NATURAL RESOURCES SYSTEMS PROGRAMME
PROJECT REPORT[1]

DFID Project Number

> **R8088A**

Report Title

> Agricultural systems simulation II
>
> Annex B23 of the Final Technical Report of project R8088A.

Report Authors

> Salim, B.A., Magesa, M. and Tumbo, S.D

Organisation

> SWMRG, Sokoine University of Agriculture, Tanzania

Date

> 2005

NRSP Production System

> Semi Arid

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

2. Agricultural Systems Simulation II

Objectives of the module

> **After completing this module, students will be able to:**
>
> - Use computer simulation models in various applications.
> - Describe the value of computer simulation models.
> - Use computer simulation models for education and research.
> - Prepare input data files for PARCHED-THIRST model
> - Simulate and interpret the outputs from PARCHED-THIRST model

Requirements for the module

> - Knowledge of word and spreadsheet software such as Microsoft Word and Microsoft Excel
> - Computer with Microsoft Windows 98/2000/XP
> - PARCHED-THIRST software

2.1 Introduction

The development of computer simulation models is expensive so it is usually undertaken when poor performance in "real life" would lead to major problems or other factors such as time, risk and resource availability are involved. In general, simulations are used when, for example,

- The cost of alternate instructional strategies is high (expense),
- The risks involved are considered too high and demonstration of competence in a controlled, relatively risk-free environment is sought (danger/risk),
- It is impossible to study concepts in "real time" (time factors), or
- When there is lack of relevant materials (material/resources).

Model applications can be classified as: scientific (i.e. helping with understanding) and engineering models (i.e. applying science to solve a problem). These are further discussed in the following sections.

2.2 Uses of Computer Simulation Models

2.2.1 Models as Tools in Teaching

Simulations are unique instructional strategies because they are representations of reality that when used in an instructional context. They are repeatable, consistent, take less time, cost less than most other instructional strategies and are always available.

As a vehicle for the acquisition of knowledge and skills in an active exploratory learning environment, simulations allow for students interaction by entering of answers, directions or decisions and solving problems.

The need for computer-assisted learning (CAL) in developing countries cannot be overemphasized. However the use of simulation models in education and training in the developing countries is still relatively small. This is largely due to the fact developing countries do not presently have the resources to develop simulation models in education and training.

There are two approaches have been suggested for use of simulation models, i.e.

- Experimentation and observation using existing simulation models: The simulation models may be used in place of conventional field or laboratory experimentation.
- Model building: The process of defining and building a simulation model and its implementation on a computer.

The primary role of simulation models in education and training is due to the fact that they act as a substitute, or adjunct, to traditional field or laboratory experiments. There are two main applications of simulation models in education and training:

- Training to perform real experiments or tasks. The classic example of this is flight simulation.
- Replacement of some real world experiments with computer simulations. The student can 'plant' a particular crop in a chosen soil type, subject it to particular environmental influences and study its performance. The student can then simulate different 'treatments' to investigate the impact of these on plant growth and yield.

2.2.2 Models as Tools in Research

Agriculture is the main activity in many developing countries. Cropping practices in these countries is known to be sub-optimal or inappropriate. Some efforts in terms of traditional agronomic research have been made to improve some of the practices. But traditional agronomic research is expensive and most developing countries cannot afford it. New tools, such as crop and soil simulation models, with their ability to integrate the results of research

from many different disciplines and locations, offer a way of improving the efficiency and/or reducing the cost of some of this research.

Crop simulation models (such as the PT Model) were originally developed as research tools. The advantages of integrating simulation modelling approaches into a research programme include the following:

- Identification of gaps in our knowledge;
- Generation and testing of hypotheses, and an aid to the design of experiments;
- Determination of the most influential parameters of a system (sensitivity analysis);
- Provision of a medium for better communication between researchers in different disciplines;
- Bringing researchers, experimenters and producers together to solve common problems.

2.2.3   Models as Decision-Support Tools

Agricultural enterprises are generally highly complex systems since farmers' activities are strongly affected by the external environment as well as by their own goals and culture. In managing these activities they are faced by an enormous range of decisions throughout the year. In agriculture, decision support systems (DSSs) are designed to help farmers take decisions by evaluating outcomes of alternative actions in the light of available information.

The term DSS covers a wide range of systems, which vary greatly in their structure and complexity. In their simplest form, a decision support tool can be a pest management threshold calculated using empirical relations and field data on a calculator. In a sophisticated form they can be interactive computer systems that utilize simulation models, databases and decision algorithms in an integrative manner. DSSs have also been defined as computer systems that assist the user in complex problem solving or decision making. DSSs typically have quantitative output and place emphasis on the end-user for final problem solving and decision making. Expert systems (ES) are another computer tool for decision making, using qualitative rather than quantitative reasoning.

2.3   The PARCHED-THIRST Model

2.3.1   Description

PARCHED-THIRST stands for **P**redicting **A**rable **R**esource **C**apture in **H**ostile **E**nvironments **D**uring the **H**arvesting of **I**ncident **R**ainfall in the **S**emi-arid **T**ropics. It is a user-friendly, process-based model which combines the simulation of hydrology with growth and yield of a crop on any number of distinct or indistinct Runoff Producing Areas (RPAs) and Runoff Receiving Areas (RRAs). It is a distributed model which simulates the rainfall-runoff process, soil moisture movement and the growth of sorghum, rice, maize and millet in response to daily climate data. The landscape is divided into units which are assumed to represent homogeneous portions of the landscape. The only transfer of mass between profiles is surface runoff. The PT model has the following components (Fig.1);

- A user-friendly interface which allows users to input, output and analyse data, set options and run the model ;
- Data pre-processing to minimise data input requirements;
- Soil moisture simulation;
- A runoff prediction component and;
- Crop growth simulation.
- Data pre-processors

The PT model has been designed to minimize input data requirements. Because it is physically-based, it uses parameters which are measurable and (with the exception of crop cultivars) do not require long series of historical data for calibration. However, where data are difficult to obtain, three data pre-processors have been included. These are the climate generator, the rainfall disaggregator and pedotransfer functions (PTFs).

Climate generator
To drive the PT model, daily climate data are required. Although there are long records for a number of sites in sub-Saharan Africa, in many areas climate data have only been collected for a few years or contain large numbers of missing data. This may be due to instruments breaking down, running out of consumables or even destruction of paper records by vermin (Kihupi, 1990). The PT model therefore includes a climate generator, which can:
- Extract the statistical properties of short-term climatic data to generate longer series of data with the same statistical properties;
- 'Fill in' missing data using the statistical properties of other data at the same site or from other climatically similar sites.

Rainfall disaggregator
The runoff component requires rainfall intensity data at intervals of less than 1 day – typically 5 minutes. Where rainfall intensity data are available, they can be input to the model directly. More commonly, intensity data are either not available or are summarised into the maximum 30-minute intensity (I30), rainfall duration and total rainfall amount. The PT model provides a rainfall disaggregator which generates 5 minute rainfall intensity data from an assumed rainfall intensity distribution) similar to that proposed by Oron et al (1989).

Pedotransfer functions
The process-based soil moisture and runoff components, in common with most other cropping systems models, require a number of time-consuming and difficult-to-measure soil hydraulic parameters including the $K(\theta)$ and $h(\theta)$ relationships for each soil type in each layer of each area simulated. Where these are not already available, the PT model provides a choice of the Rawls and Brakensiek (1989), Vereecken et al. (1989) or Campbell (1985) pedotransfer function components. These can be used to estimate all the necessary soil hydraulic properties from data such as soil texture and bulk density which are often available from standard soil surveys.
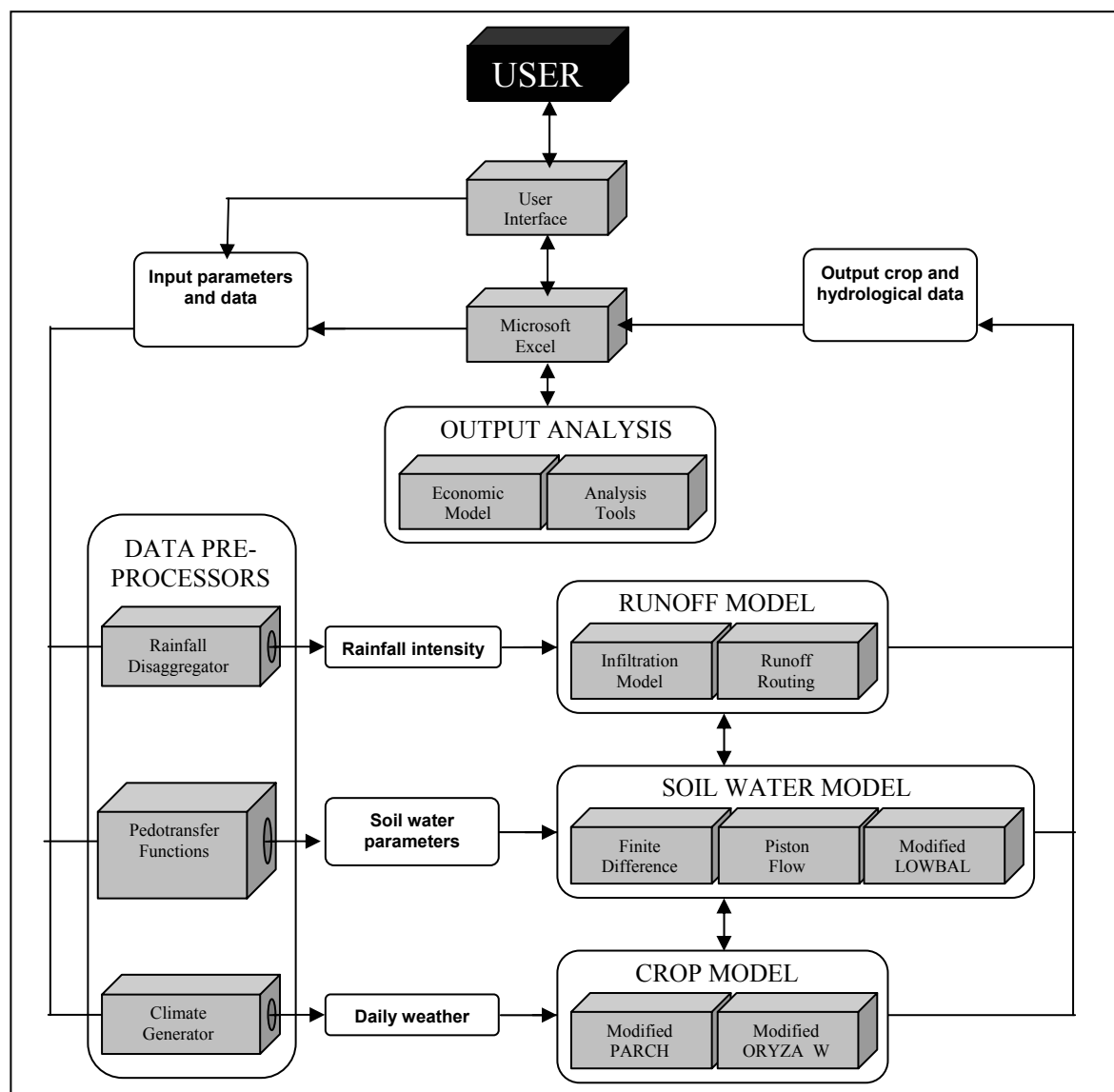
Figure 2.1: PT model components.

Soil moisture models

Accurate soil moisture accounting is vital for both runoff and crop growth simulation. The PT model provides a choice of three one-dimensional soil moisture simulation components, namely, the One-dimensional finite-difference, Piston flow, and Lowbal.

Runoff model

Runoff and infiltration on both the RPA and RRA are calculated using the Green and Ampt (1911) infiltration equation. Runoff amount is infiltration excess which is modified by depression storage and surface sealing. Runoff routing is simple, based upon the SCS unit hydrograph (USDA, 1972).

Crop models

The PT model incorporates two crop models – PARCH (Bradley and Crout, 1994) for the simulation of sorghum, millet and maize and ORYZA_W (Wopereis et al., 1996) for the simulation of rainfed, lowland rice.

2.3.2 Modelling approach

The PT Model has been developed in Microsoft Visual Basic v5.0 using an approach which has been:

- User oriented and iterative – both the usability and functionality of the model have been iteratively tailored to user needs.
- Modular/component-based – PT Model comprises a number of components which, combined, produce the required functionality. This modular approach has a number of advantages:
  - Individual components can be easily updated with only minimal alterations to the code extending the lifespan of the software
  - New components (e.g. other crop models) can be slotted in according to need.
- Object oriented – The user interface and linkages between the models is all object oriented. This increases the robustness of the model and eases debugging, maintenance and further development.

Each simulation scenario is known as a system. A system has a number of properties which include start date, sowing dates, etc. It is also made up of a number of profiles. These are one dimensional 'blocks' of soil/plant/atmosphere which are assumed to represent an area with homogeneous soils, topography, vegetation, etc. Each profile is composed of crop, soil and weed objects which define the behaviour of the profile. A soil object is itself composed of a number of soil layer objects each with defined physical properties. As well as being conceptually easy for users to understand, object-orientation.

2.3.3 Application of the PT Model

As for other computer simulation models, the PT model can be used as a planning, research and teaching tool.

For example, the PT Model can be applied in various areas such as crop management, soil management, land and water management, climatology and planning and designing of rainwater harvesting systems.

Crop Management

The PT Model can be used in simulating various agronomical aspects, which can be used in

- Assessment of the effect of planting date on crop yield
- Assessment of the effect of planting density on crop yield
- Assessment of the effect of weeding on crop yield

Soil Management

The PT Model can be used in simulating the effect of soil variability on crop yield and moisture status of the soil.

- Assessment of the effect of soil type on surface runoff and crop yield.
- Assessment of the effect of soil management practice on surface runoff and crop yield

Land and Water Management

The model can estimate the amount of runoff water that can be collected from catchments and hence: -

- Used as a basis for soil and water conservation strategies.
- Used as a basis for selection of land use option.
- Used to estimate strategic location for water storage structures like Charco dams.

The model can estimate long-term rainfall, evaporation, and drainage data, which are important information in designing size and location of water storage structures like Charco dams.

Climatology

In many sites in sub Saharan Africa, there is no consistency of the climatic data records. Data may exist for short periods and contains large number of missing data. The PT model has an inbuilt climate generator capable of generating missing data within the existing data series of the same site using the statistical properties of the other data at the same site or from other climatically similar sites.

- The model can be used to assess the effect of weather variability on crop yield.
- The model can be used in filling gaps of missing data and generating long term series of climatic data.

Planning and Design of RWH Systems

A RWH system is a system in which runoff is collected and delivered to a crop without storage other than the soil profile within the cropped area. Different RWH systems can be recognised across a range of spatial scales. A distinction can be made between:

- Micro-catchment or within-field methods, which involve transfer of water over a short distance (0-50m) usually by sheet flow;
- Macro-catchment or external catchment methods, which involve collection of water from a catchment area at a considerable distance from the receiving area and its transfer by channel flow.

The PT model is designed to assist agricultural planners and advisers whose aim is to improve cropping systems in dry-land environments, where the major factor limiting crop performance is the imbalance between water supply and demand (Gowing et al, 2001). In seeking improvements, they face difficulties in finding answers to questions such as:

- For a given field, which of the many RWH techniques is going to best match the livelihood strategy of the farmer?
- What is the optimum configuration of RWH technique?
- Given a successful technique in one area, how to identify other areas where the technique might also be successful?

The model is therefore a tool that helps to identify best-bet RWH system options at any particular area.

2.3.4   Input Data

The PT model is driven by daily rainfall and other agrometeorological data. In order to provide for simulation of long-term performance, the PARCHED-THIRST Climate Generator can be used to extend the available historical data. Daily rainfall values are then converted by the rainfall disaggregator into intensity data which are required by the infiltration model. The rainfall-runoff process is simulated as an infiltration excess with infiltration being determined by the Green-Ampt infiltration calculator. Because of the cost and difficulty of measuring soil hydraulic properties in the field, pedotransfer functions are included to allow for their prediction from readily-available soils data. The modified PARCH model adds soil-water redistribution and crop growth simulation routines which complete the system. RWH is simulated by having two profiles running simultaneously with runoff from the upper catchment and becoming an input for the lower of the two. Except for climate and soil texture, each profile can have different characteristics.

The crop growth model (PARCH), a sub-model of the PT model, uses a daily time step for the simulation of crop growth. On each day, the resources of light, water and nutrients are

`intercepted' or `extracted' and converted into assimilated dry matter. Depending upon the availability of these resources and the crop's ability to sequester them, its growth is considered as light, water, or nutrient `limited'. An index of crop stress is calculated in terms of the ratio of light to water or nutrient limited growth. This stress index is then used to control a number of the crop's stress responses, such as leaf rolling or increased partitioning to roots. Partitioning of resources between crop organs is calculated by empirically derived fractions which are adjusted according to growth stage and level of stress. Resources partitioned to the leaf canopy and root system add to leaf area and root length thereby feeding back into subsequent calculations for light interception and water and nutrient uptake.

2.3.5   Output Data

- The PT model has the ability to simulate the following:
- Crop growth
- Rainfall
- Crop yield
- Runoff
- Evaporation
- Evapotranspiration
- Drainage

2.4   Running the Program

2.4.1   Tutorial No. 1: Creating a RWH System

Background

A complete RWH system must have both a catchment area and a cropped area. In PTv2.3, these areas are represented by profiles. A profile is assumed to represent a homogeneous area of the landscape. A profile has properties which define the soil characteristics, the soil surface, the crop to be grown and any weeds. Each profile is joined to another with a link which specifies the direction of movement of any runoff. Every profile must be linked to at least one other, and at least one profile must be linked to the sink, which represents an undefined destination for runoff lost from the RWH system. Runoff from one profile can only be directed to one other profile, but a profile may receive runoff from any number of profiles.

In PTv2.3, a simulation scenario is called a system. A system, which can be thought of as a landscape, is a collection of profiles (each of which has its own properties) with information on the geographical location (including weather data to be used), a simulation start dates and crop planting dates. The system can have as many profiles as desired, but the current setting of the model allows only up to 20 profiles.

In this tutorial we will create a system with two profiles where profile 2 will be our runoff producing (catchment) area and profile 1 will be our runoff receiving (cropped) area. Profile 2 will be linked to profile 1, which means that runoff collected from profile 2 will flow towards profile 1, which will then be connected to a sink.

Procedure

To start the program, double-click on the PTv2.3 model icon or from the Start task bar go to Programs and from the program list click PTv2.3. The PTv2.3 main window and Welcome screen will appear. On the Welcome screen click on the icon Experienced Users button to be taken straight to the main system window of PTv2.3.

On the main window pane select System menu and click on New. A warning message will appear which will ask you if you want to create a new system – any changes to the current system will be lost, and will ask you to Continue, select YES to continue.

A new system will appear which has only one profile connected to a sink. We need to have two profiles. Therefore, click on right mouse button so that a pop-up menu will appear and select new profile. Alternatively, click on the profile menu in the Main Window and select New. This will create a new profile, which is numbered 2, that means profile 2. Click on the profile 2 while holding down the left mouse button and you will be able to drag profile 2 to any position on the screen. Move it to the right of profile 1 and release the mouse button.
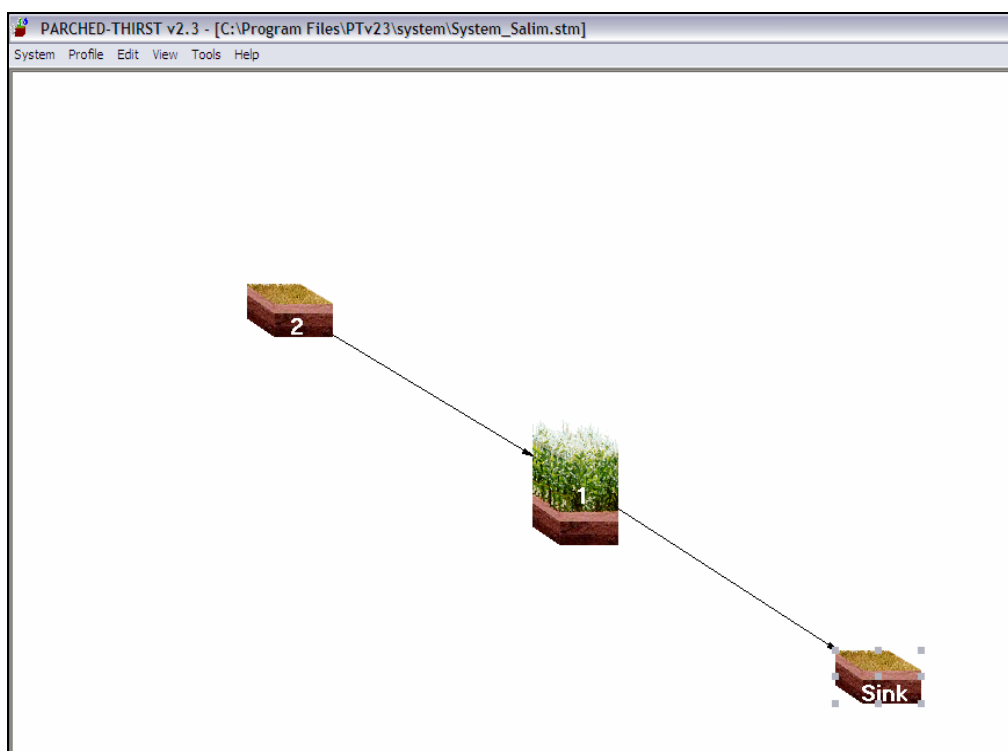

Figure 2.2: A simple RWH system showing runoff producing and receiving areas.

- The next step is to link the profiles, note that profile 1 is already linked to the sink; therefore we need to link profile two to profile one. Linkage between profiles can be achieved by a click and drag operation from the centre of source profile to the centre of receiving profile. Dragging should be done while holding down the left mouse button. Therefore, click on profile 2 and drag the link from the centre of profile 2 to the centre of profile 1. You now have a complete RWH system with two profiles where profile 2 is linked to profile 1, as shown in Figure 2.2.
- You now need to specify the properties of each profile in the system. To do this, right click on profile 2 and the pop-up menu will appear, and then select Properties of Profile 2. A window will appear (as in Figure 2.3) where you can set crop, weeds, soil properties and soil surface. For this exercise set properties as follows:
  Crop   (select "No Crop"),
  Weed   (leave "Allow Weeds" box empty)

Soil properties (leave at current settings)
Soil surface   (set area as 2ha and slope as 8%; Otherwise leave at current setting)
▪ Then set properties for profile 1 (Figure 2.4) following the same procedure as follows:
Crop   (select maize with 44,000 plants density)
Weed   (leave "Allow Weeds" box empty)
Soil Properties (leave at current settings)
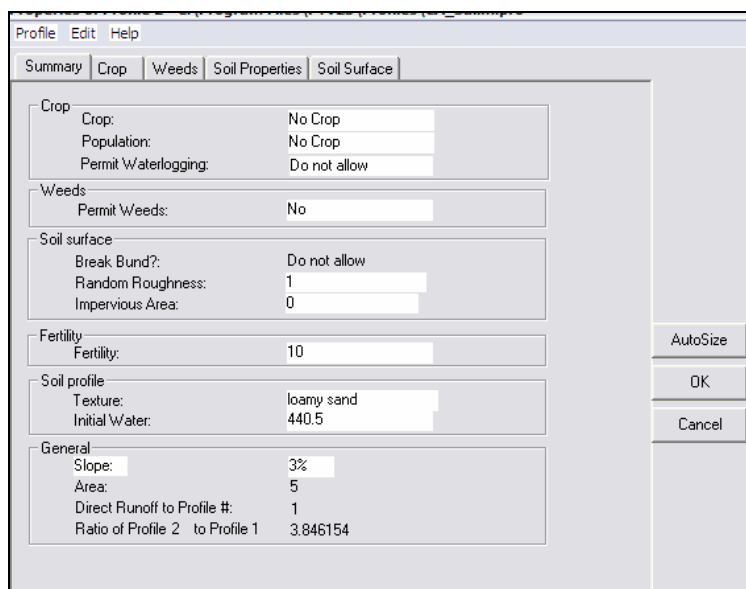Soil Surface   (tick "Area is bunded" and set height of 20 cm; Set area as 1ha and slope as 3%)

Figure 2.3: Profile 2 properties window
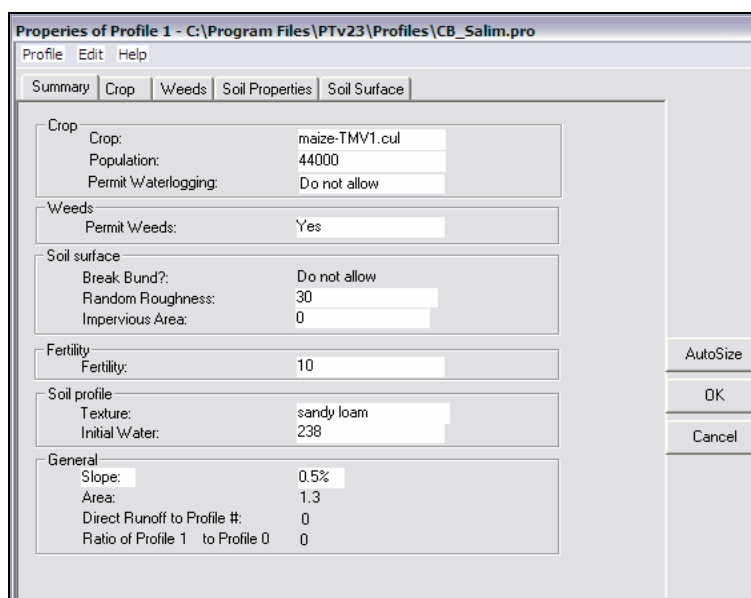
Figure 2.4 Profile 1 properties window

▪ After setting the profile properties, you have to set the system properties. From the System menu click Properties and the System Properties window will appear as in Figure 2.5.
▪ Set the following properties:

- Timing (Number of years you want to simulate and your start date for seasons) Number of Years (5 Years), Start date Season 1: 1 Feb 1980, and Second Season 1 October 1980.

To specify the number of years to simulate and the season start and end dates, do the following:
- Click the Timing tab. Figure 2.5 appears
- In the Number of years frame specify 11 (i.e. 1980 to 1990).
- In the Number of seasons frame click the 2 per annum radio button.
- In the Season start date specify the following settings in Table 2.1.

Table 2:1. Seasons start dates

	Day	Month	Year
Season 1	1	March	1980
Season 2	25	October	1980
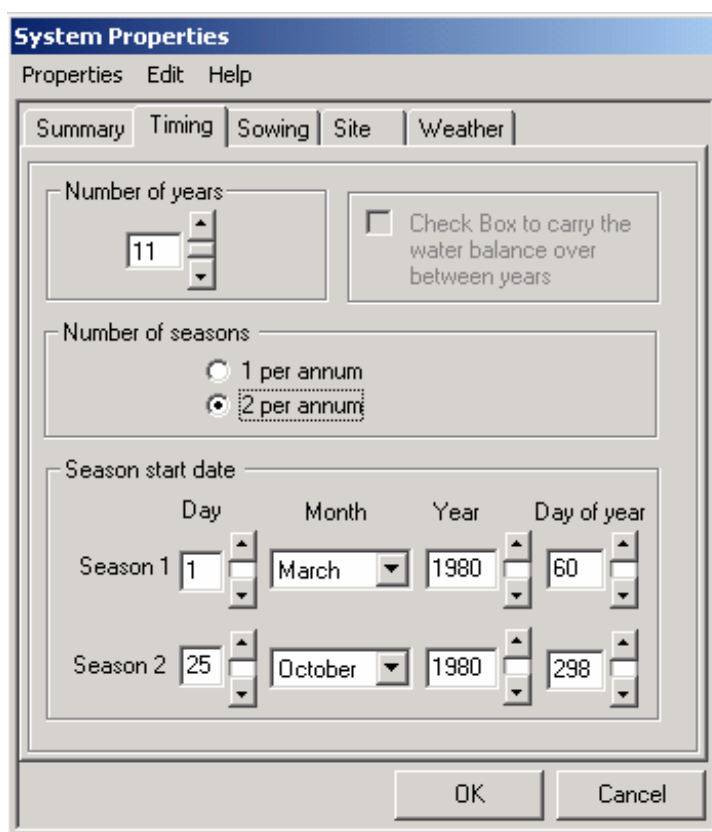
Figure 2.5: Specifying number of years, seasons and the seasons start dates.

Sowing (Select sowing criteria, this can be defined or predicted) Check predicted button to select predicted criteria where the model will sow after meeting sowing criteria. To specify the sowing date, do the following:

Click the Sowing tab. Figure 2.6 appears.
Click the Defined radio button
Use the settings in Table 2.2 in the Defined Sowing Decision frame

Table 2:2. Defining sowing dates

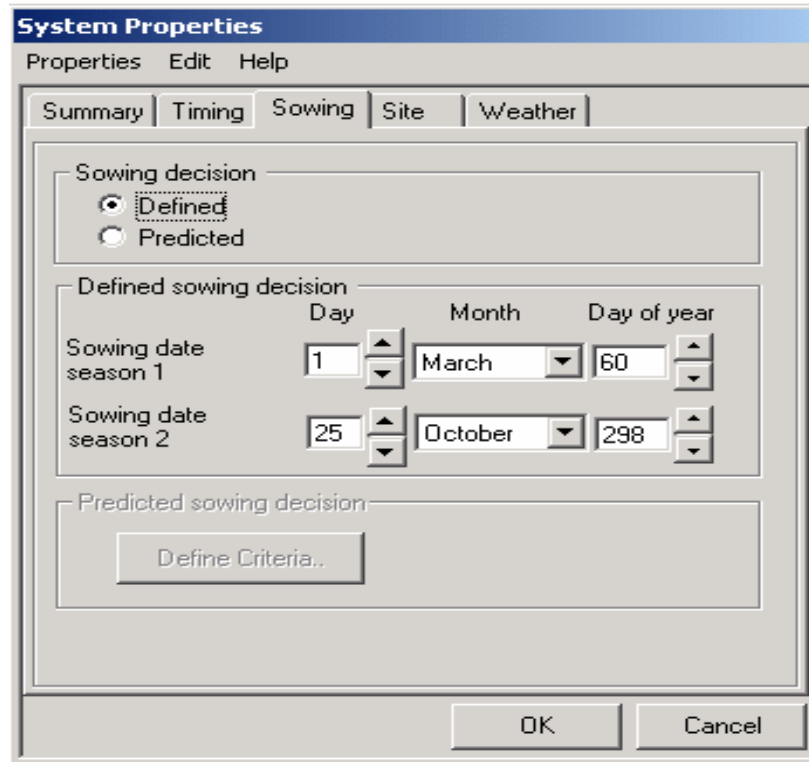| Sowing date	Day	Month
Season 1	1	March
Season 2	25	October

Figure 2.6: Defining sowing dates for seasons 1 and 2.

Site Characteristics (Specify site location and latitude): Location is Same and Latitude is -4 Degrees (-/+ means South/North of Equator). To specify the site location, do the following:

- Click the Site tab. Figure 2.7 appears
- Make sure the location button is clicked and the name Same appears in the box after the word location.
- If Same does not appear click the User Defined Location and type Same.
- In the Latitude scroll box select -4
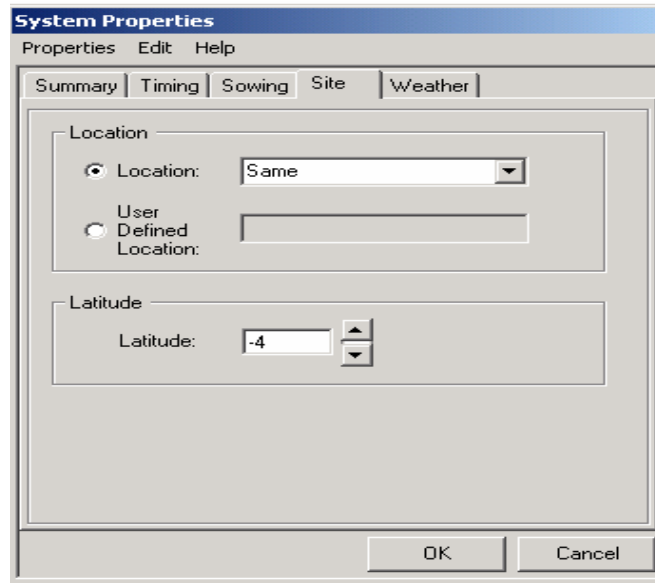
Figure 2.7: Specifying the site location

Weather (specify the weather input data location and type of the data). Location of the data is at C:\….\Weather\Generated*.Wea. Click on Same80.Wea. The model will use the data from 1980 for Same Station to run the simulation. Type of data select Standard (i.e. CSV files). To specify weather file location, do the following:

- Click the Specify Location button
- The Location message box appears. Click OK. Figure 2.8 appears.
- Make sure the Generated folder appears at the Look in box.
- Select the first file to be used in the simulation. In this case SAMEW80. The name samew80 appears at the File name box.
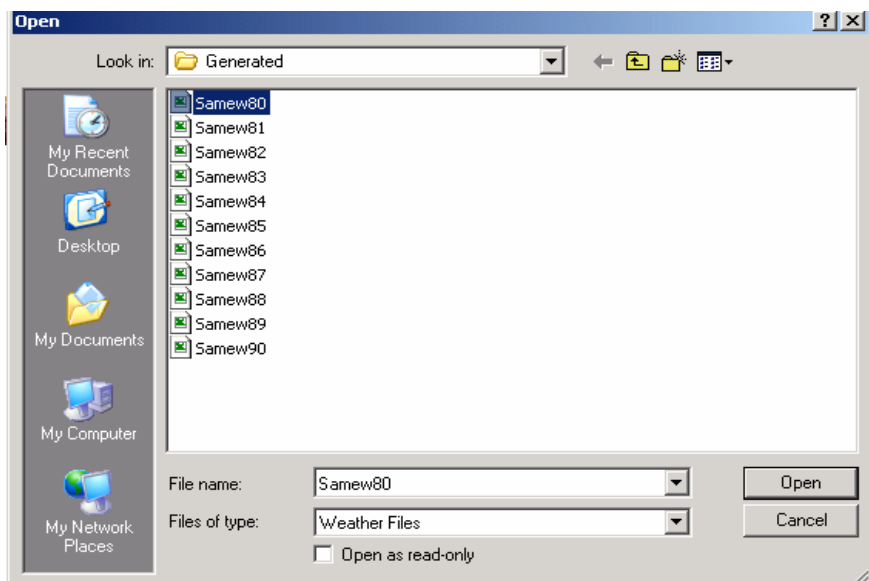- Click Open button.

Figure 2.8. Specifying weather file location

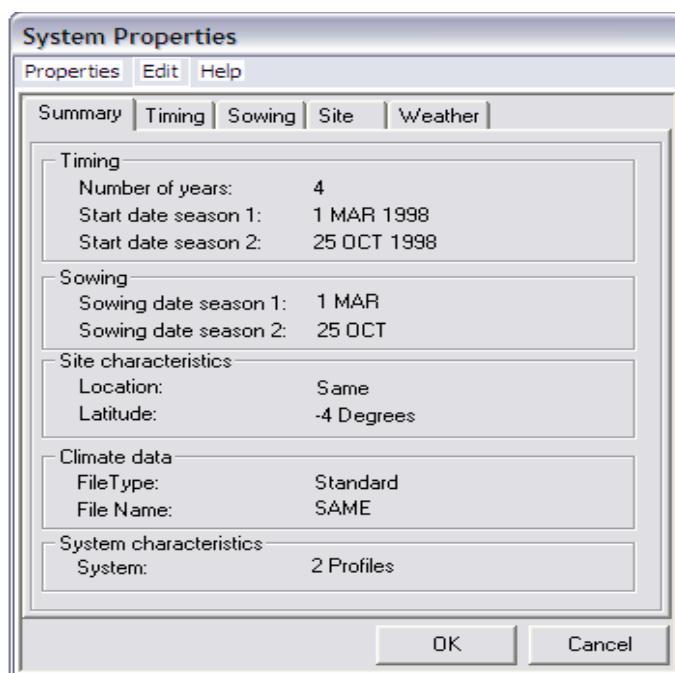The summary tab gives the settings of the System Properties settings. See Figure 2.9 below.

Figure 2.9: Summary of System Properties Settings

Systems can be saved and then opened again later using the System menu. From the system menu click save as.., and enter SAME.stm. By default, a system is saved with a ".stm" extension in the "\PTv2\systems\" directory. When a system is saved, all the profiles which make up the system are also saved at \...\PTv2\Profiles\.*.pro. So you will be asked to save the profile, give the name to the profile, as you prompted (give a name which you will remember). Note that the system file does not contain the properties of each profile, rather it contains a pointer to the location of the profile file. Thus, if a profile file is changed, so too will any system which uses that profile file.

2.5   Running a rainwater harvesting simulation

You can now run the simulation of this system by a click on the Run button in the System menu. The first thing you will be asked is where to save your simulation results. Give the file name, which you will remember and have a look on the path where your output is going to be saved, then Click OK. You will be asked whether you want to see Simulation Runtime Graphics. Click Yes and select the speed of simulation as Medium. Then Click OK. The simulation run time graphics shown in Figure 2.10 will appear.
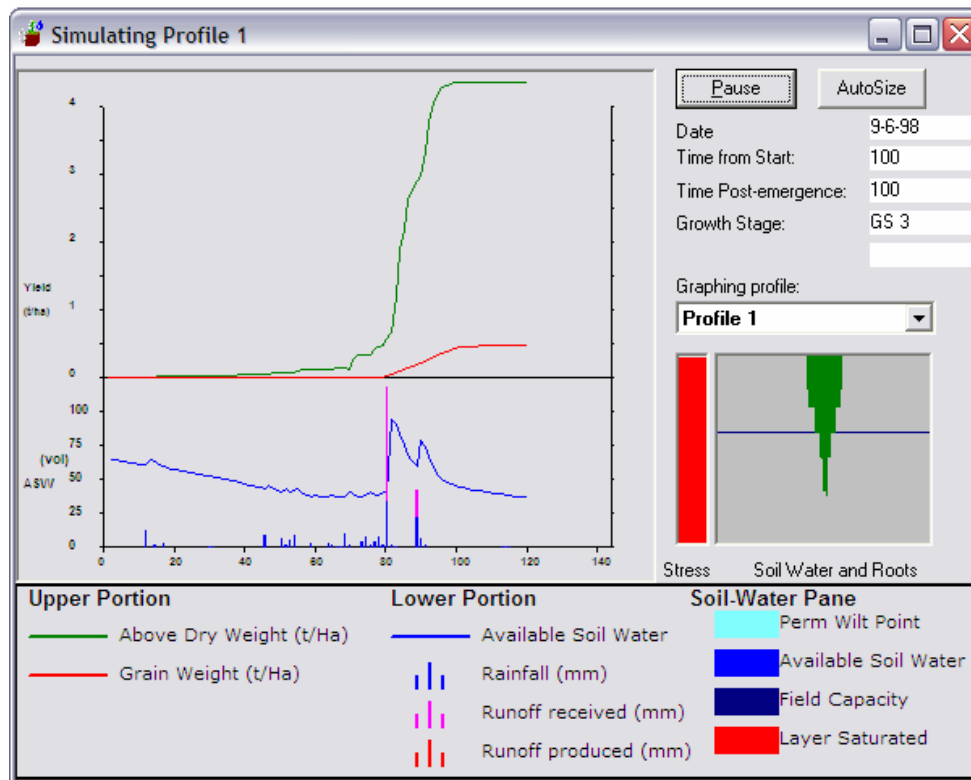
Figure 2.10: Simulation Run-time Graphics Window

You will be told that you have simulated results for the number of years you have specified. The summary simulation of the output is as shown in Figure 2.11. This can be viewed through Tools menu.
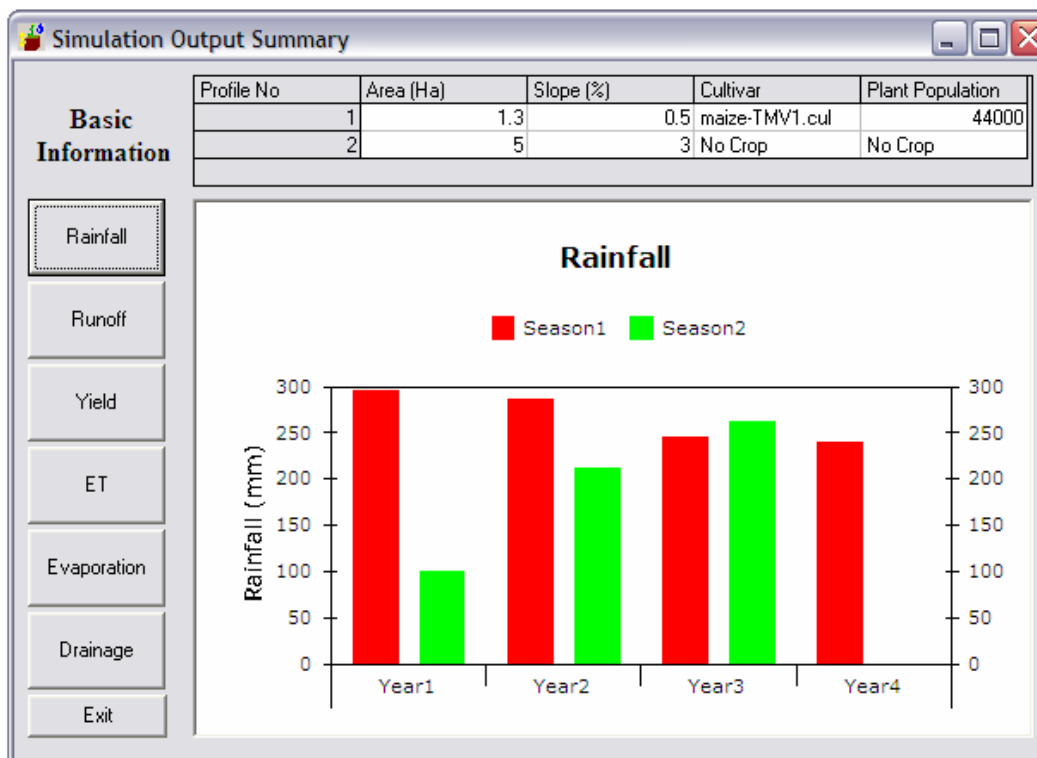

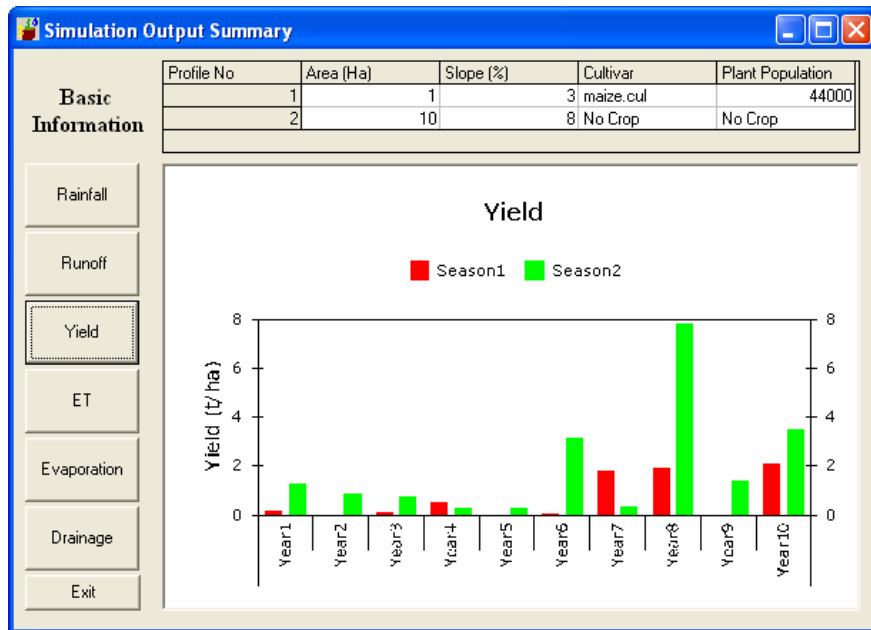Figure 2.11: Example of Graphical Output from Simulation - Rainfall

Figure 2.12: Example of Graphical Output from Simulation - Yield

2.5.1 Plotting Data, and Interpretation

Working with output file
- To open output files do the following:
- Open the Program files folder in your computer
- Open the PTv2.3 folder in the Program files folder
- Open the Output folder in the PTv2.3 folder (Figure 2.13)
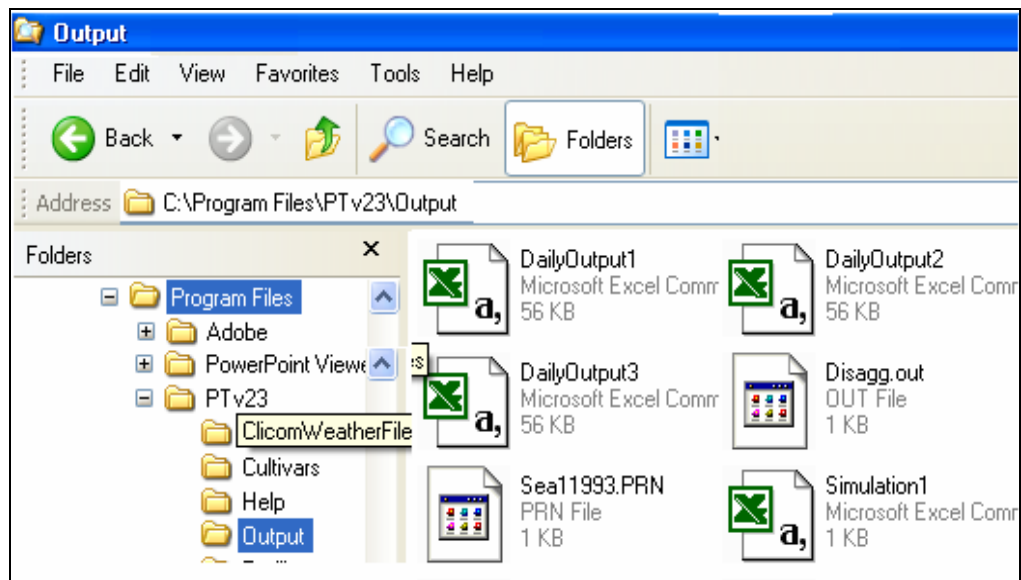- In the right pane open the output files
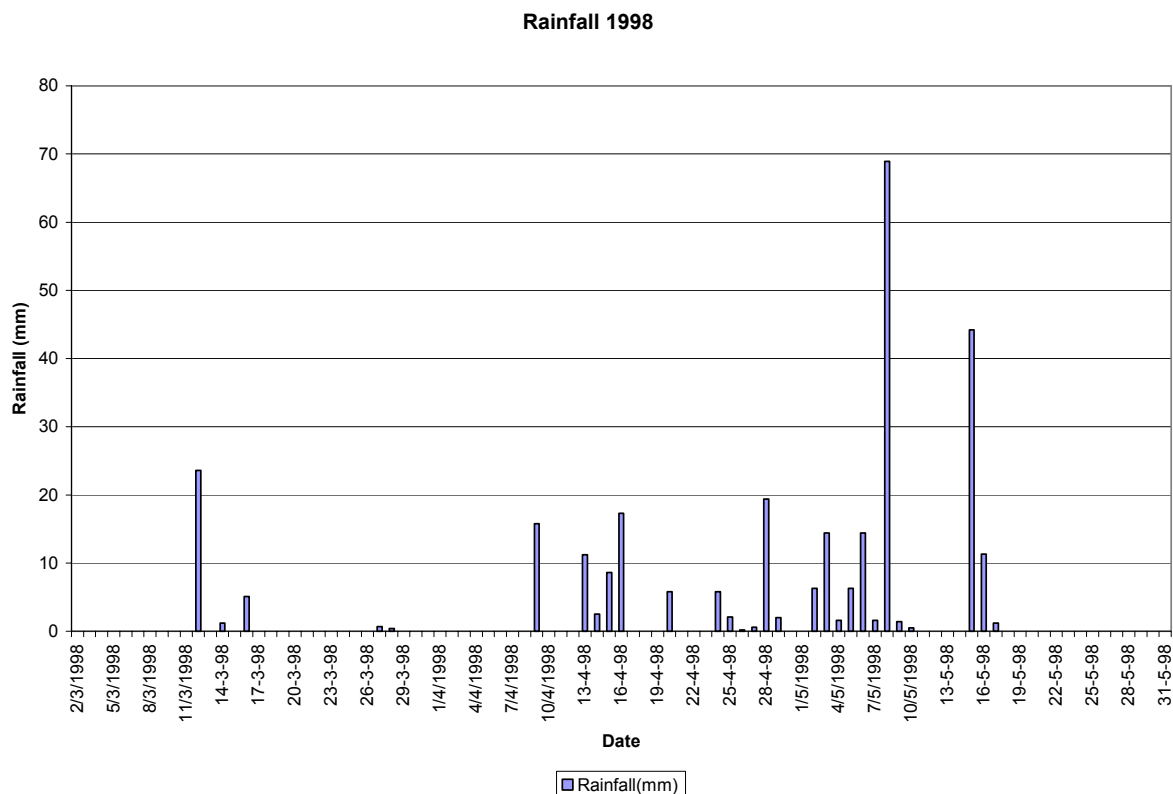

Figure 2.13: Opening Output File

Rainfall 1998

Figure 2.14: Rainfall Distribution

2.5.2   Exercises

You will work with data for one season. The season period will be specified during the lecture.

Exercise 1: Exploring the output data files
Using the DailyOutput file:
  ▪ Study the output files and try to interpret the data
  ▪ What information do you get from the data?
  ▪ Observe the date (column D) and the corresponding rainfall (column AN) for the specified season
  ▪ Open a new workbook and save it with the name of your choice.
  ▪ From the DailyOutput file copy the date and their corresponding rainfall data and paste then in the file you have just created.
  ▪ Save your file.

Exercise 2: Cumulative frequency for daily rainfall data
Using the column next to the rainfall column, calculate the cumulative frequency for the rainfall data.

Exercise 3: Plotting graphs
Plot the following graphs
  ▪ Seasonal rainfall
  ▪ Cumulative rainfall
  ▪ Total water

- Total dry weight

Exercise 4: Interpretation of information
- Study the trend of seasonal rainfall
- Study the trend of total soil water
- Study the trend of dry weight
- Study cumulative rainfall graph
- Comment on the trend of soil water, rainfall and dry weight.