WAttle - A Water Balance Calculator for Dryland Salinity Management

R. M. Argent[1] and R. J. George[2]
1. Centre for Environmental Applied Hydrology, The University of Melbourne.
2. Catchment Hydrology Group, Natural Resource Management Services, Agriculture Western Australia

Abstract Substantial areas of agricultural land in Australia are under threat from salinisation due to salt remobilisation by rising groundwater. One approach to reduce salinisation involves manipulation of the catchment water balance by altering traditional cropping and pasture practices, or introducing new systems such as agriforestry to reduce groundwater accessions. Agriculture Western Australia identified a need for a water balance simulation tool that could be used to help land managers compare management options. A water balance calculator, named WAttle, has been developed. This calculator shows water balance components (based on farm land management units) under current and potential future land management alternatives, thereby providing land managers with information on the contribution each unit makes to their farm or catchment water balance, and identifying actions they can take in their struggle against dryland salinity. WAttle runs on a daily timestep with monthly reporting. It shows monthly values of evapotranspiration, runoff and deep drainage, for up to eight land management units with different soils and crop rotations, over a period up to forty years, and then allows comparison of these components with changes to some or all of the rotations. Each land management unit is represented by a 1-dimensional cascading 'bucket' soil moisture model, with up to three storages according to soil type. Surface runoff occurs through saturation excess, with hydraulic conductivity determined by storage level. Evapotranspiration is calculated as a function of crop type, storage level, and management. The model allows users to select any or all of a forty year run period, and provides output of both monthly and total values of the balance components. WAttle Version 1.1 has been released and is currently being tested in Western Australia.

1. INTRODUCTION

Substantial areas of agricultural land in Australia have been lost to, or are under threat from, salinisation. The dominant process in this loss of productive area is the remobilisation of salt by a rising watertable, due to alteration of the hydrological balance through removal or reduction of deep rooted natural vegetation and replacement with plants that use less available water.

In the Western Australian Salinity Action Plan the Government of Western Australia [1996] recognises that one of the solutions to the salinisation problem is to have farmers and other land users adopt land management practices that reduce groundwater accessions . To assist in this, land users require information on the alternative plants and crops that are available and the effects of each. To this end, Agriculture Western Australia identified a need for a computer-based water balance simulation tool that could be used to help land users compare management options. This paper reports on a water balance calculator program, named "WAttle", that was developed to meet this need.

2. PROGRAM CONCEPTUALISATION

From a research perspective, the starting point for development of the WAttle program was unusual. Often in research practice the starting point for a computer simulation program is modelling of a particular process, and the matching of predicted to observed data takes precedence. Parameters are calibrated and invalidation of the model is attempted to ensure that the fundamental workings of the system are represented. At some later date, when the model is found to produce good results, attention may turn to encapsulating the model in a program that people can then use to explore there own local variations of the fundamental process.

In the development of the WAttle program, it was given that the fundamental processes in the water balance were already available "off-the-shelf" in the form of water balance models such as the SFB model of Boughton [1984], Boughton's AWBM [1993] or the Xinanjiang model [Zhao et al., 1980; Zhao, 1992].

Primary foci in the WAttle program development were:

- clear projection of the extension message from the program to the user; and
- attainment of a level of technical validity sufficient to represent dominant water movement processes in duplex soils.

Thus, the initial concept was to develop an attractive extension tool with a valid technical basis. To some degree, this conceptualisation of the WAttle program can be regarded as an instantiation of the object-oriented programming paradigm, with effective interaction between the user and the program being given status equal to that of technical validity.

3. PROGRAM FORMULATION

The WAttle program was developed as a series of graphical screens through which a program user progressively sets finer levels of detail of water balance components. The formulation of program screens, and the level of detail supplied on each, was such that users were led through a progression that started from the regional level and gradually became more local. Information, and user selected data, were compartmentalised so that only one component of the water balance was treated at a time.

The initial screens of the program provide information only, so that users are eased into using the model without having to interact greatly with it. Regional and local climate data are selected on the next two screens, providing the rainfall and evaporation data to the water balance model. A soil information screen is then used to set the soil storage and vertical flow parameters, while the final input screen is used to set crop or plant options, thereby providing evapotranspiration parameters. The soil and crop screens have two levels of input, with the basic screen covering simple parameters, and separate editing screens providing access to the more technical details.

The program runs on a daily timestep and reports monthly. Forty years of daily rainfall data from 102 stations are available for model runs, with users able to choose a run time from one to forty years. Output variables include daily, monthly, annual and annual average evapotranspiration, surface runoff, deep drainage, and change is soil moisture content. Monthly values of rainfall, evapotranspiration, surface runoff, and deep drainage, expressed in mm, are provided graphically as the model is run.

WAttle was written to operate in a 32-bit Windows™ environment, and is provided with a Windows help file, a user manual and a technical reference manual. It is currently designed for operation in the south-west agricultural regions of Western Australia. Version 1.1 is available via anonymous FTP from aqua.civag.unimelb.edu.au in directory /pub/users/argent as a compressed file archive named zwattle.exe

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4. PROGRAM SCREENS

4.1 Information Screens

The first screen (Figure 1) is a start-up screen that introduces the model. This is followed by a comments screen that explains the capabilities of the program, some of the limitations, and lists the institutions involved in program development. Context sensitive help files can be accessed from all screens.

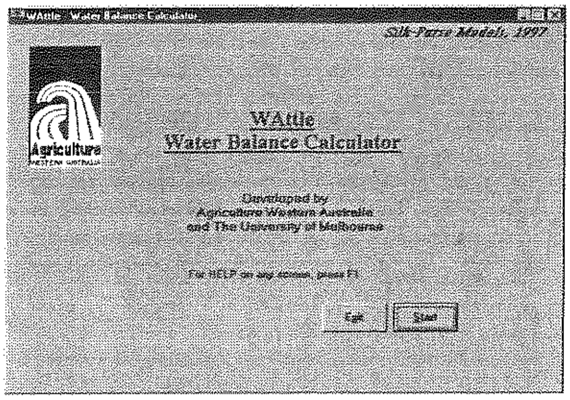

Figure 1: Start-up Screen of the WAttle Program

4.2 Location Selection

The next screen starts to include site details by providing a "hotspot" bitmap of the crop variety trial (CVT) regions of south-western Western Australia (Figure 2). Users select the region of interest by either mouse-clicking on the relevant hotspot, or selecting from a list of regions.

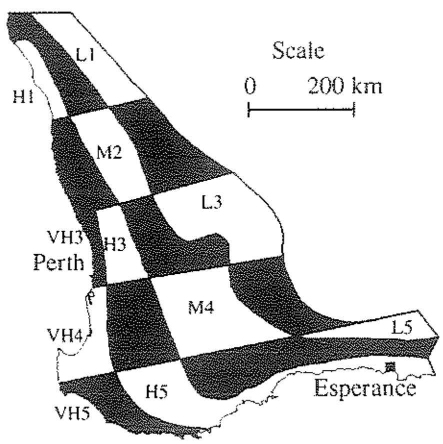

Figure 2: Crop Variety Trial Regions for Western Australia

CVT regions were selected as the primary break-up of the larger agricultural area because they are climate-based and provide distinct districts with a reasonable number (around ten) of high quality daily rainfall

6. WATER BALANCE OPERATION

The WAttle program uses a cascading, three-level 'bucket' water balance model. This balance is based upon the ELM SOILWAT model of Parton [1978], and the balance of the SOILWAT module in APSIM [McCown et al., 1996], PERFECT [Littleboy et al., 1992], and various of the CERES series of models, particularly the CERES derivative SIMPOTATO [Hodges et al., 1992].

The daily balance for any soil layer is based upon the soil moisture available over the lesser of the effective rooting depth of the crop in question and the soil layer thickness. For example, if a crop or plant has roots in the A horizon only, the balance is performed on the A horizon only, and any drainage from the A horizon goes to the deep percolation component, irrespective of the presence or otherwise of a B Horizon.

Model operation starts by adding the daily rainfall to the A Horizon soil store. Maximum possible actual ET is calculated as the product of daily pan evaporation, a pan factor (set to 0.8) and a daily crop factor, with a linear reduction factor on ET for soil moisture levels below 75% of saturation. Runoff, deep drainage and actual ET are determined for the store, and then subtracted to give a new soil storage level. Storage changes and deep drainage are then determined for lower soil storages, if present and active.

Deep drainage from a soil store with a moisture content (ST) above the drained upper limit (DUL) is determined, as shown in (2), by a function of the saturated hydraulic conductivity (Ksat; expressed in mm/day) and a square function of the proportion of moisture held between the DUL and the saturation moisture content (SAT).

$$D = Ksat*[(ST-DUL)/(SAT-DUL)]^2 \quad (2)$$

This equation is a very simplistic representation of the flow for saturated and unsaturated conditions, but it works. With the program reporting on a monthly timestep, any reasonable function that, once unsaturated conditions are reached, sharply reduces D below a value equivalent to Ksat, is sufficient.

As an example of program operation, the following parameters were set:

- Region: H4
- Rainfall Station: Boyup Brook PO
- Management Unit: 1
- Soil: Shallow Loam Duplex
- Long Term MAR: 641 mm
- Current Rotation: Clover Pasture
- New Rotation: Perennial Grasses

The program was run over the ten year period from 1970 to 1979. The output data shown graphically in the program during this run are presented in Figures 3-6.

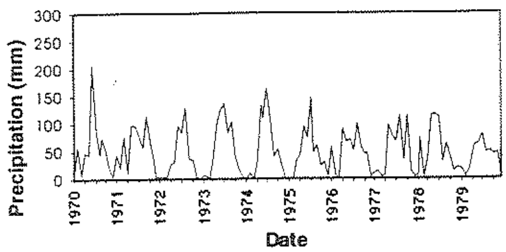

Figure 3: Monthly Precipitation

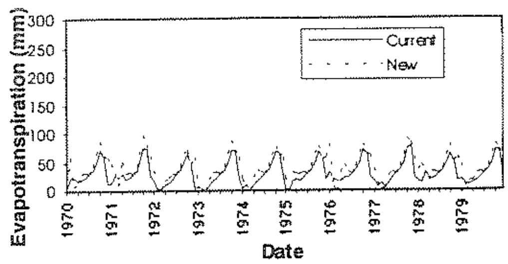

Figure 4: Monthly Evapotranspiration for Current and New Rotations

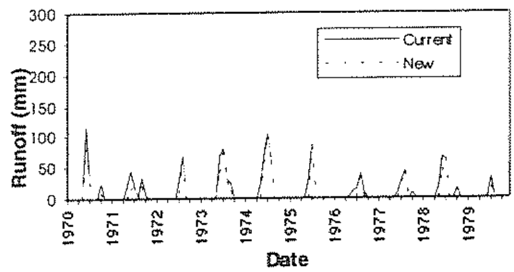

Figure 5: Monthly Runoff for Current and New Rotations

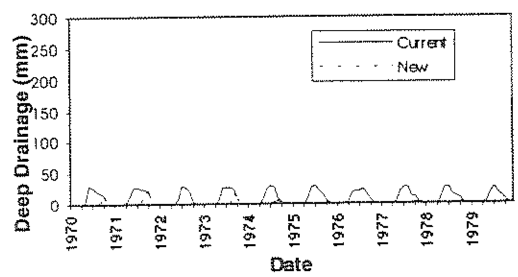

Figure 6: Monthly Deep Drainage for Current and New Rotations

The data presented in the program, and shown in Figures 3-6, are of sufficient detail to provide users with an overview of differences in the water balance components between the current and new rotations. In this case it can be seen that a change from clover pasture to perennial grasses has benefits, in terms of increased water usage through evapotranspiration, over most of the year, and particularly in the April - June period. This benefit does not greatly influence runoff, but has significantly reduced the deep drainage component, and stations, and also for which representative daily evaporation values could be used. Once the region is selected, the user is provided with a list of rainfall stations for the region. They select their nearest station for the model run, and are also able to provide a local value of mean annual rainfall (MAR). This value is used as a proportion constant for calculation of the daily rainfall value in the model. Having provided the information necessary to select the regional evaporation and local rainfall data sets, the user moves to the management units screen.

4.3 Management Units Screen

The management units screen provides a mixture of flexibility in the selection of soil parameters. Users are able to set up to eight sets of soil properties for different units that they manage, and have direct access to edit the soil profile thicknesses. Other, more technical, soil properties, such as the saturation, drained upper and lower soil moisture contents, and effective daily hydraulic conductivities, can be edited from a separate screen accessed from the management units screen. With local soil properties set, and one management unit selected for the model run, the user passes to the crops screen.

4.4 Crops screen

The crops screen has two simple sets of drop-down lists of crops - one for the current rotation and one for the potential new rotation. Users can set up to eight years of different crops or plants in each rotation. Twenty-four crop or plant options are available for each year of each rotation, including bare soil, annual crops (summer and winter), annual and perennial pasture, and shrubs and trees. Perennials, shrubs and trees are only able to be selected as rotations of one year duration - i.e. continuous growth - and are assumed to be growing at a mature rate. Crop factor and rooting depth parameters for each plant or crop option can be individually edited in a separate screen accessed from the crops screen. Crop factors are marked with a colour coding according to the quality of the data used in their determination.

4.5 Model Run, Output and Reporting

Once the climate, soil and crop parameters have been selected the program run screen appears. Monthly reporting of rainfall, runoff, evapotranspiration, and deep percolation is provided graphically as the program runs, with all variables shown in mm. The time period for the run can be from one to forty years, using data from the period 1954 to 1993. The program first runs the current rotation, then the new rotation. After both rotations have been run, it is possible to view graphs of the differences in water balance components between the current and new rotations. There are editing options available from the run screen to return to the management units or crops screens to either reset soil or crop parameters or select a different new rotation option. When the model has been run for the current rotation, it is possible to view the report screen.

The report screen provides the output data, including average and actual annual values of the water balance components. Daily, monthly and annual model output data are able to be exported to a text file for further analysis, or as input values to other models, such as groundwater flow models.

5. WATER BALANCE COMPONENTS

The water balance used in the WAttle program is given in (1).

$$P = ET + R + D + \Delta S \qquad (1)$$

Where: P is daily precipitation (rainfall), ET is evapotranspiration, D is the daily deep drainage and ΔS is the change in soil moisture content.

Historic rainfall data are available in the program for a variable number of stations for each of the eighteen CVT regions (Figure 1). For each station there are 14600 daily rainfall values, representing the forty years from 1 January 1954 to 31 December 1993. Data for February 29 (ten points in forty years) have been removed to give forty years of 365 days.

Average daily values of pan evaporation from a representative station in each CVT region were selected for use in the model.

Soil parameters used in the model are:

- the thickness of the A and B horizons;
- the saturation, drained upper and lower soil moisture limits for the A and B horizons;
- the drained upper and lower soil moisture limits for the deep storage soil below the B horizon;
- the saturated hydraulic conductivity for flow from the A to the B horizon (in mm/day); and
- the saturated hydraulic conductivity for flow from the B Horizon to the deep storage soil (in mm/day).

Soils data were obtained from Agriculture Western Australia (N. Schoknecht, pers. comm.), Jensen et al. [1990], Maidment [1991] and Dingman [1993].

Crop and plant data were obtained from Agriculture Western Australia (D. Hall, pers. comm.), Reid [1981], Doorenbos and Pruitt [1984], and from the Valmont Industries world wide web site [Valmont Industries, 1996]. The available parameters are minimum, effective and maximum rooting depth, and crop factors for each month.

so should have an impact on recharge and watertable rise. Changes in watertable levels are not estimated because WAttle is a one-dimensional model and is inappropriate for such calculations.

7. CALIBRATION AND VALIDATION

No formal calibration and validation of the WAttle program or the water balance model has been undertaken. To date the testing of model output has involved having experienced field researchers run the program for known field situations and compare the output values with their experience. Apart from a few situations where the model assumptions do not hold (such as having the local watertable intercept the deep storage, or where significant runoff arises from infiltration rather than saturation excess), the model output has been accepted for use in the field. Field testing of the WAttle program is currently being undertaken in Western Australia and, although this testing is concentrating upon the user interaction with the program, any technical deficiencies that arise during simulation will be noted and corrected.

8. CONCLUSION

The WAttle program provides a useful extension tool with a scientifically acceptable water balance model that can be used in the management of dryland salinity. By providing information relevant to the needs of management in a flexible and elegant form, backed up by a good extension network, the WAttle program is a solid step in the right direction for implementation of the Western Australian Salinity Action Plan.

9. REFERENCES

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