface flow (drainage or infiltration). Run-on and runoff options allow the calculation of a sequence of soil profiles along a slope with runoff. Drainage and infiltration can be calculated with linear or tabular relations between groundwater level and drainage/infiltration flux, or with analytical equations of Hooghoudt and Ernst.

For regional water management analysis the groundwater system may interact with a simplified surface water system. The model may serve as a pre-processing tool for solute modelling. In that case drainage levels can be used to mimic interflow and subsurface drainage to levels (figure 3) characterised by different residence times.

The interaction between soil water and deep groundwater (regional ground water flow, figure 3) is described by the use of either time dependent pressure heads, soil water fluxes or the relation between both.

When the model SWAP is applied at field scale level, natural soil heterogeneity may be considered within a field. The model has options to accommodate hysteresis in the retention function, spatial variability of soil hydraulic functions, preferential flow in water repellent soils and in soils with macro pores

SWAP contains a simple and a detailed crop module. In the simple crop model the crop development with time is prescribed as leaf area index (or soil cover fraction), crop height and rooting depth as function of development stage. The detailed crop module is based on the crop growth model WOFOST.

Solute transport mechanisms are included in the model. SWAP simulates the solute processes convection, diffusion and dispersion, non-linear adsorption, first order decomposition and root uptake. This permits the simulation of ordinary pesticide and salt transport, including the effect of salinity on crop growth. In case of detailed pesticide transport or nitrate leaching, daily water fluxes can be generated as input for the pesticide model PEARL (Leistra et al, 2000); Tiktak et al, 2001) or the nutrient model ANIMO (Groenendijk and Kroes, 1997).

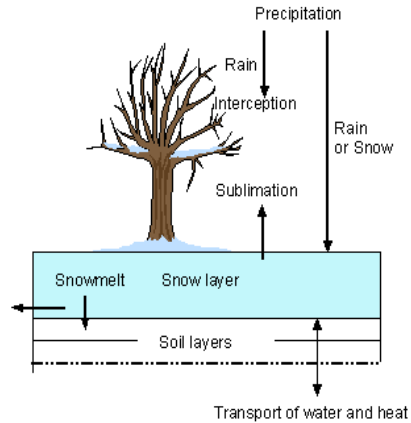


Figure 2. Schematic overview of modelled snow processes

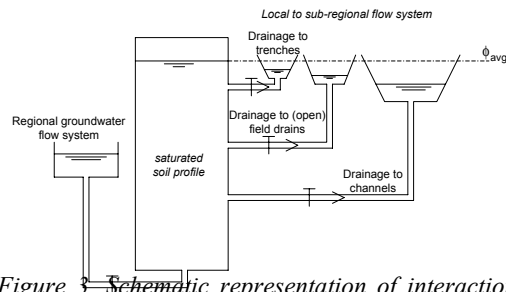


Figure 3. Schematic representation of interaction between saturated soil profile and local drainage system and regional flow

Soil heat flow is solved either with analytical or numerical solutions. The analytical solution assumes uniform and constant thermal conductivity and soil heat capacity. At the soil surface a sinusoidal temperature wave is assumed. In case of the numerical solution, the thermal conductivity and soil heat capacity are calculated from the soil texture and the volume fractions of water and air as described by De Vries (1975). At the soil surface the daily average temperature is used as boundary condition. An example of simulated and measured soil temperatures at 5 cm depth is given in figure 4.

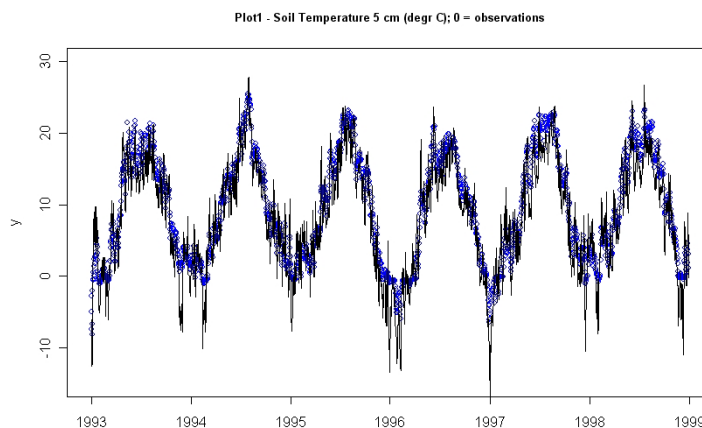


Figure 4. Example of simulated soil temperatures at 5 cm below the soil surface

SENSITIVITY

A global sensitivity analysis was performed with the SWAP model by Wesseling and Kroes (1998). Generation of parameter values and the analysis were carried out for different crop-soil combinations.

The analysis was carried out with a range of meteorological years, which included average and extreme meteorological data. Input parameters were selected that are associated with a number of processes in the SWAP-model: soil physics, evapotranspiration, drainage, regional hydrology.

For each input-parameter a distribution type, its average, variance, minimum and maximum value were selected using existing databases and expert-judgement.

Conclusions drawn from the analysis are:

- Boundary conditions (both upper and lower) are of crucial importance;
- For all soil-crop combinations the soil and crop evaporation were strongly depending on the function describing the Leaf Area Index (LAI);
- Drainage, simulated as lateral discharge, is very sensitive to the surface water levels;
- High groundwater levels are strongly related to surface water levels; low groundwater levels depend on a combination of LAI, soil physical parameters and surface water levels.

LIMITATIONS

The SWAP model has limitations in temporal aspects because it was developed for calculations with daily meteorological input data. Exceptions are e.g. studies with surface water runoff, for which the user may provide actual, short time rainfall intensities. In general, model results should be analysed on a daily base. For many cases this will be sufficient; for analyses using more detailed meteorological (less than 1 day) data, other models such as SWAPS (Ashby et al., 1996) are recommended.

When applying the model it should be realised that the horizontal and vertical space of application are limited. It is a one dimensional model designed for processes in the unsaturated zone, where it is most powerful. In the saturated zone a pseudo 2-dimensional approach allows interaction with a surface water system, but this is very sensitive to the scale of the application.

Other limitations of SWAP 3.0 are:

- no simulation of regional groundwater hydrology;
- no interaction between crop growth and nutrient availability;
- no non-equilibrium sorption of pesticides and no simulation of metabolites

MODEL APPLICATIONS

Use of the model and its results depends on the kind of user and the scale of the application. One may distinguish different users and different scales of application (table 1). Local scale applications are field or lysimeter applications. Some farmers may apply this type of model for field recommendations, but in general the local/field applications are carried out by researchers or extension officers.

Regional scale applications are applications where the field scale level can be viewed as a natural basic unit of larger regions. Most natural or cultivated fields have one cropping pattern, soil profile, drainage condition and management scheme. This information comes increasingly available in geographical data bases. Geographical information systems can be used to generate input data for field scale models, to run these models for fields with unique boundary conditions and physical properties, and to compile regional results of viable management scenarios. The regional scale is of most interest to water managers and politicians. Simulations are very often carried out by researchers.

From an application point of view one may distinguish direct and indirect use of model results. Examples of direct use of the model is given for each combination “user - scale of application” in table 2. Especially in the field of irrigation there may be direct use of the results. Irrigation demand or potential can be estimated and used to conduct field sensors. Irrigation potentials and strategies can be directly translated into spatial distributions. Other

Table 1. Relation between users and scale of application

User	Scale of application	
	Local	regional
Farmer	X	
Extension officer	X	
Researcher	X	X
Policy makers		X

examples of direct use are: optimize timing and amount of sprinkling or surface irrigation. Also the effects of different drainage designs in relation to long term water and salinity stress can be evaluated. SWAP may simulate water and solute balances for different land use options. Also SWAP may generate optimal surface water levels depending on the actual situation, desired groundwater levels, and expected weather conditions.

Table 2. Examples of direct use of model result for combinations of user and scale of application

User	Scale of application	Model result
Farmer	Local	Irrigation demand
Extension officer	Local	Irrigation potentials
Researcher	Local	Irrigation strategies
Researcher	Regional	Distribution of irrigation potentials
Policy makers	Regional	Spatial and sectoral irrigation strategies

One may also distinguish indirect use of model results. Some examples are given for each combination “user - scale of application” in table 3. A farmer or an extension officer may apply the model for long term prediction of water demand. Researchers may apply the model to analyse field experiments, carry out methodological comparisons and generate input as a powerful preprocessor for solute modeling. Policy makers are often interested in effects at regional scale, such as recharge of aquifers, irrigation strategies and leaching of nutrients or pesticides.

Table 3. Examples of indirect use of model results, given for combinations of user and scale of application

User	Scale of application	Model result
Farmer	Local	3-day prediction of water demand
Extension officer	Local	Demonstrate impact of different soils on irrigation demand
Researcher	Local	<ul style="list-style-type: none"> • Analyse field measurements • Compare methods to determine transpiration (e.g. FAO59 vs others) • Generate input for leaching models
Researcher	Regional	Analyse leaching potentials
Policy makers	Regional	<ul style="list-style-type: none"> • Reduction of recharge of aquifers • Minimize evapotranspiration excess • Optimize Irrigation strategies • Reduce leaching of pesticides and/or nutrients

An extended list with examples of applications is given at the web site:

www.swap.alterra.nl

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