4. IRRIGATION GAMES

4.1 Background information

Games have been a useful training tool for a long time. They normally are an abstraction from reality, in which the player (designer, operator, student) can highlight specific points to be learned. Participants in such an educational game normally are requested to play a certain role, and are thereby confronted with specific tasks, for which they need knowledge, skills, etc., the development of which is the educational objective of the game. Such knowledge may be used to test or apply some theory which has been studied, and the skills may include presentation, confidence building, negotiating, team-work, stress handling, crisis management, et cetera.

The latter list of topics suggests that games have been especially used in the area of management. Indeed, after earlier military applications, there has been a strong current of upcoming management games in the late 1970's and in the 1980's, especially in the business community, where handling people rather than handling facts and hardware was something that could and needed to be taught in so many management courses. There would be many more up-to-date reference books, but possible starters may be Graham & Cray (1969), as mentioned by Webster (1989) and Elgood (1987), referred to by Burton (1989).

In the early 1980’s, it appeared that this wave of management courses and the inherent games also caused some motion in the training of irrigation managers and other professionals involved in irrigation. Business management training methods could also be applicable in agriculture, and more specifically in irrigation, seemed to be the feeling. Moreover, donor organisations were willing to finance such endeavours (e.g. Ford Foundation) and quite a number of development institutions were, more than before, involved in exporting irrigation training abroad (e.g. Silsoe College, at the Mananga Agricultural Management Centre in Swaziland).

In addition, there was some hope that the upcoming personal computers could assist in assessing the consequences (in terms of time, money, people, water, crops, animals and what-not) of endless near-reality combinations of inputs and decisions. More recently, Webster (1989) stipulated that the new Interactive Video disc technology increased the possibilities enormously and similar expectations are expressed by Ward (1992) regarding multimedia as a learning strategy. Such developments stress that visual elements are very important in management simulations.

The term simulation, which used to be restricted to acting "real" situations by a group of people with the advent of the computer, became also used for mathematical models describing relations between variables using algorithms. When one began to use terms like simulation games, things became slightly confusing.
Therefore, Smith (1986) tried to distinguish between simulations and games. Simulations attempt to imitate reality as accurately as possible, usually with a technical or procedural core specified in detail, whereas games can be more abstract. Moreover, games often involve role-playing and normally have an internal (play the role properly) as well as one or more external objectives (such as: team building, promoting discussion).

However, one is not always that strict, as the title of a report by Chapman (1981) illustrates: "Gaming simulations of irrigation systems ..". The writer of the Green Revolution Game (see e.g. Chapman, 1989) states in this report that many games are simulations and vice versa. He mentions that it is e.g. possible to distinguish models on the basis of their degree of realism, whether single players or multiple players are involved, and whether the games are structured or structure-creating.

In the same paper, Chapman suggests that four different irrigation simulations may be developed, one for realistic main system simulation (REMASS), one called a below the outlet game (BOG), a third one linking the two (named BOGMASS) and a fourth covering the design, implementation and operation (DIOP). As far as we are aware these have not been developed as foreseen, but it illustrates a growing confidence in the potential of (computer-assisted) simulations and games for irrigation management training at the time.

One could consider a Smith (1986) article in the Irrigation Management Network Newsletter as a (British) summary of the developments since Chapman’s first ideas, although Parrish (1982) and others had also been developing irrigation simulation games at Utah State University in Logan, USA. In addition, Cornell University, USA, was involved as well in developing a computer-based Irrigation Rehabilitation Game (Steenhuis et al., 1989).

The games listed below are mainly those mentioned in Smith (1986), with a few additions. However, as far as we have been able to trace, there has been little development in this area since that time. A possible reason is that the market for such packages is relatively small and that the development costs are relatively high. Whatever the reason, the following sub-chapters describe what we have been able to obtain so far.

### 4.2 Non-computer based games

Although this report looks at computer programs, we make a brief exception to indicate what four non-computer-based irrigation games are about, i.e.

- The River Wadu role-playing exercise;
- The Juba sugar estate game;
- Simulation of irrigation management below outlet (SIMBOL);
- The Irrigation Management Game.
* The RIVER WADU role-playing game *

The game was originally described by Carruthers (1981) and a ten-year experience is found in Carruthers & Smith (1989). It is an irrigation planning game, used in the training of post-graduate agricultural economists.

It is designed to give students experience with a wide range of the practical problems arising in irrigation project planning. The game is normally played with 4-5 teams of students and takes about 20 hours to complete. The input is a mix of information from Thailand, Tanzania and fabrications. The main emphasis is on agricultural economics and other aspects are only treated in a simple manner. Carruthers (1981) mentions that the original version had connections with World Bank training materials (from the Economic Development Institute (EDI, 1979) and with a Farm Management Game developed at Wye College (Youngman, 1974).

In the more recent version (Carruthers & Smith, 1989), the students adopt the role of being part of a project identification mission from an external financing agency. They receive information, conduct interviews, set criteria, collate and use data, and appraise options and report on their findings. This function of the player in the project cycle allows to stress the multidisciplinary character of irrigation planning and to develop interview and presentation skills. It is run with students at the end of a Master’s course for agriculturists, engineers and agricultural economists.

* JUBA SUGAR ESTATE *

This package is described by Kenyon & Carter (1986) and, more extensively, by Carter (1989). It is based on the Juba sugar estate in Somalia, and it involves the management of scarce inputs like water and fertiliser and scarce resources like labour, capital equipment, money and fuel. Participants take roles as persons in a small management team and have to reach decisions concerning the use of inputs and resources. Objectives of the game are to provide insight into the complex interactions between resources, inputs, activities and management decisions. Meanwhile, team work and understanding of complementary job functions is enhanced as well.

The game is suitable for 3-20 people. The only role of the microcomputer in the game is for the controller to check important calculations. Further computerisation was envisaged in 1989. The Juba Sugar Estate game centres on the logistic and priority issues of resource allocation and thus is more useful for managers than for irrigation engineers.

* SIMBOL *

This is a simulation exercise for an interdisciplinary group of irrigation researcher or practitioners, who may learn to see and discuss complex interactions. It stems from the
Indian Institute of Management in Bangalore, Karnataka, India (Sundar, Rao, e.g.). A brief manual (with relevant forms) describes the details (Anon., s.a.). The area is a large command area where "kharif" (wet) season and "rabi" (dry) season are considered, farm inputs must be bought and where water and crops must be chosen, so that income is generated. Yield response to water is tabulated and in the end a financial balance is made. The rationale of provided inputs and options and the modalities of the game are not completely clear.

* IRRIGATION MANAGEMENT GAME *

A role-playing classroom exercise played by 10-20 participants. It was primarily developed for training irrigation engineers and scheme managers. The game is played on a run-of-the-river scheme, based on Indonesian experience (see Figure 1.1). It places participants in two opposing roles, viz. that of village water managers, responsible for water distribution at farm level, and that of Irrigation Department staff, responsible for main system management. A simple yield relation with provided irrigation water is used, and yields and incomes per tertiary unit are returned as a measure of performance. The ensuing discussion period is the more important part of the whole exercise.

Figure 1.1. Map belonging to the Irrigation Management Game (Burton, 1989)
Development of the game started at Wye College (Carruthers) in 1982 and was further tested and refined by Burton (first with MacDonald & Partners, Cambridge, UK, now with the Institute of Irrigation Studies at Southampton, UK). MacDonald were selling the package at GBP 350. Burton (1989) described some experiences with the game, concluding that the major effects of the game are stimulating frank discussions, identifying common problems and solutions, and forming a group feeling among participants.

4.3 Computer-based games

Computer-based games lack the inter-personal relations and interactions which seem to be so important in the aforementioned role-playing games. Except on a futuristic advanced level, computer games are individual activities, in which the participant plays against (the designer of) the system. Even the position of the player (facing a screen instead of facing people) already indicates that developing social skills, building team spirit, etc. are not objectives of computer-based irrigation games. However, such games may have their role in training and education: much of it needs to be done individually and not all experience needs to be group-based. There are definite links with more general ideas on computer assisted learning (CAL) or computer assisted instruction (CAI), which are outside the scope of this publication.

In the course of our inventory, we could obtain four irrigation games, which are played on a microcomputer, i.e.:
- The Wye College Irrigation Game;
- The Sukkur Barrage Game;
- The IRRIGAME;
- Irrigation REHAB;
and references to a few more, such as two programs from Mott MacDonald: NILE and MAHAKALI. We shall briefly discuss these six below. For details on the first four games, see Annex 1.

* WYE COLLEGE IRRIGATION GAME *

This game was described by Smith (1989) and is in fact a mixture between a role-playing game and a computer-based game. Participants in the game are requested to play a farmer or an irrigation manager under the supervision of a game controller. Participants must make decisions on crops and input levels, support services, maintenance of structures, etc. and the decisions are then fed into the microcomputer, which calculates farm accounts and system accounts, and shows various summaries. Scheme managers and farmers receive a separate instruction manual and the controller can manipulate general inputs to a certain extent, thereby providing unexpected changes. The two major underlying problems are how to deal with a shortfall in maintenance funds and how to react to a poor water distribution over the irrigation areas of the game.
We had some difficulties in getting the computer to react properly on some test input data with our version 1.0 of the program. Although the source code is provided in Basic and may, according to the authors of the manual (Smith & Youngman, 1988) be changed according to local requirements, it is not clearly structured and not easily accessible. The conclusion is that the computer part of the game is not a polished, ready-to-use marketed product; it would require considerable time and effort to make it so.

* SUKKUR BARRAGE GAME *

This package simulates incoming flows, head-pond levels, canal indent levels and release volumes for three left bank and four right bank canals for Sukkur Barrage on the Lower Indus river in Pakistan. The aim is to keep head pond levels steady at given upstream flows by setting barrage gates and canal headworks gate openings for in-built seasonal water requirements. Various displays can be called, such as the barrage plan, the river hydrograph, and a water balance chart. The performance of the player in choosing daily settings for a maximum of 20 days is recorded. Different levels of complexity can be chosen.

The program was made by MacDonald & Partners, Cambridge, UK, for the training of operators at the Barrage under an assistance program (Ede & Gunn, 1987; Stoner et al., 1989; Dempster et al., 1989) and is now also available to outsiders at a price of GBP 100.

Figure 1.2. Performance chart from the Sukkur Barrage Game (Stoner et al., 1989).
CHAPTER 4

There is a small manual available (MacDonald, 1987) and hardware requirements are very modest, although a colour screen would be needed to take full advantage of the nice graphics. The main drawback of the program and the manual is the lack of explanation of what the game can teach a general user and how one can improve one’s performance. Figure 1.2. illustrates one of the performance charts after 4 of the possible 20 time steps.

* IRRIGAME *

This game is an irrigated crop management game in which the user is requested to make wide range of choices on parameters like advisory services, rainfall, crop type, soils, agronomic practices and irrigation method. After internal climatic data have been recalled, the program displays depletion, rooting and crop height graphs per week of the growing season and prompts you to irrigate (when & how much) or not. At the end of the growing season summaries and graphics are produced which should allow the user to assess the consequences of his choices. The game can be operated at various speeds, but the actual ‘scoring’ or performance is not very clear without a manual.

The current program mentions that it is made by Boman at the Agricultural and Irrigation Engineering Department of Utah State University in 1986, based on earlier work by Parrish and Mulkay (Parrish, s.a.; 1982). It is available from the Software Engineering Division of the Department of Biological and Irrigation Engineering at Utah State University (USU, 1992).

* IRRIGATION REHAB *

Developed in the 1980’s at Cornell University, Ithaca, this was originally a non-computer game, based on field research on a distributary in the Gal Oya project in Sri Lanka. This was later computerised into an Asian version (described by Oaks et al., 1986). A further Africa version, related to the Goinre Irrigation System in Burkina Faso was developed slightly later (Sikkens et al., 1987). A general description is provided by Steenhuis et al. (1989). With an optional Relay Adapter Card, a provided slide set can be automatically accessed.

The game aims at promoting interaction among various disciplines involved in rehabilitation of irrigation schemes, and teaches design skills under conditions of limited and non-precise data. There are six phases in the game, ranging from introduction and data acquisition, through preliminary design and farmer meeting, to final design and evaluation.

* NILE *

A simulation program, which is an example of a relatively simple program with advanced graphics, meant to give the practising engineer a feel for the volumes of water
involved in the Nile basin management (Stoner et al., 1989). It is mainly a training aid and not an operational tool. The basic system consists of a large database, a planning module, an operations module and an output module, which are all connected with the user via a superb graphics interface (using GEM graphics libraries). Figure 1.3. shows one of the graphics screens (regrettably in black and white only).

![Image of graphics screen](image)

Figure 1.3. Sample screen from Nile basin management simulation (Dempster et al., 1989)

Large amounts of data are stored in the database, relating to climate, topography, soils, water consumption of various sectors, etc. Then there are planning decisions to be made at the start of an operating cycle, an operation to be run with chosen interventions, while at the end results and effects of planning and operating decisions are shown.

* MAHAKALI *

This Mott MacDonald irrigation management simulation model was developed for a smallholder irrigation project in Nepal and deals with irrigation down to the field level, contrary to the Nile model. It aims at providing a training tool for planning and insight in operation of a set of engineering works. There is a production mode, dealing mainly with general agricultural production, and a main canal operation mode, using one-day time steps. In addition, a tutorial is present (Dempster et al., 1989; Stoner et al., 1989). The same advanced computer graphics as in the Nile model have been applied, adding considerably to the user-friendliness, which was a starting point in developing the models, as they were primarily intended for improving staff performance of staff with little or no computer experience.
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5. WATER REQUIREMENTS AND SCHEDULING

5.1 Crop water requirements

Calculating irrigation requirements is a basic exercise in many technical irrigation activities, such as designing canal systems and structures, estimating pumping requirements, preparing irrigation distribution schedules, operating existing irrigation systems and evaluating water use efficiencies. As the crux of irrigation activities is the optimum supply of water to agricultural crops, knowledge of the crop water requirements is essential.

Crop water requirements are difficult to measure directly and accurately, and hence estimation methods have been in use for a long time. Relationships between actual crop water use and easily measurable meteorological parameters have proved useful over time, such as pan evaporation, air temperature and, especially, sunshine and radiation. Many local correlations were developed, the best including a radiation term (which provides the vaporization energy) and a humidity & wind term (which provides the vapour gradient and transport). Penman (1948) combined these two approaches in a formula for the evaporation from an open water surface $E_0$. His formula has been extensively tested and modified. The modified Penman equation (Doorenbos & Pruitt, 1977) is widely accepted, although the latest CROPWAT version employs the Penman-Monteith approach, recommended by a 1990 FAO Expert Consultation in Rome.

There may be other formulae and models in use in academic environments (e.g. among crop physiologists). However, for normal engineering practice, the most common way to calculate crop water requirements in irrigation is the procedure described by Doorenbos & Pruitt (1977). They calculate a reference evapotranspiration $ET_0$ (replacing Penman's open water by a specified grass cover) from standard agro-meteorological data, mainly: sunshine, temperature, humidity and wind speed. There are minor controversies over "constants" to be used in some relations, but reasonable estimates of the reference evapotranspiration are produced for normal conditions (compare also: Jensen et al., 1990).

The link between crop water requirements $ET_c$ and this reference $ET_0$ is made through formulating crop coefficients $k_c (=ET_c/ET_0)$, which vary mainly per crop and per crop development stage. Such crop coefficients and a possible division into practical crop development stages for many common crops have also been provided in Doorenbos & Pruitt (1977).

Even if all agro-meteorological data for the Penman formula are available, the calculation of $E_0$ or $ET_0$ is time-consuming and hence ways have been sought early on to facilitate the computation. Tables have been prepared (e.g. McCulloch, 1965) and nomographs were made (e.g. Koopmans, 1969), but the advent of the computer has
really made an impact on the use of the (modified) Penman formula. Early attempts (like an Algol program by Chidley & Pike, 1970) were followed by many others. Some were for private or incidental use, some for in-house application (e.g. Schellekens et al., 1992), some for local use (e.g. Kalders, 1988), while a number of them were published and thus available for general use. Most of these programs include the use of crop factors, and some go into scheduling.

The scheduling is dealt with in a next sub-chapter, but we shall look at $E_T0$ and $E_Tc$ first, on which we have reviewed CRIWAR, CROPWAT, ETREF, ETCROP, IRSIS, and a spreadsheet CWRTABLE. They are briefly discussed below. Details are given in Annex 1.

5.2 Programs for water requirements

* CROPWAT *

This program, developed by the Land and Water Development Division of the FAO in Rome (Smith, 1992), basically follows the Doorenbos & Pruitt (1977) publication in calculating the modified-Penman reference evapotranspiration from agro-meteorological data, and then calculates crop water requirements for specified crop data. It builds on to the original program of Gupta et al. (1977). But is does more: it further allows the development of irrigation schedules and scheme water supply data, with a chosen effective rainfall method. The data input is more flexible than with CRIWAR (see below), and the manual, contained in Irrigation & Drainage Paper 46 (with a floppy containing version 5.7), has been improved gradually since earlier versions. The main menu, presenting the available program options, is shown in Figure 5.1.

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MAIN MENU CROPWAT (5.7)

PROGRAM OPTIONS:

1. $E_T0$ Penman-Monteith calculations
2. Crop water requirements
3. Irrigation scheduling
4. Scheme water supply

-> 5. Printer setting
-> 6. Drive & path setting

9. Exit CROPWAT

Your Option: 5
```

Figure 5.1. CROPWAT's main menu, version 5.7 (Smith, 1992)
The most recent version (#5.7 of October 1991) was tested, although the CLIMWAT database with required agromet data for 3262 stations in 144 countries accompanying this version was not available. The manual and the guidelines provide sufficient information to master the program quickly. The accuracy of the ET calculations is hard to assess at short notice. It is in principle a very useful program, that is readily available and works well on normal MS-DOS computers, with clear screen messages. Details of earlier versions can e.g. be found in Smith, 1986; and additional explanatory notes in van Eeden, 1988.

* CRIWAR *

This is a small Fortran program, which follows the Doorenbos & Pruitt (1977) publication on crop water requirements closely. The user is prompted for answers, choices and inputs in a rather old-fashioned way and meteorological data entry can only be done in one set of units. Reference evapotranspiration is calculated for the given meteo set and, if required, crop water requirements are calculated for different crops in an irrigation command area, using weekly or monthly values. Required irrigation water volumes are calculated by the program, after correcting for (one standard) effective rainfall.

Input data can and output data will be made by the program. Results differ somewhat from CROPWAT results, the reason for which cannot be determined immediately. The program and manual have not been published, although references have been made in the literature to Vos et al. (1988).

* ETREF *

This program is in fact part of a package, developed at the Centre for Irrigation Engineering in Leuven, Belgium (Raes et al., 1986), which contains a sequence of programs called ETREF, ETCROP and DEFICIT (and a program ETSPLIT to calculate evaporation and transpiration separately). Again, the package follows Doorenbos & Pruitt (1977) and allows the user to quickly calculate the reference evapo-transpiration according to the modified Penman method (ETREF), apply a crop factor to find the crop water requirements (ETCROP) and, finally, after looking at effective rainfall, to find net irrigation requirements (DEFICIT). The program was released in 1986 and the typical inflexible Fortran input chart is old-fashioned. Input units are more flexible than in CRIWAR and the manual is more detailed than for CROPWAT. There is no sample data file or case study provided on the distribution disk. The program package seems to be a fore-runner to IRSIS.

* IRSIS *

Stands for IRrigation Scheduling Information System package. It was developed in Leuven and was published in 1988 (Raes et al, 1988). It addresses irrigation scheduling
at the field level (see below), but it starts by allowing the user to calculate the reference evaporation and the crop water requirements according to the modified Penman method described in Doorenbos & Pruitt (1977). As such it seems to be a successor to the ETREF package mentioned above. The IRSIS program places more emphasis on the application of such calculated values in the planning of irrigation schedules and in the evaluation of irrigation actions. There is a relatively modern user interface in the form of structured displays and a well-edited manual. Hardware requirements are certainly not excessive.

* CWRTABLE *

This is a simple Lotus 1-2-3 spreadsheet from the Institute for Irrigation Studies at Southampton, UK, allowing the user to calculate water requirements for up to five different cropping patterns for a total of 52 periods (e.g. 52 weeks in a year). Input data are reference evapotranspiration data (calculated beforehand) and crop factors. The program e.g. illustrates the effect of different planting dates on irrigation requirements. It is suitable for introducing students to the usefulness of spreadsheets for irrigation calculations, rather than for general application in irrigation project planning. It also illustrates the point, however, that spreadsheets are in fact quite useful for a number of standard applications in irrigation (which may e.g. include calculating ETo or ETcrop, or designing a simple trapezoidal canal).

* Other programs *

There must be many more local or internal versions of such crop water requirement computation programs in various stages of completion (see e.g. Schellekens et al., 1992). FAO's CROPWAT seems to be rather universally applied. There is another program named CROPWAT, released by Utah State (USU, 1992), which calculates eight different reference evapotranspiration, following Jensen et al. (1990). Again another USU program PCET calculates crop water requirements for local conditions for the past week and predict it for the next week (USU, 1992). The RR-2.0 program (Ravelli & Rota, 1991) seems to calculate crop water requirements much like CROPWAT does. Another example is given by Saksena (1991), who mentions ETo, IRRREQ and WARABANDI programs used in India. CEMAGREF (1992) apparently have a Fortran program for calculating regional water requirements (BILANREG), which we have not been able to test.

5.3 Irrigation scheduling

Irrigation scheduling can be understood as the determination of the right time and amount of irrigation application for optimal crop production. It addresses the basic questions of when the next irrigation is due and how much water to apply (assuming that the "how" is known). Since water is applied to the crop via the soil, the process is theoretically quite complicated and involves factors such as initial soil moisture
conditions, rates of change in soil moisture (evaporation, evapotranspiration), root extraction patterns, moisture transport in the root zone, limits of soil moisture suction in relation to plant growth, relationships between suction and moisture content, infiltration, re-wetting and percolation. Each of these sub-areas has been studied widely, leading to a large knowledge base. Modelling and simulation have been introduced in many of these areas over the past 20 years. Sophisticated computer simulation for irrigation scheduling now includes (evapo)transpiration models, soil moisture movement models, root and crop growth models, although most models can as yet be used for analysis and not for real time scheduling. More general information on computer-based scheduling can be found in recent publications of Hoffman et al. (1990), Stewart & Nielsen (1990), and Hanks & Ritchie (1991).

In the scheduling programs discussed below the process is rather simplified, however. Most of the programs contain three elements:

- Potential evapotranspiration, as the "drawing force" depleting the soil water;
- The soil moisture storage, as a percentage of the volume between field capacity and wilting point, depending on the soil type and crop rooting depth;
- The relation between soil water content and crop yield. If the soil water falls below a certain value, yield reductions may occur, depending on the crop type, crop stage and evaporative demand.

The programs then calculate the optimum irrigation intervals under potential evapotranspiration, and water depths applied. Programs also have possibilities to simulate the effect of sub-optimum intervals, by calculating reduced ET values and relating these to yield reductions. The result is the change of soil moisture content with time. In all programs the theory on this aspect has been taken from Doorenbos & Kassam (1979), who summarized the then available knowledge on crop yield response to water.

Still, the scheduling programs are mostly a theoretical exercise. They can be used for design of surface irrigation or to assess what-if questions. Their practical operational value for smallholders in tertiary units is limited because the basic elements as application depth and interval are usually largely determined by external factors. They can be useful, however, for students, lecturers, engineers and planners to "play" with relatively simple data on water requirements, yield response to water and soil moisture retention, and see the consequences of different combination. The programs CROPWAT and IRSIS discussed below fall in this category.

Another category of programs are geared to assist the individual (large) farmer who wants to use his own personal computer for a tailor-made advice on when to irrigate his crops and how much to apply, not only on the basis of a day-to-day operation, but probably also in advance, so that he can weigh alternative cropping plans (see also Heermann et al., 1974). In this respect, large center-pivot sprinkler installations for instance would be well-advised to make use of a computerised scheduling service.
This type of computer scheduling packages can be institutionalised into a commercial or public service, where large databases are kept and where advice can be sought by individual farmers. Examples of such systems are not uncommon in the Western world: Carr (1984) mentions irrigation scheduling services in the UK, Parkes (1987) in Scotland, Mau (1986) in Israel, Bastrup-Birk (1989) in Denmark, and ASAE (1981) describes early developments in the USA. Hoffman et al. (1990) give description of an irrigation information support system (CIMIS) in California, and in Southeastern Australia.

5.4 Irrigation scheduling programs

* CROPWAT *

This program, already mentioned in Section 5.2, further allows the development of irrigation schedules for different management conditions, after calculating crop water requirements and scheme water supply. The additional information required is on rooting depth, on maximum soil moisture storage and on allowable depletion level, and on yield response factor per development stage. The latter data are taken specifically from Doorenbos & Kassam (1979).

The program provides a summary of irrigation intervals over the season, with detailed data per irrigation day and over the season. For the timing and for the application depth one has various options which can be chosen, evaluating the result e.g. by the variations in irrigation interval, by the occurring stress conditions, by the obtained irrigation efficiencies or simply by the overall yield reductions. This part of the program is the most useful, keeping the options limited and thus practicable. The explanations in the manual and the provided guidelines are useful.

* IRSIS *

Also mentioned above for the water requirements part. It further appears to do virtually the same as CROPWAT. For a given climate, crop and soil, optimum water distribution under limited water supply can be calculated, irrigation schedules can be planned, and irrigation actions can be simulated (see Figure 5.2. for an example of graphic displays used in IRSIS).

Consequences of irrigation actions are also shown in terms of water use efficiencies and yield depressions (based on Doorenbos & Kassam, 1979). As mentioned above, the structured displays are a nice feature of the program, as well as the nicely-produced manual. It would take a few days to get familiar with the terminology, the program logic and the keyboard actions, but the case study helps in this respect. We have not made an actual comparison between the results of IRSIS and CROPWAT for the same inputs, but on the outside we would expect similar results as both are based on the same principles and publications.
Figure 5.2. Root zone depletion for a case in IRSIS (Raes et al., 1988)

* Other programs *

Utah State University’s Software Engineering Division also has irrigation scheduling programs (USU, 1992)) for real-time scheduling for rotation and demand delivery systems (IRRISKED), based on the USBR irrigation management service (IRRITALK), and a spreadsheet template for water delivery to users on a rotation basis (IRRTURN). Goldsmith et al. (1988) also mention the use of spreadsheet programs for irrigation scheduling. We have not tested these or any other scheduling programs such as SCHED, a USDA-ARS scheduling program (Harrington & Heermann, 1981), or WATSCED, a Hydraulic Research (Wallingford) program for irrigation scheduling for smallholders (Howard & Benn, 1986). We also could not test ISAREG, a scheduling simulation model developed in Portugal (Texeira & Pereira, 1992). There are, undoubtedly, many more irrigation scheduling programs, but within our limitations of time, money and knowledge, we are not in a position to include others than those mentioned.

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