A water balance simulation model for teaching and learning – WaSim

Tim Hess[†] and Chris Counsell[‡]

[†] *Cranfield University, Cranfield, Bedford, MK43 0AL, UK*

[‡] *HR Wallingford, Howbery Park, Wallingford, Oxfordshire OX10 8BA, UK*

Abstract

Developed by HR Wallingford and Cranfield University (with support from the UK Department for International Development), WaSim is a computer-based training package for the teaching and demonstration of issues involved in irrigation, drainage and salinity management. WaSim is a daily water balance model that simulates the soil water / salinity relationships in response to different management strategies (e.g. drainage designs and water management practices) and environmental scenarios (e.g. weather data, soil types, cropping patterns).

1. Simulation models in education

Computer simulation models are increasing being used as teaching tools as a replacement for, or adjunct to traditional field or laboratory exercises. Many benefits have been cited

- Speed.
- Controlling the ‘environment’.
- Performing impossible, or undesirable experiments.
- Focus on the learning experience.
- Substituting for physical resources and tutor’s time.
- Synthesising expertise.
- Gaming and sensitivity analysis.
- Distance and self-learning.
- Observing obscure processes.

Although there is little quantitative information in the literature from Environmental Sciences, computer assisted learning in other disciplines has been quantified experimentally. These of comparative studies suggest that computer aided learning is at least as effective as traditional methods, and in many cases has positive benefits in terms of motivation and retention.

Paper presented at the ICID British Section Irrigation and Drainage Research Day, 29 March 2000. HR Wallingford.

2. The need for 'another' model

There are very many water balance simulation models commonly used world-wide, which benefit from many years of development and validation. However, different purposes (applications) require different packaging of the models. Many of the existing models were developed for research use where the emphasis is on the validity of the output and rigour in the scientific understanding. Packages for educational use have a much greater demand on the ease of use of the interface, simple parameterisation and clear visualisation of results, and less on the accuracy of the prediction. It is important that a model responds to simulated conditions in the right direction and the correct order of magnitude, but relative changes in output are more important in conveying the understanding of the system than absolute predictions. Many of the existing models therefore are unsuitable for educational use, or can only be used once extensive training in the use of the software has been completed.

The objective of the WaSim project was therefore to develop a computer package focused primarily on teaching and learning that is easy to use, has minimal data requirements, good visualisation of model calculations, a reasonable level of accuracy and is flexible in term of the range of water management situations that can be simulated.

3. The models

3.1 Water balance

The water balance model is a one-dimensional, daily, soil water balance. It aims to simulate the soil water storage and rates of input (net rainfall and irrigation) and output (evaporation, transpiration and drainage) of water in response to climate. The upper boundary is the soil surface and the lower boundary is the impermeable layer . Water is stored between these two boundaries in five stores (layers):

1. the surface (0 – 0.15m) layer,
2. the active root zone (0.15m – root depth),
3. the unsaturated layer below the root zone (root depth – watertable),
4. the saturated layer above drain depth (watertable – drain depth),
5. the saturated layer below drain depth (drain depth –impermeable layer).

The boundary between layers 2 and 3 will change as the roots grow. Before plant roots reach 0.15m, layer 2 will have zero thickness. Similarly the boundary between layers 3 and 4 will fluctuate with the watertable. Soil water moves from upper layers to layers below only when the soil water content of the layer exceeds field capacity but the rate of drainage is a function of the amount of the excess water. Upward capillary rise occurs from the water table to the root zone.

a) water balance *b) salt balance*

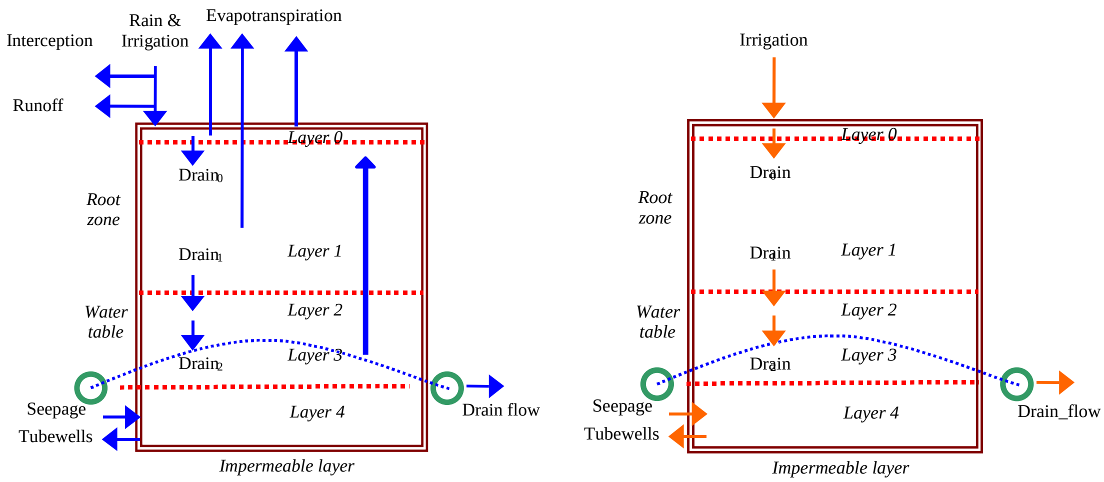

Figure 1. The water and salt balance models used in WaSim.

3.2 Salt balance

The model is a salt mass balance of a one-dimensional profile with boundaries and layers as for the water balance model. The two inputs of salt to the systems are from irrigation water applied at the surface and seepage from canals. Seepage is assumed to contribute directly to the watertable below drain depth. The outputs of salt are in the drainage water and water pumped from tubewells.

4. Input data

4.1 Climate

The model requires daily reference evapotranspiration and rainfall data. An accompanying utility, WaSimET is provided for calculating reference evapotranspiration from daily climate data using the Penman-Monteith, FAO Modified-Penman, or Penman methods. Climate data is imported from text files and screened for missing or out-of-range data. Data errors are then flagged and can be edited with WaSim. The climate data can be plotted (Figure 2) or tabulated and saved as a WaSim climate file.

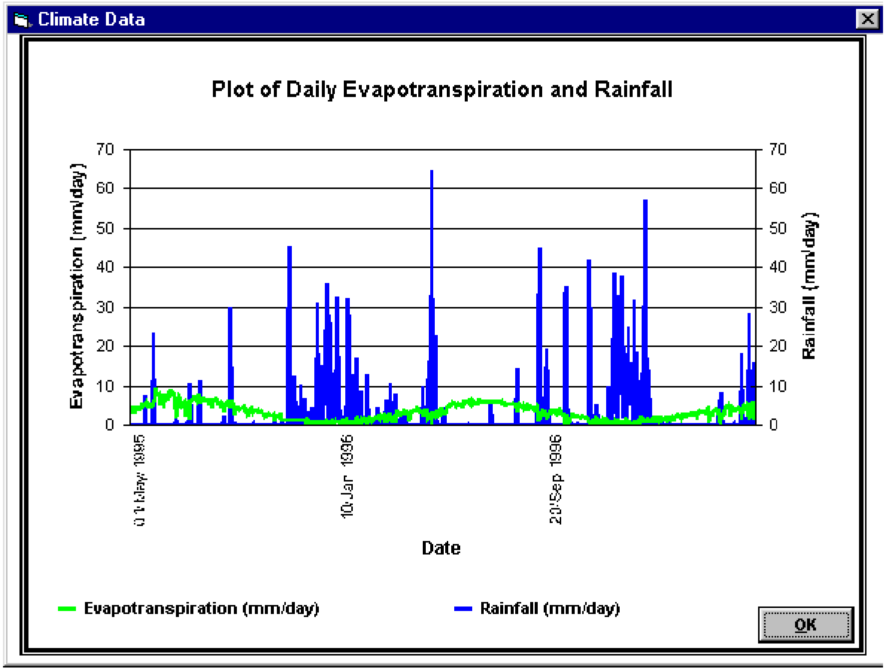

Figure 2 Plot of climate data

4.2 Crops and soils

Up to three crops (with fallow periods between) can be combined in a cropping pattern. For each crop, information is required on the cover development and rooting depths. Basic soil moisture characteristics are required, but typical guidance values provided. The crop and soil information is added to a database for future reference.

4.3 Irrigation

Irrigation schedules are developed for individual crops. Irrigation may be scheduled in two ways;

- Rule based scheduling. The cropping season can be divided in to a maximum of 12 periods, during which different scheduling rules can be applied. The rules (e.g. irrigate at 25mm soil water deficit and refill to field capacity) determine the timing of irrigation and the amounts to be applied.
- Calendar scheduling. Irrigations can be specified for fixed dates (e.g. apply 60mm 30 days after planting) to simulate irrigation by a fixed calendar. This option can also be used to simulate the impact of an actual irrigation schedule.

The scheduling criteria include the ability to suspend irrigation due to rainfall, or constrain the schedule due to limiting system capacity.

4.4 Drainage

The drainage system is defined in terms of drain diameter, depth and spacing. The model also allows for a simple representation of the impacts of canal seepage and tubewell extraction. The model can also be run without drainage or as a free draining system. Drains can also be ‘closed’ for part of the year to simulate ‘Controlled drainage’ for sub-irrigation.

4.5 Salinity

The salinity of the irrigation water and salt tolerance can be specified for each crop in the cropping pattern.

5. Features of WaSim

In order to make the WaSim software useful for teaching and learning, a number of special features were incorporated.

5.1 Visualisation of the simulation

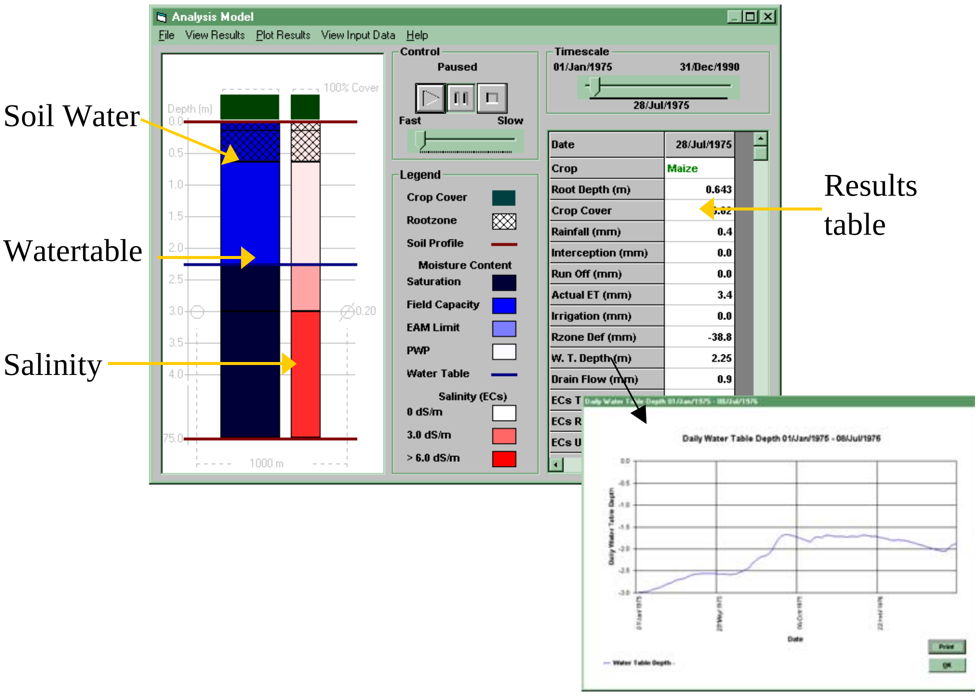

Figure 3 Visualisation of the model run in WaSim.

If a model runs as a ‘black-box’ its educational value is limited – the student needs to be able to get a feel for what is going on during the simulation. WaSim attempts this by use of a dynamic animation of the soil water and salinity in each of the modelled layers (Figure 3). The simulation can be paused and played using the ‘play controls', to allow the student or tutor to stop it at a particular point and ask 'what is happening now?' or 'why do you think that this has happened?'. The results are also shown in a results table (which can be scrolled back to see what happened prior to the current date). Right-clicking on any row in the results table will also graph the results.

The graphical animation can be switched-off to increase the speed of long-simulations.

5.2 Presentation of results

At the end of the simulation all calculated outputs relating to the climate, soil water, salinity, water table and crop status are written to an output file which can then be viewed, summarised and plotted using the results engine. This provides the flexibility to investigate any aspect of the simulation and produced customised graphs. The results of up to five simulations can be overlaid to compare scenarios and the graphed series can be exported to a spreadsheet for further analysis if required.

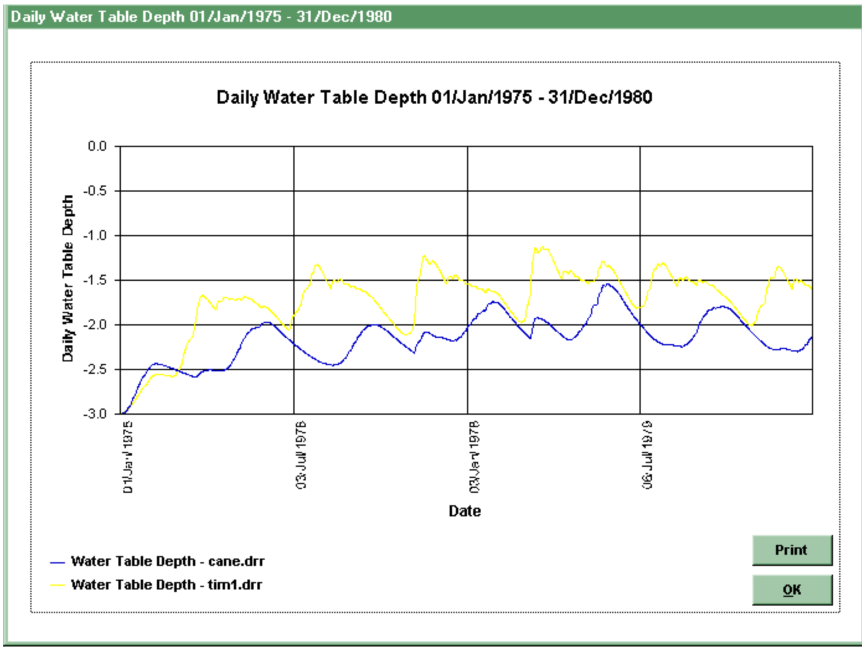

Figure 4 Example of an overlaid graph in WaSim comparing water table fluctuations under two irrigation scheduling regimes.

5.3 Use levels

The user can choose from three user levels.

- Full access. The user has complete access to the database of crop, soil and water management parameters. They can create new entries and edit existing ones. This level would be used by the tutor who can set-up locally relevant scenarios.

- Normal access. The user can create new entries in the database, but cannot delete existing ones. This might be used by the more advanced students.
- Restricted access. The user can select crop and soil files from the database, but cannot change any of the values or delete and records. This ensures that all students will be using the same parameters in their exercises and should all get the same results!

6. Availability

WaSim will be released in the spring of 2000 and will be distributed free of charge on the internet and on CD-ROM. The package contains,

- WaSim simulation software,
- WaSimET software for calculation of evapotranspiration,
- Default crop and soil database,
- on-line help files,
- User manual,
- Technical manual,
- Tutorial manual & case studies.