User's Guide for the Land Use Change Water Balance Model (WATYIELD)
SMF 2167

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1. Installation

The water balance model WATYIELD is supplied ready for installation on a Windows operating system for a PC. It has been tested on Windows 95 and later versions. Landcare Research cannot guarantee the model working on all computers; if you have difficulty during installation please contact Jagath Ekanayake (EkanayakeJ@LandcareResearch.co.nz) or Tim Davie (DavieT@LandcareResearch.co.nz).

1.1 Download from the website

At the following website you should find a downloadable file called WATYIELD.zip.
http://icm.landcareresearch.co.nz/land_cover_effects_on_water_availability.htm
When downloading this file you may be prompted to install immediately from the website. If this prompt does not come up then you will need to download the file and then unzip the three files using the decompression software such as *Powerarchiver 2000*. The three files should be: setup.exe; setup.lst; WATYIELD.cab. The files can be unzipped to a temporary location, as they are only needed for installation (i.e. they can be deleted after installation).

Double click on the setup.exe file and the model should install in the directory that you specify. Sometimes there are warnings that some of the *dll* files are currently being used or are later versions than those already on your computer. Both of these warnings can safely be ignored. When the installation has finished you will find the model (called WATYIELD) in your programs menu.

1.2 Download from CD

In the directory called MODEL you will find a setup.exe file. Double click on this and the model should install in the directory that you specify. Sometimes there are warnings that some of the *dll* files are currently being used or are later versions than those already on your computer. Both of these warnings can safely be ignored. When the installation has finished you will find the model (called WATYIELD) in your programs menu.

2. Introduction to WATYIELD

The basis of the Decision Support Tool (DST) is a water balance model (WATYIELD) developed by staff at Landcare Research to examine the effects of land use on water yields and low flows. It is intended for use in situations where there is a limited amount of data on the climate, soils, and vegetation of a catchment, and is similar to the approach widely used for computing crop water requirements. A graphical user interface provides quick and easy access to the water balance model and facilitates the input of data required to run it. WATYIELD accesses the input data and parameters through an Excel spreadsheet specifically formatted for the purpose. Graphical displays of modelled daily runoff, soil drainage, and total profile water stores are available on screen, as well as tables of annual modelled water yield and mean 7-day low flows. Graphical and tabulated comparisons can be made with measured values if these are available.

WATYIELD is based on calculating the soil-water balance from a daily rainfall time series and an estimate of evaporation for the site. The daily drainage from the soil, Q, is obtained from the water-balance equation:

$$Q = P - E - \Delta S$$

where P is rainfall, E is evaporation, and ΔS is the change in water stored in the root zone of the soil profile. Rainfall is the independent variable and must be derived from measurements made near the site. Evaporation from vegetation has two main components, interception and transpiration. Interception, E_i, is calculated from the daily rainfall. Transpiration, E_t, is derived from a climatological "reference evapotranspiration, E_{ref}" using parameter values to represent the vegetation type (pasture, scrub, forest etc.). E_t is calculated firstly for well-watered conditions.

Three soil parameters are used to adjust the weather-controlled evaporation for effects of dry soil conditions to obtain soil-water controlled transpiration: a surface layer store (Scotter et al. 1979), and total- and readily-available water in the root zone (TAW and RAW; Allen et al. 1998). Several compilations of measurements of available water in soils have been published, which provide data to progressively greater depths as ideas about the effective rooting depth have evolved: to 0.45 m (McDonald 1968), to 0.76 m (Gradwell 1974), to 0.9 m (National Soils Database at Landcare Research) and to depths up to 2 m in several field studies of water use reviewed by Woodward et al. (2001). New Zealand Standard (1973) also provides a useful summary for soil groups, which allows users to calculate TAW for a rooting depth that they consider appropriate. In general it is a good idea to test the sensitivity of the calculated water yield and low flows to TAW before devoting too much effort to finding "correct" values.

Part of the drainage, Q, is immediately discharged to the stream as quickflow, R_f, and the rest passes through a base-flow store and contributes to base-flow, R_b, estimates of which are calculated from a storage-outflow model. Two parameters, the base-flow index (BFI) and a recession constant (k), define the base-flow system. The daily stream flow, R, is the sum of R_f and R_b.

There are two essential assumptions in this approach:

1. Processes such as surface runoff induced by compaction or water repellency are not explicitly included in WATYIELD, as the relevant information is usually not available.
2. When summed over a long period of time the drainage from the root-zone, ΣQ, is equal to the stream discharge, ΣR, and there are no net losses or gains through groundwater flows (i.e., the catchment is water tight.). When WATYIELD results are compared with measured stream flow a significant overestimate by the model may indicate that there are losses to groundwater.

2.1 Dividing a catchment into sub-areas

The catchment in question can be divided up into a maximum of 10 sub-areas based on features that distinguish those areas and are likely to influence water yield or low flow, e.g., cover type, soil characteristics, and rainfall. Each sub-area can be as small as 1% or as large as 100% of the total catchment area. Where the purpose of the analysis is to assess the effects of a change of land use on the stream flow regime it is essential to identify the potential change at this stage and to create the sub-areas where the change will occur. Some knowledge of the catchment's present land cover, and general soil characteristics, is desirable when dividing the catchment up into its constituent areas. It is also instructive to have some understanding of the relative importance of each sub-area from the point of view of its contribution to annual water yield. For example, the upper reaches of a catchment will normally produce more runoff than those areas lower in the catchment because of higher rainfall in the headwaters. WATYIELD's on-screen outputs are designed to assist the user in assessing the importance of the various sub-areas as contributors to total water yield

2.2 Data requirements

The minimum data requirements are daily rainfall totals from a local or nearby rainfall station, and average monthly reference evapotranspiration from a climate station (New Zealand Meteorological Service 1986; see also Section 2.2). For calibration purposes, or if a comparison is to be made between measured and modelled flow, WATYIELD also accepts measured flow as daily values. As with most computer models the run time increases in proportion to the amount of input data, and will be dependent on the processing time taken by your computer. We have found that up to 12 years of data (approximately 0.5 MB) can be processed by the program with little time delay. Extra years can be accommodated if you are prepared to wait.

The same daily rainfall series and average monthly reference evapotranspiration are used for all sub-areas. However, the rainfall can be scaled up or down for each sub-area, on the basis of additional data if available, or from rainfall isohyetal information.

2.3 Parameters for sub-areas

The following parameters are assigned to each sub-area: (1) an estimate of the amount of rainfall lost through interception (the interception fraction), (2) a factor to convert the reference evapotranspiration to a loss equivalent to transpiration for the cover type when it is well supplied with water (the crop transpiration coefficient), (3) factors to calculate evaporation under water stress conditions. These include the surface or top layer store, total available water in the root zone of the soil profile (TAW), and readily available water in the root zone (RAW). These parameters are needed for calculating a daily soil-water balance. They provide the modelled amount of water draining from the soils of the catchment sub-areas under the vegetation cover selected for each.

2.4 Base-flow parameters

If WATYIELD is being used to assess the effects of a land-cover change on low flows, two base-flow parameters are needed for the catchment. In WATYIELD, they are considered as whole-catchments properties. The first of these is the input to the base-flow store, which is represented by the base flow-index (BFI), defined as the proportion of total flow appearing as base-flow. The second accounts for the timing of the output from the base flow-store and is represented by the base-flow recession constant (k). It defines the rate of base-flow recession.

3. Input variables

3.1 Rainfall

It should be noted that rainfall can be the largest source of uncertainty in WATYIELD predictions. Therefore, every attempt must be made to ensure that the rainfall record used as input is as representative as possible.

3.1.1. Review of data as a contribution to the definition of sub-areas and to provide the weighting for rainfall in each sub-area

(1) Find the required sources for the daily rainfall record. If there is no rain gauge or climate station that you are aware of in the area, ask the land-occupier or contact the nearest regional or district council, or NIWA.

(2) Request the data for the site and make sure that you get the precise location and elevation for each station. If there is more than one gauge close to or within the catchment you can get the records and average them if there is little difference between them, to produce a single complete time-series, or use the individual records to weight the annual totals. Check also at this time for other long-term rainfall records in the vicinity, or for the availability of rainfall isohyetal maps. This information will be useful later in weighting the record for the sub-areas according to elevation.

3.1.2. Preparation and input of the data file.

(3) Ask for the data to be sent in millimetres and in the format DD MM YYYY XXX.X. Note that the Excel template accompanying WATYIELD can also accept data in the format MM DD YYYY XXX.X.

(4) Check the record for missing data, and apparent anomalies. The program will not accept anything other than numeric data. Therefore if the word "missing" appears in the columns, replace it with 0 or an estimate. If the gaps are lengthy, use data from other stations to fill them in. Otherwise, the data may have to be deleted, and the file split into years or periods. This should be avoided wherever possible, because splitting the file into years will mean that it has to be initialised for each segment. For example, if there are only 12 months of data to work with, WATYIELD may need to run through the first 6 months before it is properly initialised.

The daily gross rainfall (P) is input to your TEST_DATA.XLS file from a file of daily rainfall values. These values may be either manual measurements, such as those taken at 0900 hours at standard climatological or rainfall stations, or computed from chart or electronic records from automatic gauges or weather stations (the latter are usually for calendar days). The file must be complete, i.e., it must contain a value for every day.
Do gaps in rainfall records matter? Files of manual data may contain periods where a gauge has not been read for a few days but the total for the period is correct. Automatic gauges may contain longer gaps, with or without aggregate totals for the period of the gap. In all cases gaps should be filled with estimates derived from measurements at other sites in the region. The structure of the water-balance calculations in WATYIELD makes outputs from the model more sensitive to aggregate totals over a period of a few days than to errors in distributing that total over the days in the gap. Long runs of false days with zero rainfall can cause apparent periods of water stress and false reductions of evapotranspiration rates, so aggregates should be split up in a reasonably realistic way based on other sites in the region.

(5) Import the data into an Excel spreadsheet. Note that it may be better to create a new or separate spreadsheet for importing data at this stage. Data can then be checked for errors or omissions and corrected if necessary before importing them into the formatted spreadsheet.

(6) Open the new spreadsheet, click on "Data", followed by "Get external data", then "Import text file", and go to the location of the rainfall data file. Click on "Import".

(7) If you have identified the data file with an extension other then .txt, left click on "All files" in "Files or type", then left click on the file.

(8) In the “Text import Wizard – Step 1 of 3” click on “fixed width” and identify the “start import at row” which is normally “1”. Then click on “next”.
(9) With step 2, “Data preview”, create the column for the date by moving the two left-hand arrows to the right to merge with the one on the right. This gives you two columns: one for the date, and one for the rainfall record. Then click on “next”.
(10) On Step 3 click on “Finish” and “ok”.
(11) Save the file.

If you need to convert the file to a MM/DD/YY format do so by highlighting the column, right clicking on it, then left clicking on “format cells”. Under “category” left click on “Date” then on “3/14/98” to change the format to MM/DD/YY.

It is now time to copy the date and rainfall columns to the Excel spreadsheet template making sure that they are pasted into the correct columns; begin at row 24, column D for the date, and column E for the rainfall.

The same procedure described above for obtaining, preparing and including a rainfall record in the spreadsheet template can also be used for flow. If available, it can be copied into column C at row 24.

3.2 Reference evapotranspiration

The approach used here follows one that has commonly been used for agricultural crops and was recently revised by FAO in Allen et al. (1998). The average monthly “reference evapotranspiration” (E_{ref}) for the site is equivalent to potential evaporation for an extensive surface of actively growing short grass under well-watered conditions as calculated by the Penman–Monteith method. It is the maximum quantity of water that can be evaporated from such a surface in a given climate, and was formerly referred to as “potential evapotranspiration”. It is calculated from meteorological data and vegetation parameters for the reference crop.

The most accessible source for this information is the *New Zealand Meteorological Service Miscellaneous Publication 189* (New Zealand Meteorological Service 1986). It summarises monthly evaporation from 51 stations. These values of E_{ref} and some additional information can be found in a separate spreadsheet accompanying WATYIELD (ET&RRMP189.xls). A spreadsheet for calculating the FAO reference crop evapotranspiration is also available on the FAO web site and can be used with your own data or with data from *New Zealand Meteorological Service Misc. Publ. 177.* (1983). The summary tables in *Misc. Publ. 189* (New Zealand Meteorological Service 1986) include wilting point deficit, runoff, and soil moisture deficit for each of four available water capacities: 40, 80, 120, and 160 mm. These may be helpful in the selection of initial values of the amount of water in the soil store.

As a first approximation, you need to find the station closest to your site. However, because evaporation varies with elevation, the record from a site with a similar elevation to the reference site may be better than one closer but at a markedly different elevation. Once you have decided on the best value available for your site, the daily means for each month are calculated and these values typed into the Excel template (row 5, column AD). You can also calculate the daily values from the monthly record and insert them into column F, starting at row 24, and copying and pasting until the record is complete. This is obviously much more laborious. However, it gives you the opportunity to, firstly, enter additional, possibly more representative data for selected periods (if these are available), and secondly to smooth the daily totals, rather than using an average daily value for each month.

4. Input parameters

4.1 Background information

The next task is to identify the most appropriate input parameters used by WATYIELD for the catchment as a whole, or for each sub-area. This may best be preceded by assembling as much information as you can on the catchment or area in question, relating to climate, geology, soils and vegetation cover. This does not have to be exceptionally detailed at this stage. For example, the general lithological characteristics can be identified from the 26 sheets making up the *Geological Map of New Zealand* at a scale of 1:250 000. Likewise, general information on New Zealand soils is available in the regional soil maps accompanying *Soil Bureau Bulletin 27* "General survey of the soils of the South Island of New Zealand" (1969), also at a scale of 1:250 000. The Soil Bureau, which was part of the DSIR, also published numerous bulletins describing the soils of New Zealand, and Landcare Research has carried on this tradition. Many of these publications are listed in Landcare Research's Manaaki Whenua Press web page (www.mwpress.co.nz). Click on "main catalogue", "soils and land science", and "list of soil publications". These can also be purchased from Manaaki Whenua Press. Another useful reference is the new *Land Environments of New Zealand* publication *(LENZ)* (Ministry for the Environment 2003).

The best source of information at the regional level for determining the vegetation cover is the Land Cover Data Base (LCDB). It is based on data acquired from satellite imagery, and is made up of polygonal boundaries representing land cover types, with each polygon containing a code representing the land cover type. The data are compatible in scale and accuracy with the 1:50 000 topographic map series. Since the imagery was obtained mostly between October 1996 and March 1997, it represents the New Zealand land cover at that time. This should be kept in mind when dealing with long-term hydrologic data sets. If these, for example span 10–20 years, the land cover may have changed substantially during this period. The LCDB comes under the jurisdiction of the Ministry for the Environment, and is accessible commercially through Terralink International, PO Box 2872, Wellington. Their email address is info@terralink.co.nz, and their website is at www.terralink.co.nz. The main mapping unit is one hectare, and there are 16 classes of cover. The main ones of interest for WATYIELD are: bare ground, primarily pastoral, primarily horticultural, tussock grassland, planted forest, and indigenous forest.

4.2 Vegetation parameters

4.2.1 Interception fraction.

This is the fraction of rainfall that is intercepted by the vegetation canopy and lost back to the atmosphere as wet canopy evaporation. It should be noted that WATYIELD only considers the fraction of rainfall intercepted, and not the amount stored on the canopy, and thus does not incorporate the details of the interception process. Rather it simply assumes that a given fraction of daily rainfall is intercepted according to the vegetation type. The best sources of information here are the reports prepared as part of this project: Report 1 on radiata pine (Rowe, et al. 2001), Report 2 on Douglas fir (Rowe et al. 2001a), Report 3 on other cover types including native forest and tussock grassland (Rowe et al. 2001c), and Report 5, which summarises the hydrological effects of different vegetation covers in the New Zealand context (Rowe et al. 2002). Note in particular, Table 10.3 on p. 46 of Report 5.

Once you have decided on appropriate values for the interception fractions, these can be entered in the formatted spreadsheet (cells F10 to O10) in accordance with previously identified sub-areas. Alternatively you can use the default values in WATYIELD. Clicking on "get vegetation parameters from the data base" on Screen 7 can access these. On Screen 7.1 you can click on "check the vegetation data base" to determine the default values for each vegetation class. Note that the interception value for tussock grassland is for tall tussock (> 0.5 m), and that for scrub is for a cover <2 m tall. Note also that a mature forest is defined as one that has achieved canopy closure, remembering, however, that within a mature forest there may be mixed age classes.

4.2.2 Crop coefficient.

Information on the crop coefficient, required to reduce the reference evapotranspiration to a figure representative of transpiration for common vegetation covers in New Zealand, is more difficult to obtain. There is a lot of detail in Allen et al. (1998), but this mostly refers to crops. We suggest you use the default values in WATYIELD as a first approximation. Again these are available on Screen 7. These can be added to the formatted spreadsheet between cells F11 and O11, according to earlier decisions made regarding the identification of land covers associated with each sub-area.

4.3 Soil water storage parameters

The main source of information for the soil water storage parameters is the soil fundamental data layers (FDLs). The FDLs contain spatial information for 16 soil attributes obtained from the national soil data base (NSD). It comprises a collection of GIS layers that describe soil units mapped throughout New Zealand in terms of their identification and distribution, and their measurable site and soil properties both physical and chemical. Included in these attributes are total profile available water (TAW) and profile readily available water (RAW). There are six classes in each. For example, the TAW for class 1 (very high) ranges from 250 to 350 mm for the soil profile to a depth of 0.9 m, or the potential rooting depth, whichever is the lesser, and class 6 (very low) ranges from 0 to 30 mm. Information on both the TAW and RAW for all the country is available commercially from Landcare Research (newsomep@landcareresearch.co.nz, or willoughbyj@landcareresearch.co.nz). N.B. in the default values within WATYIELD, it is assumed that RAW is half that of the TAW.

Maps produced as part of the database for the FDLs (available through Landcare Research) may show, for example, the TAW to be part of Class 3 (moderately high) which ranges from 90 to 150 mm. Alternatively, it is possible to calculate the TAW and RAW for a given location if the soil type is known. For example, the New Zealand Land Resource Inventory (NZLRI) maps contain soil information at a scale of 1:63 360, adapted from publicly available soil surveys produced by Landcare Research and its predecessor, the New Zealand Soil Bureau. The NZLRI is a spatial database mapped at a scale of 1:63 360 consisting of polygons that enclose areas of uniform characteristics, e.g., soil units down to a size of 0.25 km^2. The smaller-scale (1:250 000) soil maps (New Zealand Soil Bureau 1968) can also be useful in identifying soil types for a given catchment. As with the vegetation parameters, a decision needs to have been made earlier about the number and type of sub-areas in the catchment in question. Once the appropriate RAW and TAW have been assigned to each sub-area, the values can be added to the spreadsheet template (F7 to O7 for TAW, and F8 to O8 for RAW).

Another source of information for RAW and TAW is the Woodward et al. (2001) which is summarised in report 3 for this project. Woodward et al. (2001) provide measured values of Raw and TAW for a series of soils throughout New Zealand.

To account for the effect of rain when the soil profile is relatively dry, a surface-layer soil-water storage zone is defined (based on Scotter et al. 1979 p. 456), from which up to 25 mm of water can be evaporated. This surface or top-layer store can thus be set at 25 mm, unless there is specific information on the soil cover of the catchment in question for this figure to be modified.

If there is no reliable source of information to assist with choosing soil-water-storage parameters, the default values in WATYIELD can be used. As a first approximation, these values have been derived from soil textures, and can be accessed from Screen 6 by clicking on "get soil parameters from the database". Selections can be made for each sub-area with some basic knowledge of the likely prevailing soil texture in each.

4.4 Base-flow parameters

These are required if WATYIELD is being used to assess the effect of a land-cover change on low flows. The two parameters used in WATYIELD are the base-flow index and the base-flow recession coefficient, which provide estimates of outflow from a base-flow store similar to that used by Boughton (1993, 2002).

4.4.1 Base-flow index (BFI).

This is defined as the proportion of total flow that appears as base flow (Hewlett & Hibbert 1967; Jowett & Duncan 1990). Its calculation requires a record of streamflow from a nearby catchment, or one with similar lithological and climatic characteristics. Most New Zealand hydrological databases, such as TIDEDA and HYDSYS, have procedures for separating total flow into storm flow (or quickflow) and base flow (or delayed flow). If the flow record for a nearby or similar catchment covers a number of years, the separation procedure can be done for each year and an average annual total flow and base flow calculated for the period.

If no flow record is available or suitable, there is one other potential source for estimating the base-flow index. Jowett & Duncan (1990) list this parameter as one of the flow variability indices that they established for 130 sites on New Zealand rivers. They used seven flow indices to classify all rivers into six groups with similar variability. The mean base-flow index decreases with increasing variability, from 0.78 in Group 1 to 0.28 in Group 6. A map shows the catchments in their respective groups, and is useful as a guide to establishing base-flow indices for other rivers close to those displayed.

4.4.2 Base-flow recession coefficient (k).

This parameter defines the rate of base-flow recession from the base-flow store. If R_b is assumed to be runoff derived from base flow, then:

$$R_b = S_b\,(1 - k),$$

where S_b is the amount of water in the base-flow store. R_b is calculated for each day as a function of the amount of store in the previous day.

Theoretically, k can range from zero to unity, but usually resides at the upper end of the scale (0.900 to 0.999).

To calculate k a tabulated daily streamflow record is required from a catchment nearby or from one with similar characteristics. The first task is to identify long, uninterrupted recession periods, and then to check to see how many days it takes for the flow to halve during the recession. It is often easier to identify the lowest daily flows on the recession curve, and to move back up the curve to see how many days are required for the flow to double in value. This needs to be done as many times as possible, and preferably 2-to-3 for each year. Rather than calculate the average value for the days over which the flow halves or doubles, it is better to focus on the longest recession periods that appear in the record, and calculate the average of these.

Table 1, from Martin (1973), enables values of k to be estimated from the number of days taken for flow during the recession to halve or double.

Table 1. Values for k with their corresponding $t_{0.5}$ values representing the time taken, in days for base flow to halve (adapted from Martin 1973, p. 58).

K	$t_{0.5}$ (days)	K	$t_{0.5}$ (days)
0.800	3.1	0.970	23
0.900	6.6	0.980	34
0.910	7.3	0.985	45
0.920	8.3	0.990	68
0.930	9.6	0.995	137
0.940	11	0.996	177
0.950	13	0.997	232
0.960	17	0.998	334

5. Initialisation of WATYIELD

Initialisation is simplest if the rainfall data series starts in mid-to-late winter when both stores are likely to be at or near their maximum water content, except in areas with low rainfall. The default values are 90% of the maximum for the two soil stores. For regions with a mean annual rainfall <800 mm, a value of 50% of the maximum water content should be used.

If the rainfall data series begins in midsummer (e.g., 1 January) the soil may be assumed to be dry. For the upper store, a value of 20% of the capacity should be used, except in areas where rainfall exceeds 1600 mm, when the default value should be used. For the whole store, the initial value is 20% of TAW for rainfalls up to 1200 mm, 50% for rainfalls of 1200-1600 mm, and 90% (the default value) for rainfall > 1600 mm. Table 2 will assist users in choosing initial values, using mean rainfall as a guide.

Table 2. Suggested choice of initial values (mm for upper store, and % of TAW for whole profile store) based on rainfall (<800 mm to >1600 mm)

	<800 mm	800–1200 mm	1200–1600 mm	> 1600 mm
Upper soil store (imm) Start date:				
Summer	5	5	5	5
Winter	22	22	22	22
Whole soil store (% of TAW)				
Summer	20	20	50	90
Winter	50	90	90	90

5.1 Initial value for content of base-flow store

An estimate of an initial value (mm) for the amount of water in the base-flow store (S_b) can be obtained using the following equation:

$$S_b = (P - E_{ref})*BFI/(1 - k) \qquad (\text{if } P > E_{ref}, \text{ otherwise } S_b = 2 \text{ mm})$$

where P and E_{ref} are average values for the month in which WATYIELD is initialised, calculated as the mean daily values in mm/day, b is the base-flow index (BFI), and k is the recession coefficient. If $P < E_{ref}$, a small positive value (2 mm) is inserted for S_b.

6. Worked Example

The following example is for Rocky Gully in South Canterbury. It was originally presented as part of a "blind" test run for a workshop held in late 2002, to show how WATYIELD could be used to predict mean annual water yields, and mean annual 7-day low flows.

6.1 General information

Rocky Gully is a medium-size catchment located on the north-east-facing flanks of the Hunter Hills 50 km west of Timaru. Information from Environment Canterbury showed the catchment area above Rockburn (map reference, J38:325-513) to be 23 km^2 . Sheet 20 (Mt Cook) of the *Geological Map of New Zealand* map series (scale 1:250 000) shows Rocky Gully to be underlain by moderately indurated greywacke and argillite, and Sheet 8 of the soil map of the South Island (New Zealand Soil Bureau 1968) reveals three main soil types: Kaikoura soils (57) covering 40%, Hurunui soils (41d), 50%, and Kakahu soils (29cH) at 10%. In the old soil classification these are mostly yellow-brown earths. The Land Cover Data Base shows the catchment to be 50% tussock, 47% pasture, and 3% scrub.

6.2 Input data

6.2.1 Rainfall.

Environment Canterbury supplied the daily rainfall record from a station in the Rocky Gully catchment (map reference, J39:302-489) which covered the period 1964 to 2001. However, the record had numerous gaps until 1987. Consequently, the period February 1988 to December 2001 was chosen to represent the rainfall for the catchment. Any small gaps were filled with zeros or estimates. The mean rainfall for the 14-year period was 845 mm. The topographic map showed that the gauge was located on a ridge, midway up the catchment at an elevation of 900 m. However, because the headwaters extend up to 1340 m, it was decided to increase the rainfall by a factor of 1.3 –1.5 in the upper reaches, and reduce it to 0.9 in the lower reaches.

6.2.2 Reference evapotranspiration.

The nearest official reference evapotranspiration site is at Waimate 35 km to the south (New Zealand Meteorological Service 1986). The mean annual evaporation at this site is 686 mm.

6.3 Input parameters

6.3.1 Interception fraction.

According to the LCDB, scrub covers less than 5% of the catchment. Thus it was decided to split the land cover evenly between tussock and pasture, and to assume that the former was confined to the upper 50% and the latter to the lower 50%. However, because the catchment reaches an elevation of over 1300 m, it was decided to assign an interception fraction of 0.15 in the headwaters (sub-area 1). This was increased to 0.2 (the default value for tall tussock grassland) in the upper reaches (sub-areas 2 and 3) where the tussock cover was expected to be more complete, and decreased to 0.15 to account for a mix of short tussock and introduced pasture in the middle reaches (sub-areas 4 and 5).

6.3.2. Crop coefficient.

The default values in WATYIELD for the crop coefficients were used (0.3 for tall tussock grassland, and 1 for pasture), with some adjustment for an incomplete tussock cover in sub-areas 1, and 4 and 5.

6.3.3 Total profile available water.

The soil map (New Zealand Soil Bureau 1969) shows the catchment to comprise an approximately equal mix of Kaikoura soils (upper reaches) and Hurunui soils (lower reaches). The prevailing texture of the latter is silt loam, and for the former sandy loam. Silt loam has a default value of 200 mm in WATYIELD, and sandy loam, 150 mm. Because of the likelihood of these soils becoming thinner with increasing elevation, these values have been reduced in those sub-areas making up the upper reaches of the catchment.

6.3.4 Readily available water.

This was set at 50% of the total available water.

6.3.5 Initial water contents.

The initial top-layer water content is assumed to be 25 mm in all cases, and the initial profile water content to be 10–20% lower than the total available water. The initial base flow-store was also set at 25 mm.

6.3.6 Base-flow index.

Because there was no specific information made available for estimating the base-flow index, as a first approximation the data provided by Jowett & Duncan (1990) were used. They included the nearby Opihi and Oreti rivers in their Group 3 for which a BFI of 0.47 was identified. Based on known BFIs for catchments of similar size and geological characteristics elsewhere, this value was regarded as being too low. Instead a value of 0.60 (approximately midway between Jowett & Duncan's (1990) Groups 1 and 2) was adopted.

6.3.7 Recession coefficient.

Environment Canterbury supplied the master base-flow recession for the nearby Pareora River, from which a k value of 0.98 was derived.

6.4 Summary of input parameters

Table 3 lists all the input parameters for the 10 sub-areas used in WATYIELD calculations for the existing land cover.

Table 3. Input parameters used in WATYIELD calculations for mean annual water yield and mean annual 7-day low flows for Rocky Gully based on the existing land cover (tussock, tussock and pasture, pasture, and pasture and scrub).

Sub-area	Land-cover	Rainfall wghting	Interc. fraction	Crop k	TAW mm	RAW mm	Initial WC mm
1	Tuss.	1.5	0.15	0.4	50	25	40
2	Tuss.	1.4	0.2	0.3	100	50	90
3	Tuss.	1.3	0.2	0.3	100	50	90
4	T+P	1.2	0.15	0.5	100	50	90
5	T+P	1.1	0.15	0.5	100	50	90
6	Past.	1	0	1	200	100	190
7	Past.	1	0	1	200	100	190
8	Past.	1	0	1	200	100	190
9	Past.	1	0	1	200	100	190
10	P+S	0.9	0.1	0.9	200	100	190

6.5 Output data

The modelled mean annual flow for the period 1989 to 2001 was 436 mm (314 L/s), and the measured value was 320 L/s. For the mean annual 7-day low flow the modelled value was 0.30 mm (80 L/s) and the measured was 78 L/s. The mean annual and 7-day low flows were calculated in L/s, using the conversion factor, 1 mm = 10 m^3/ha (or 1000 m^3/km^2). Note that the averages above are all based on calendar years. While this may be suitable for annual water yields, it may be better to use the water year option in WATYIELD when comparing modelled and measured 7-day low flows.

Taking the worked example a step further, WATYIELD was used to predict what the effect on water yield would be if sub-areas 6, 7, 8, and 9 (comprising 40% of the catchment) were converted to mature forest. This necessitated changing the interception factor and the crop coefficient from 0 and 1 to 0.3 and 0.7 respectively for these four areas. The mean annual flow fell 6% to 409 mm, and the mean annual 7-day low flow fell to 78 L/s (a 3% reduction). The reason why the reductions in the two types of flow are small is because the main water-producing areas (sub-areas 1, 2, 3, 4, and 5, which make up 50% of the catchment) have retained their land cover of tussock, and tussock and pasture. If those parts of the catchment with a combined tussock–pasture cover (sub-areas 4 and 5) were to be converted to improved pasture, WATYIELD predicts an even bigger reduction in annual water yield for the period (405 mm or 7%), and the same for the 7-day low flow (0.75 L/s or 7%). Output on Screens 9.2 and 9.3 can assist in assessing the relative contribution of each sub-area to annual water yield and to the 7-day low flow.

To better understand WATYIELD and how it operates, an Excel spreadsheet containing the templated data for Rocky Gully for the first 6 months of 1994, and all of 1995 for the existing land cover is appended to the user's guide. You can work through this and alter the input parameters, especially those relating to land cover, to establish the extent to which a change in canopy can affect water yields and low flows.

You can also try saving the data you generated from running WATYIELD. The model gives you two options for this: saving to a text file, or saving all data directly to the template spreadsheet. The latter option should only be used if you are working with a data series that spans less than a couple of years, because the saving process is rather slow. The faster alternative is to save only the output summaries (monthly, and annual flows and 7-day low flows) to the template spreadsheet, and the daily values to a CSV file. You can then import the daily values to the spreadsheet if required. To do this, select "Screen" in WATYIELD and click on "save to a text file". In the title box, type in the name you wish to use to identify the summary output file (no need for an extension). Click on "Save". This saves only the summary output. You are then given the option of saving all the daily data (e.g., modelled discharge, soil water etc.) to a CSV file. Again, type in the file name you have selected (it can be the same as the one you used previously), and click on "Save". Open the CSV file and import the data to the template spreadsheet. Have a look at the accompanying Excel spreadsheet for Rocky Gully. It lists the information you can save from your WATYIELD simulation. Once the summary data have been imported into the spreadsheet, you can then calculate annual averages for comparative purposes.

7. WATYIELD operation

WATYIELD operates by uploading information from the input Excel spreadsheet; processing the data; simulating the daily time series; and then saving the information to another spreadsheet or to a comma separated variable (csv) file.

7.1 Data input

On starting WATYIELD an introductory window appears (figure 7.1). Proceed with a model simulation by clicking on the NEXT button.

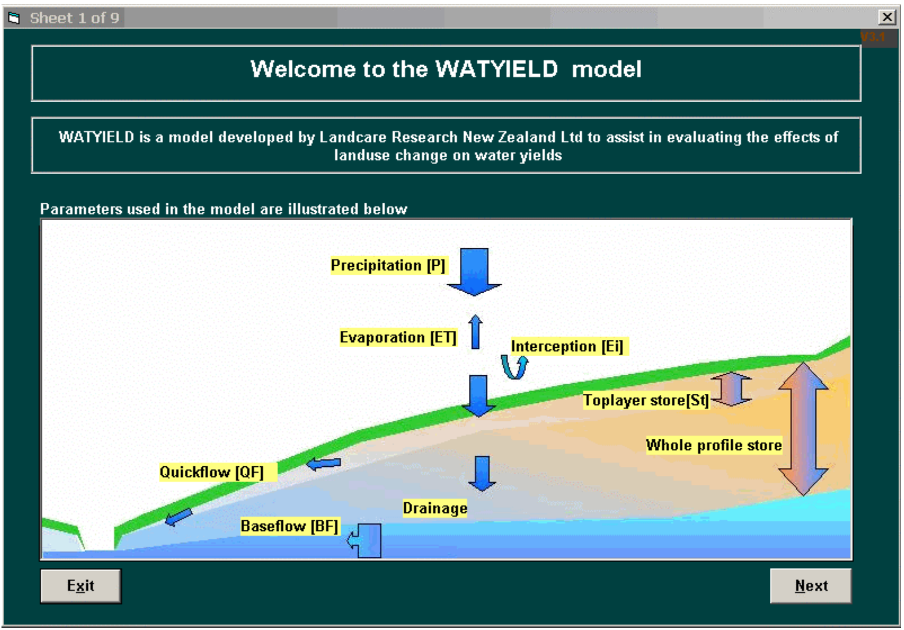

Fig. 7.1: Initial window of WATYIELD, showing the processes and parameters represented in the model.

The second window to appear sets out the input parameters required by WATYIELD. These are loaded one at a time from the input spreadsheet, by working your way down the window (figure 7.2). The yellow arrow indicates which input parameters needs to be loaded next.

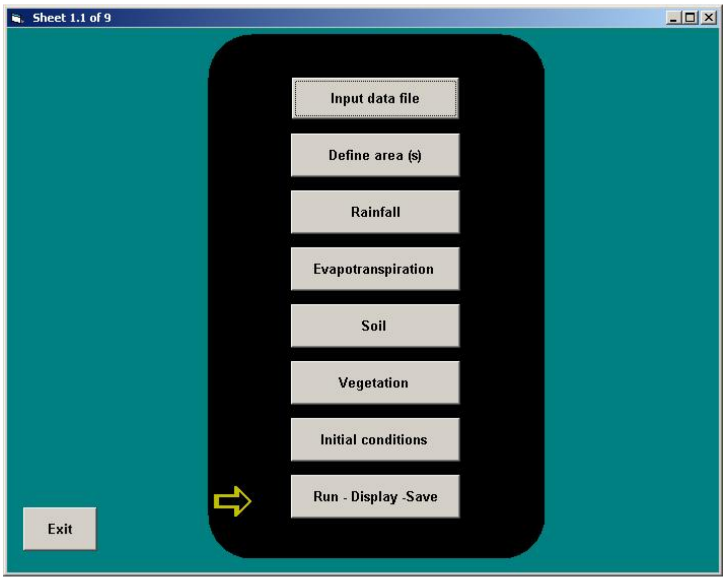

Fig. 7.2: The window indicating input parameters to be loaded.

When moving down from the initial input data window (figure 7.2) WATYIELD will by default load the input values from the specified input spreadsheet but it is also possible to change them as they are input into WATYIELD. There are three stages at which you can change input parameters in order to simulate land-use change:

- By altering the input spreadsheet
- By altering the values as they are input into WATYIELD (using the database option)
- During the final stages of model runs (see section 7.2.1)

For example the percentage area of each sub-catchment is specified in input spreadsheet but can also be changed during the data input stage (see figure 7.3). If it is changed at this stage the input values will over ride the input spreadsheet values.

At each data input window (e.g. figure 7.3) you will be asked to specify where the data are coming from (either spreadsheet or changed through the input screens) and then to "capture data". The "capture data" button loads the information into the model memory ready for simulation of daily streamflow. After pressing "capture data" you will need to press the "Next" button to proceed to the following input window (after going through the index window shown in figure 7.2).

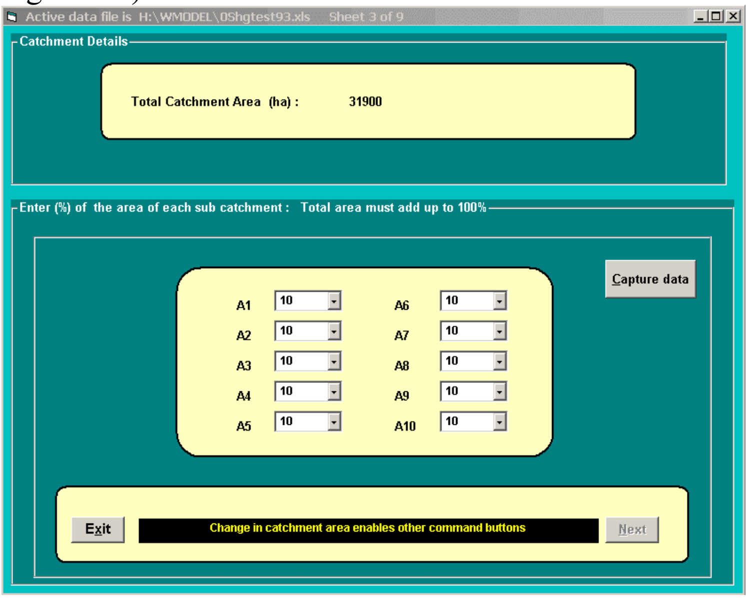

Fig. 7.3: Window for inputting the catchment and sub-catchment areas.

When inputting the daily rainfall (see figure 7.4) it is also possible to input daily streamflow values. This is an optional extra for comparison of "simulated vs observed" as a test for WATYIELD. The daily streamflow should be in column C of the input spreadsheet. N.B. WATYIELD does not require measured streamflow values to run; it is purely for testing of the model prediction. In order to load measured streamflow values it is necessary to tick the box labelled "Measured streamflow data series". This is not ticked by default.

It may take quite a long time to load a long data series (e.g. over two years of rainfall data). A progress window will show during the uploading process.

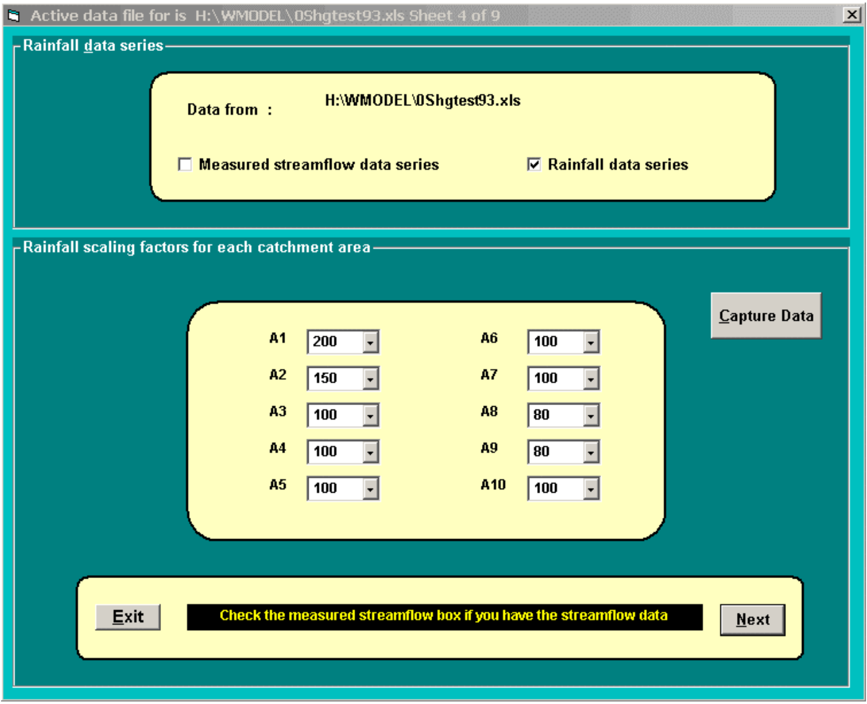

Fig. 7.4: Window for inputting daily rainfall (and streamflow as an optional extra)

When all of the data are loaded the yellow arrow will indicate "Run-display-save"; at this point you are ready to run a simulation with WATYIELD.

7.2 Running simulations

Figures 7.5 and 7.6 are the two main display windows for WATYIELD under different simulations.

At the top of the window shown in figure 7.5 is the button to "Run the model". This takes the input parameters that have been loaded in the previous steps and performs a model simulation. When this has finished you need to either:

- Show WATYIELD output in graphical fashion (using the "Show me" button)
- Show WATYIELD output in a series of tables
- Save WATYIELD output to be displayed later.

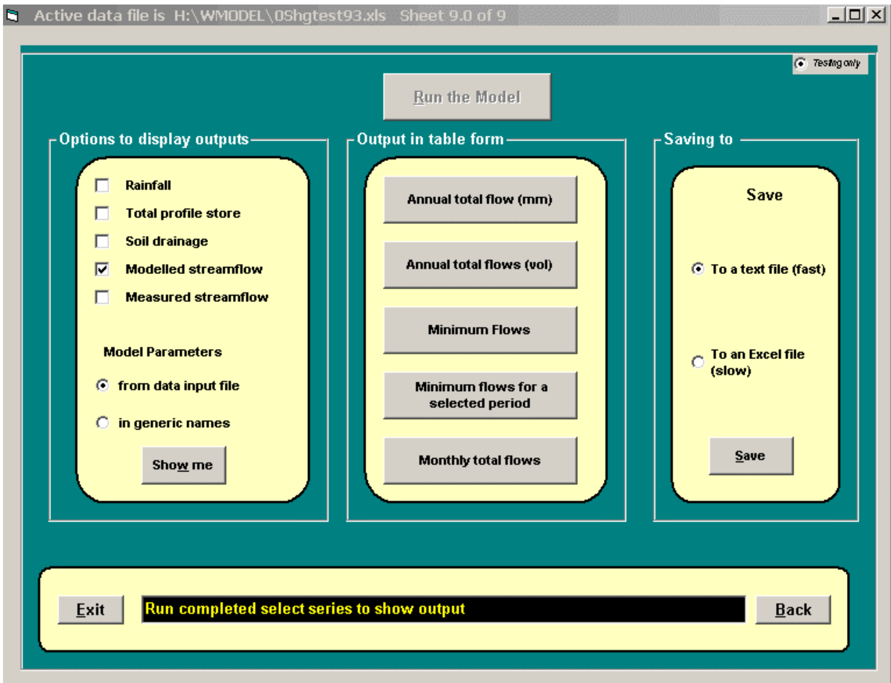

Fig. 7.5: Window to run WATYIELD (having previously uploaded input parameters).

7.2.1 Graphical output

Once WATYIELD has been run the graphical output option is available to display different outputs. The default output to display is the modelled streamflow but you may also display: rainfall; total profile store (effectively the soil storage); soil drainage; and measured streamflow. The units of display are always mm/day. It is not recommended that you display all the options at once as it clutters up the display.

Figure 7.6 shows the graphical output using the "from data input file" option. Figure 7.7 shows the graphical output using the "Use generic parameter values" option. In both of these cases the initial model simulation uses the input parameters from the data capture steps earlier. The bottom half of the display shows what these values are and allows you to change them to simulate land use change. If this is done then the "re-run" button is used and the graphical output will display the new and original simulation. For example: the interception fraction for sub-catchment A1 could be changed to 0 to simulate a land-use change to pasture for this region; or in figure 7.7 the "pasture" option could be selected for sub-catchment A1.

When multiple simulations are performed the graphical display will always show the latest simulation and the original simulation, i.e. it will lose the simulations in between. N.B. The graphical output is not designed for display (i.e. printing or publishing), it is designed for looking at results during a simulation. If you wish to have high quality display it is recommended that you save the output in a spreadsheet or csv format and use a graphics package to display the results.

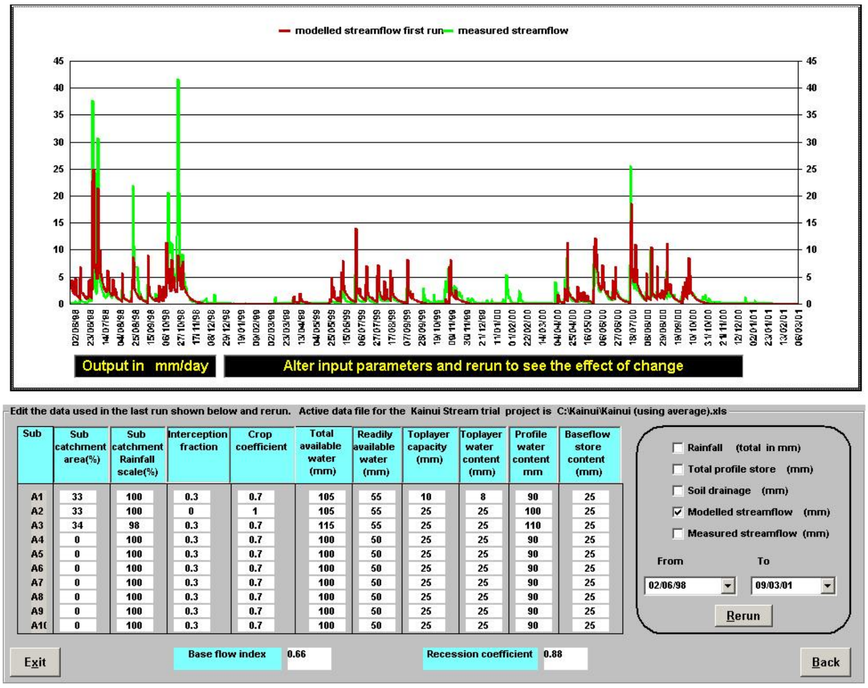

Fig. 7.6: Output window showing simulation results and input parameters that may be changed for re-simulation.

If you wish to view results for a shorter interval than the whole period used as input, then use the "From" and "To" menu items to zoom into results over a shorter period. Once you have selected the new "From – To" period you will need to rerun the model. N.B. Although this suggests WATYIELD is rerunning for the newly selected period,. This is important to realise as a short model run may be unduly influenced by initial conditions.

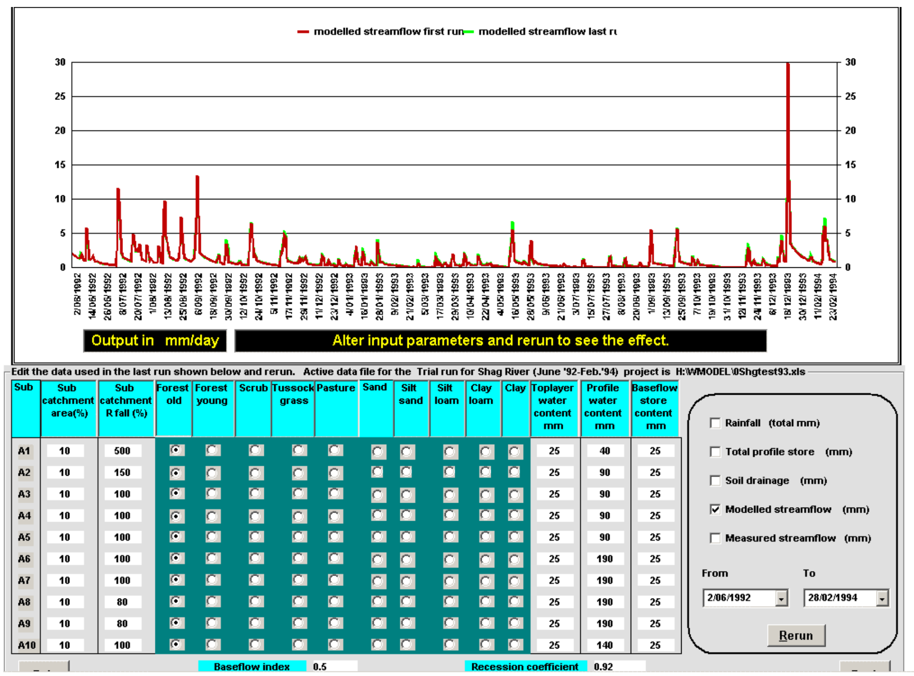

Fig. 7.7: Output window showing simulation results and changeable input parameters in a generic format.

7.2.2 Output tables

Once WATYIELD has been run the results can be displayed as tables using the options in the middle of figure 7.5. You have the option of selecting either a calendar year or a water year (July 1 to June 30). In the case of low flows it is much more sensible to select a water year. The units for each output table are shown in the top right of each table. N.B. The tables will be blank until the “Show me” option is selected (after choosing which water year is required).

7.2.3 Saving results

Results can be saved either into a formatted spreadsheet (this is a slow process, even with a fast processor) or into a comma separated variable (CSV) format file. When multiple simulations have been carried out, both of these options will save the first and last simulation. The formatted spreadsheet will also contain the tabular output described in section 7.2.2.

7.3 Common errors

Run time error 13: This is most commonly produced by gaps in the input variables (i.e. rainfall or streamflow). WATYIELD requires a continuous data set. Go back to input spreadsheet and make sure there is a data entry for every day to be simulated. This may require interpolation from nearby rain gauges.

Input spreadsheet won’t load (or edit) because it is already in use: This is a bug of the programme that we couldn’t fix. If you try to load an input spreadsheet, or edit an input spreadsheet, immediately after using it previously WATYIELD seems to lock the spreadsheet up. The simplest solution is to save it with another name.

Modelled streamflow poorly matches measured streamflow at the start of the simulation: This will be because the initial conditions do not match the actual conditions at time of simulation. The best methodology for setting initial conditions is to use wet values (i.e. soil close to saturation) and start the simulation during the winter when it might be expected that the soil store be near to full. If this doesn’t work then it may be necessary to ignore some of the early simulation results.

Modelled streamflow poorly matches measured streamflow throughout the simulation: There are essentially three reasons why this might happen:

- The input variables may be incorrect (e.g. rainfall from a “nearby” gauge may not accurately represent the actual rainfall).
- The input parameters are incorrect (e.g. soil properties are incorrect)
- WATYIELD is unable to simulate the selected catchment.

It is a matter of hydrological judgement which of these three is the most likely. It is worth noting that during testing WATYIELD worked well up to a scale of around 25-50 km^2 but it struggled to accurately reproduce hydrographs in large catchments. It is also worth noting that WATYIELD does contain constraining assumptions, such as no leakage to deep groundwater, so if this is suspected then the model may not be working well.

8. References

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