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AN INVENTORY OF IRRIGATION SOFTWARE FOR MICROCOMPUTERS

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1. INTRODUCTION

The role of microcomputers has been increasing at a fast rate during the past 10 years or so. Before 1980, computers were used relatively scarcely, and mainly in universities and research institutes in western countries. With the introduction of microcomputers in the early 1980's computer use has not only become much more common in the industrialized world, but has also gained wider acceptance in developing countries, especially over the past five years. Some of these more general trends in computer use are described in Sections 2.1 and 2.2.

Computer use has also increased in the world of irrigation and drainage (see Section 2.3) and thus also within the International Institute for Land Reclamation and Improvement (ILRI). Because the Institute has a main task in collecting and disseminating knowledge in these two areas, it is only logical that it has a genuine interest in the application of microcomputers. Computers have been used at ILRI for various purposes, such as developing simulation or calculation models, besides administration and word-processing. They have also been used as a training tool in irrigation and drainage courses, particularly in the annual International Course on Land Drainage, organized by the Institute since 1961.

Although hardware developments in the personal computer area have been fast and price reductions have led to their widespread use in many modern institutions concerned with irrigation and drainage, especially the software situation in this area is lagging behind. Many institutions and private persons recognized the potential benefits and started developing branch-specific software for research, training, design and management. This led to a rather large volume of literature, discussing mathematical models and computer programs, but it is difficult to obtain a user-oriented overview of the programs that are available, useful and working well.

In a number of disciplines surrounding irrigation, computer modelling efforts have been summarised from time to time, e.g. in hydraulics (Waldrop, 1985), in soil water dynamics (Hillel, 1977; Feddes et al., 1988), in agricultural hydrology (ASAE, 1980; Haan et al., 1982; ASAE, 1988), and in drinking water supply (e.g. Coulbeck & Orr, 1989). When writing this publication such a summary was, as far as we were aware, not available for the entire field of irrigation and/or drainage. The International Commission on Irrigation and Drainage (ICID) pays attention to sub-issues from time to time, as e.g. during a workshop on Crop Water Models in Rio de Janeiro in 1990 (see also Pereira et al., 1992). Moreover, the ICID Workshop on Subsurface Drainage Simulation Models in The Hague, The Netherlands, in September 1993, will bring together knowledge in another sub-area. Although efforts thus exist in certain sub-sectors of irrigation, we nevertheless thought that it would be useful to make a start with a more general inventory of microcomputer models available to the irrigation practitioner. The majority of the work was done during the first half of 1992.

The result of such a state-of-affairs inventory, with major emphasis on usability, is presented in this publication. The set-up and the organization of this search are discussed in Chapter 3.

Meanwhile, two more important sources of information became available, both on the sub-area of canal models and programs. One was the proceedings of the 1991 National Conference of the Irrigation and Drainage Division of the American Society of Civil Engineers at Honolulu, Hawaii (Ritter, 1991) and the second the International Workshop on The Application of Mathematical Modelling for the Improvement of Irrigation Canal Operation, held at Montpellier, France, in October 1992 (CEMAGREF/IIMI, 1992). We have included information from these occasions as well, mainly in Chapters 7 and 10.

As indicated, our target group is the general irrigation practitioner, and not the computer expert or the specialist in a particular irrigation sub-area. This means that highly sophisticated models at the frontiers of knowledge are excluded. We are looking for computer programs which, in the first place, provide a convenient and user-friendly tool to perform the basic task of a computer: facilitating computations. Existing knowledge may be built around this core to deepen insight, to teach and learn, to facilitate designs, to monitor, to analyze and manage operations, and to answer "what if" questions, thus adding aspects of modelling and simulation.

This publication, and the software discussed in it, is thus meant for people working in the field of irrigation who are e.g. (i) dealing with applied research, (ii) junior lecturers and students in colleges and universities, and other instructors, (iii) general design engineers, and (iv) irrigation consultants. We suppose that such practitioners have a keen interest in the use of microcomputers as a tool in their profession, not only to facilitate such common jobs as writing scientific reports, but also for analyzing research data or historical records, planning irrigation schemes, solving design and operational problems. Additionally, computer use as a tool for education and training is clearly within our scope.

The text is written from the irrigationer's view and not from a computer science angle. Although the reader need not be a computer expert, a basic understanding of IBM compatible microcomputers and common peripheral devices working under MS-DOS would be useful, and we suppose that a notion of general application software for word processing, spreadsheets and databases is present. Any programming knowledge (in Basic, Fortran, Pascal, etc.) is not required.

Apart from the mentioned limitations (irrigation, target group), the current inventory emphasizes on readily available software. This primarily refers to the price. A program costing US $ 5000 or much more is not normally readily available to our target group. There seems little use in discussing or demonstrating a package that nobody can afford. This means that the program should be roughly public domain software: either free or available at a nominal fee for copying, postage and handling. In the inventory, we have mentioned some of these expensive programs, but they have not been tested. Another aspect of availability is that many programs are lying somewhere on a shelf, and although a publication may have been written about it, they are not publicly available. We may refer to them, but could not evaluate these either.

This inventory is not complete. Not only because of the limited time and budget available, which means that we could not read everything or visit or write to every prospective institution or person, even if we would be aware of them. But also because it would be impossible to wait until we are satisfied that we have covered all there is: new material is being developed almost daily. Also, rigorous and systematic testing and evaluation of the mentioned programs (and others) could be undertaken at a later stage, as a further development. The general idea is to set the ball rolling. ILRI would thus welcome any advice on errors and omissions, so that a possible future version can be more complete and thereby more useful to our readers.

Finally, the inventory concentrates on bringing together readily available programs. The brief testing of the programs was primarily aimed at user-oriented aspects like their operability, usability and general user-friendliness. We have not assessed the more technical software engineering qualities.

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2. COMPUTER USE; TRENDS, TYPES AND LIMITATIONS

2.1 General trends

In this chapter, we mention a few more general trends in the use of computers first, then distinguish between different types of computer application, and see - before knowing the results of the inventory - if we can distinguish certain patterns in the irrigation scene. Later comments can then be viewed against this background. The list of trends is by no means exhaustive, and could be quite different from other points of view, like e.g. the manufacturing industry. We are listing these trends to pinpoint general developments which have contributed to the development of the irrigation software that we are discussing later in this publication.

The first general trend is a shift from the use of mainframe computers to stand-alone microcomputers. Larger institutions still operate with user networks served by a mainframe computer, but especially the use of a computer at home, and the increase in the number of (very) small private companies have contributed to this shift. Since the IBM-designed personal computer was widely available in 1983/84 and rapidly became an industry standard, computing power in terms of processing speed and memory capacity has increased enormously. The development of reliable and versatile peripheral devices such as quick-access, large-capacity hard disks, high-resolution monochrome and colour monitors, and trustworthy quality printers also helped. Of course, the availability of diversified application software for these microcomputers stimulated this development as well. And maybe first among the factors influencing this shift from mainframe to microcomputers is the price development of all systems components.

A second noticeable trend has been the inclusion of computer science in the educational system, often starting with some first contacts in primary school to more structured exposure in secondary school. Especially also at college and university level, computer classes have become an integral and essential part of almost all curricula. Even for the non-computer freaks advantages in writing reports and theses, which includes word processing, data analysis and making graphical presentations are clear. The inclusion of computers in all sorts of processes in government and industry, taking over tedious and repetitive jobs, has also led to a vigorous growth in basic computer studies and computer applications. The idea that many technical calculations can be easier performed by tailored computer programs has led to many university theses being devoted to the development of computer programs.

A third visible trend is a derived and flourishing offshoot of the greater availability of computational power, i.e. a branch of study which could be termed modelling and simulation. On the one hand the mathematical and numerical sciences are developing systems and approximations which can be applied in many disciplines, while on the other hand many disciplines can widen their horizons by exploring hitherto impossibly complex frontiers of knowledge. The building of models and the testing of alternative solutions in simulated runs are very practical applications of computers and software in many institutions, ranging from simple alternative pipe designs to macro-economic planning models. Consequences of certain actions are increasingly judged by the outcome of simulation runs in appropriate models.

A fourth trend is the move of computer knowledge from the universities and research institutes into an application field, where the user of a microcomputer and a good software program does not have to bother too much about the specifics of the hardware (very much like using a compact disk player) or the detail of software development (or CD recording and manufacturing) to benefit from their use. Computers, and software even more, also have limitations which one should consider, but the group of less-informed users has been growing very rapidly.

Such general trends are not only visible in many offices in western countries, but are increasingly present in developing countries as well. Computers are gradually becoming a normal part of life in the third world as well, and not only by or through development agencies.

2.2 Types and purposes of computer use

In general terms, various types of computer applications can be distinguished, with both hardware and software aspects. One could consider types of computer use like:
- for performing repetitive calculations quickly and reliably; this function could be characterize a computer as a greatly improved calculator;
- assisting in typing and printing written documents; this word-processing function would then be an improved typewriter; WordPerfect easily comes to mind as an example of a software package with this function;
- producing graphical images like pictures, diagrams, graphs, animated cartoons, etc., some of which may be used for illustrating text in documents, leading to desktop publishing techniques and software;
- as a drawing aid, through digitizing pixel locations, including coloured images; this function would roughly be that of an improved engineering drawing board; the term CAD (computer-aided design) applies and AutoCAD is one of the common software packages for this purpose;
- as an optical or other physical signal collector and analyzer and/or as a process controller in industry, e.g. in controlling robots; a common relevant acronym is CAM (computer-aided manufacturing);
- as an operational control tool in civil and military machinery and other equipment (airplanes, cars, CD players, medical scanners, missiles, space ships);
- as a means of instruction, by guiding the user through prepared educational material; terms like CAL (computer-aided learning) or CAI (computer-aided instruction) apply;
- as a means of communication as such (in telecommunications, E-mail) or as connection with large databases (libraries, registers, climatic data, etc.);

- as a commercial tool (office automation, accounting, distribution, logistics, planning, statistics, etc.), i.e. for routine administrative or clerical duties or for management purposes;
- as intelligent knowledge based systems or expert systems, which provide expert knowledge on a subject for consultation;
- as a research tool to venture into such areas as artificial intelligence, chaos theory and the like.

This list includes an unorganized mix of commercial, scientific, research and engineering applications. It could easily be made longer by including more specific examples of computer use in all kinds of professions or other aspects of life. However, the message is more important, and that is that the computer is now so common in our life and time, even if we are not always fully aware of it, that its progress into a subject like irrigation is by no means an exclusive or special affair. Rather, if one sees to what degree the use of computers has penetrated in some other areas, one may wonder why it has not spread in irrigation much wider than it has. Part of the reason may be that the following criteria for computerisation do not always apply, i.e. volume of work, high required accuracy, reliability, repetitiveness, complexity, speed (French, 1989). Apart from such general criteria, computer use in certain irrigation situations may not be technically feasible, cost-effective or socially acceptable. We shall not venture further into such an analysis, but, in the following section, mainly try to list areas where computers are used in irrigation.

2.3 Computer use in irrigation

Irrigation entails much more than computers, of course, and many scientists advocate the central position of people rather than technology. Even so, this does not mean that the technical and engineering aspects should be neglected or could not benefit from the application of computers. Even social sciences could benefit from an interface with some computer-based tools and techniques. Let us first consider in broad overview, with some points from the previous chapter in mind, in which areas computers, and more specifically microcomputers and their software (seeing the title of this publication) are or can be advantageously applied.

Computers are used in irrigation in the following broad areas and phases of project development:
- in research and education (compare Verwey (1985) for comparable uses in hydraulics and hydrology);
- in the planning and design of irrigation systems, either by sophisticated individual farmers, by western extension agencies or by professional designers of consulting engineers;
- during the implementation of major projects, e.g. in levelling work and in supervision and management;
- in the manufacture of irrigation hardware like pumps, sprinklers, drippers, valves, plastic pipes, etc.;

- in the operation of field systems, mainly for pressurized irrigation systems like sprinkler and drip irrigation (e.g. Karmeli et al., 1985); such computerized operation may include reservoir operation, barrage operation, controlled pumping and fertigation in greenhouses. Systems can be fully automated or may be based on simpler technology, with only computerized data processing;
- in monitoring of irrigation systems; this may be automated; a computerized data collection and analysis system may be set up for immediate or later adjustment; reporting could easily be fitted into such a system.

We are, in this inventory, biased to a large degree towards the first two points, and also to the last two. We would exclude the "industrial" applications like manufacturing as well as sophisticated (real-time) operation and control, often indicated as "automation". It is rather difficult to make clear distinctions and strict classifications, but in our search for programs and information on computer programs for irrigation we are excluding manufacturing and automated control.

We thus limited our search area to some extent, and if we further restrict ourselves to the use of microcomputers, we should be mainly concerned with programs specifically written for irrigation applications. One could further try to analyze which general reasons there may be for developing irrigation software within this selected area. The following objectives could be distinguished:

a) Exploration and improvement of the knowledge base. For this purpose computer modelling and simulation studies are a powerful tool. One can expect more complex programs in any state of applicability, mainly concerned with research.
b) Application of existing knowledge in an efficient way. This mainly refers to the development and publication of simple, user-friendly software packages for design, management, operation and monitoring of various irrigation elements, all based on existing knowledge, and applied in extension, design offices and in operational scheme management.
c) Training of irrigationers. This training function could cover especially made irrigation training modules (CAL or CAI), but various mixes of material for functions a) and b) should be made for the different educational levels.
d) Dissemination of knowledge through consultancy and advice. Although this aspect may be considered as part of function of b) and c), there are differences. It may be handy to have a limited number of short informative software packages available (tables, quick data analysis, word processing, small databases) software packages handy. Advice can then be based on easily accessible factual knowledge (for which otherwise books would be consulted). In this sense one could think of a computerized Compendium for irrigation, possibly in sections.

In this publication type (b) software is mainly expected to be addressed, because type (a) is too experimental, type (c) probably is still under development, and type (d) may only be present in personal luggage. This is approximately in line with the earlier mentioned aim at the irrigation practitioner. On the same note, Clarke (1989) expects that the greatest future demand from microcomputers in irrigation will be for the design of computer software that is appropriate to the problem to be solved, that is relevant to the needs of the users, is easy to understand and to use and is readily available on the most widely used computer systems.

When talking about software types, one could distinguish irrigation programs that are based on existing application software packages like Lotus 1-2-3 (for spreadsheets) and dBase III (for databases), their more modern versions or their sisters and brothers. Some internal programming can be done within these environments, so that separate irrigation templates and programs can be made. On the other hand there would be programs written in the more common programming languages like Basic, Fortran, Pascal, C or the like, which allow more special conditions to be programmed. Such a distinction is slightly arbitrary, except that spreadsheet templates are limited in size and complexity, and database programs normally lack graphics and have limited printing facilities. Spreadsheet templates would be quite adequate for many day-to-day routine calculations in the running of irrigation schemes like calculating evapotranspiration from climatological data or planning the water distribution in a canal system. Database programs may be handy for meteorological and hydrological records, for recording cropping patterns and yield data, and for administrative tasks like staff records, workshop records, pumping data, and financial matters. In most cases it is easier to use such existing application packages for routine tasks than writing a completely new Basic program. Such programs are expected to be written for the education, research, design and more complex management tasks in irrigation.

2.4 Limitations

The previous paragraphs may have suggested that the computer can and must do virtually everything imaginable. That was not our intention: we want to stress that, although microcomputers and their software can become an important tool in irrigation, the relatively new technique may also create unjustified expectations.

There is an inherent danger of trying to use microcomputers to solve problems in irrigation which do not need computerisation at all. To briefly illustrate this point, we may refer to Clarke (1989) who, quoting from experience in training irrigation staff, identifies the following five potential pitfalls in the use of microcomputers:

- *Precision rather than accuracy*: calculations are done quickly and to more decimal places than may be needed. This pseudo-accuracy not only applies to figures, but by implication also makes the (simplified) computer solution seem more trustworthy. Boundary conditions, assumptions, simplifications, and limitations of empirical or experimental relations are easily forgotten, and the eight-digit figures produced easily legitimize such omissions.
- *Dependence on the computer*: it can easily happen that an unskilled user substitutes his own judgement and initiative for "the computer says ...", supposing that the software developers are always right. It is always useful to understand the theory on which a program is based before employing it; this especially relates to its

limitations. Occasionally, students who have worked with a computer during their training may feel incomplete and unable to perform if they do not have a personal computer at hand.

- *Technology for the sake of technology*: it is not uncommon to find that computers are used as a panacea: it will help against all kinds of ailments. However, many irrigation schemes can be run perfectly well without them, and their introduction should be based on advantages and disadvantages, carefully weighed by professionals knowing about irrigation and about computers (compare e.g. Anstey, 1992).
- *Computer training*: upon the arrival of computers in an irrigation scheme or institution, there is normally a limited number of software packages available. Staff are often exploiting only a minor portion of the total capacity of the computer due to improper training. Not only should existing packages like spreadsheet programs be explored to the full, but it would also be advisable that the users can judge what the supplied programs can and cannot do, and what alternative software packages are available.
- *Software design*: there often is a rather hasty decision that own irrigation software must be written. This may be thought to produce a modern and scientific image, but may mask a lack of knowledge of existing programs. If indeed necessary, specialist computer programs must be written so that others may be able to use it as well, even if there is no initial intention of publishing it. If there is, there are some criteria, which we discuss further in Chapter 13.

Such a list of limitations of computer use (in irrigation) could probably be made longer, but let this suffice to illustrate that microcomputers should be diligently used in irrigation as much as in other disciplines. They are a tool for man, albeit extremely useful at the proper time and place.

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3. ORGANIZATION OF THE STUDY

3.1 Set-up and execution

For a proper understanding of the followed procedures, it should be kept in mind that the authors are primarily irrigation engineers, without extraordinary knowledge of and experience with microcomputers. This has hopefully put us in a better position to assess the practical use of the tested programs than many more advanced computer users and program developers.

The work for this inventory of irrigation software for microcomputers was mainly organized along three lines, i.e. reviewing relevant literature, collection of programs and manuals, and test-running programs. The collection of information on existing programs, over and above those available at the start of the study, was done through:
- consultations with University Departments, Institutes and Consultants in The Netherlands;
- writing letters to experts and institutions in various countries, either known by the authors, or on the basis of reviewed literature.

A non-exhaustive list of contact addresses related to the reviewed programs, to other mentioned programs, or to general microcomputer use in irrigation, is presented in Annex 2. Such addresses may be useful for a follow-up by interested readers on certain programs.

The literature review, a continuous process, included the following activities:
- checking the personal filing systems of the authors and following up references;
- tracing references mentioned in collected manuals and in received information;
- a key word search in the AGRALIN library system via the ILRI Library.

A literature database, with short annotations, was set up using Cardbox-Plus (BSL, 1988), but is not reproduced in this publication.

For testing the programs a Compaq Deskpro 386N was used, with a monochrome VGA screen and a 1 MB internal memory (normally available 640 kB), with a single 3.5" floppy disk drive (1.44 MB) and a 40 MB internal hard disk. A printer was only attached when specifically required; in that case an Epson LX-800 9-pin matrix printer or a HP-Deskjet printer was used. In a few cases a math co-processor was required, which was not present in the Compaq; then we switched to an Olivetti M250 or an IPC 386SX Portadesk, which had a co-processor. The test results and other relevant information were recorded on a uniform, one-page test form.

3.2 Structure of the report

The core of the publication is the discussion of programs in Chapters 4-12. The chapters are organized according to a simple classification, because listing all names of programs alphabetically was not considered useful.

One could follow relevant chapter headings of common major irrigation textbooks, or one could think of a computer-based classification: spreadsheets, data-base oriented, Fortran, etc. Instead, we arrived at the following grouping, mainly based on distinguishable irrigation subjects for which at least some programs were available. There is also a rough trend from single-purpose programs into more integrated ones towards the end. They constitute the next eight subject chapters, and one miscellaneous addition:

- *irrigation games:* a special subject related mainly to instructional methods; some computer-based, some not;

- *water requirements and irrigation scheduling:* from calculating evapotranspiration with Penman's formula to preparing field and scheme irrigation schedules;

- *field irrigation methods:* mainly design, operation and analysis of surface irrigation: level basins, borders and furrows;

- *canals and canal networks:* design of single canals, from simple hydraulic (Manning) calculations to longitudinal sections and branching network simulation using unsteady flow;

- *pipes and pipe networks:* from simple diameter calculations to network optimization and network solvers;

- *irrigation structures:* the use of stage-discharge relations and the design of measuring and other hydraulic structures;

- *water management / operation:* various programs for (main) system management, including planning, operation and monitoring;

- *drainage:* mainly as related to irrigation, including drain spacing, soil moisture models, groundwater flow and root zone salinity, surface drainage, reuse of drainage water, crop growth;

- *other programs:* programs not fitting in the above classification, which could include subject like agrometeorological data, scheme lay-out, land levelling, pumping, and economics.

Each chapter starts with a very brief overview of the subject matter, so as to be able to place the programs into their context. Then a short description of the relevant available programs follows, and short notes on current developments or other useful information may conclude the chapter, before the references are given. To each of these chapters belongs a set of test forms, in which more details are presented on each of the discussed programs. These test forms are reproduced in Annex 1, arranged in alphabetical order of the program name.

In the text as well as in the detailed forms, assessment of the collected programs has been based on the following easily identified user-oriented aspects only:
- required hardware to run the program;
- operability: structure, logic and operation of the program;
- documentation: availability, clarity and appropriateness of the manual;
- general user-friendliness;
- availability.

This means that e.g. computational accuracy and further correctness were not tested; most other software engineering qualities of the programs were also not addressed.

Some of these aspects are difficult to convert into simple and strict criteria. Hardware requirements are rather objective and specific, but user-friendliness is a widely-used but rather vague term, open to different interpretations. Availability not only means that it is clear how and where to obtain a program, but also that it is public and cheap. Chapter 13 contains some more details on possible criteria for irrigation practitioner's software, although we realize that such judgements are rather volatile; in a few years' time the situation may be different.

Finally, in Chapter 14 the findings are summarized, a number of conclusions are formulated and suggestions are presented on possible follow-up action.

3.3 Loose ends

Although we have tried to identify as many programs as possible during the limited search period (February - August 1992), we certainly have missed many. This will primarily apply to programs which have not been published, which often concerns programs in use with universities or consultancy firms.

As a case in point, we received an overview of 26 irrigation programs in use with Utah State University (USU, 1992), just before the closing date of our inventory. Because it would take too long to purchase, test and describe all these programs, we did not do so. We can only mention a few programs in more detail, and refer the reader to this publication. Another case is the 17 (mainly) irrigation programs of the French CEMAGREF (CEMAGREF, 1992). In the period between the end of the search and the final preparation of this publication, more programs have surfaced, which we could not include and more literature has become available, only part of which could be included. Certainly, there will be more such cases, and we would be grateful to the reader if he would inform us about such missing summaries, single programs, updates, and the like.

In some chapters there is a last paragraph or section titled "other programs". Here some programs are briefly mentioned which we know to exist, but which we could not (timely) obtain to scrutinize. They could also be programs that are in our possession, which could be interesting, but are not working properly at the moment.

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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.

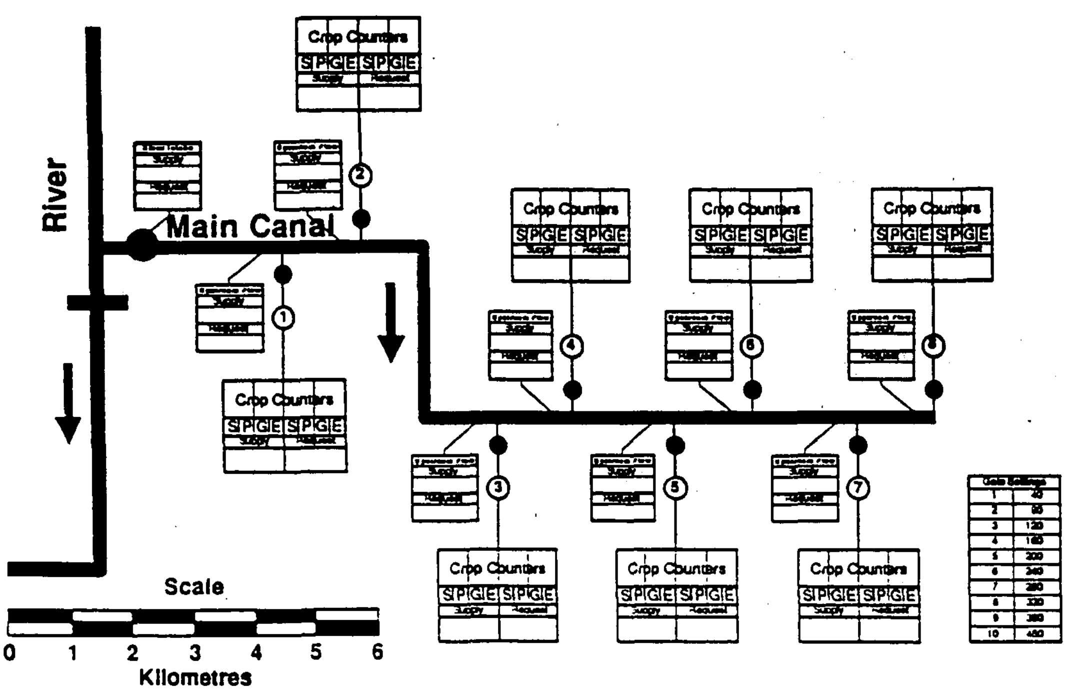

Figure 1.1. Map belonging to the Irrigation Management Game (Burton, 1989)

Development of the game started at Wye College (Carruthers) in 1982 and was further tested and refined by Burton (first with MacDonald & Partners, Cambrige, 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.

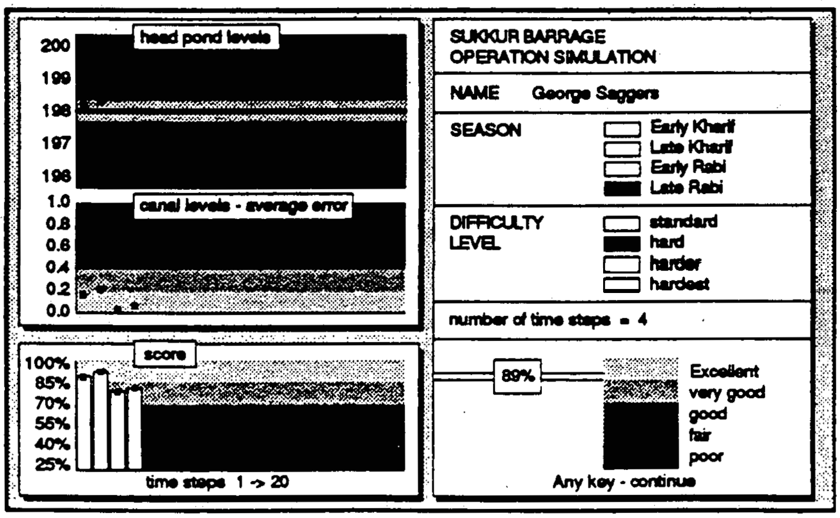

Figure 1.2. Performance chart from the Sukkur Barrage Game (Stoner et al., 1989).

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).

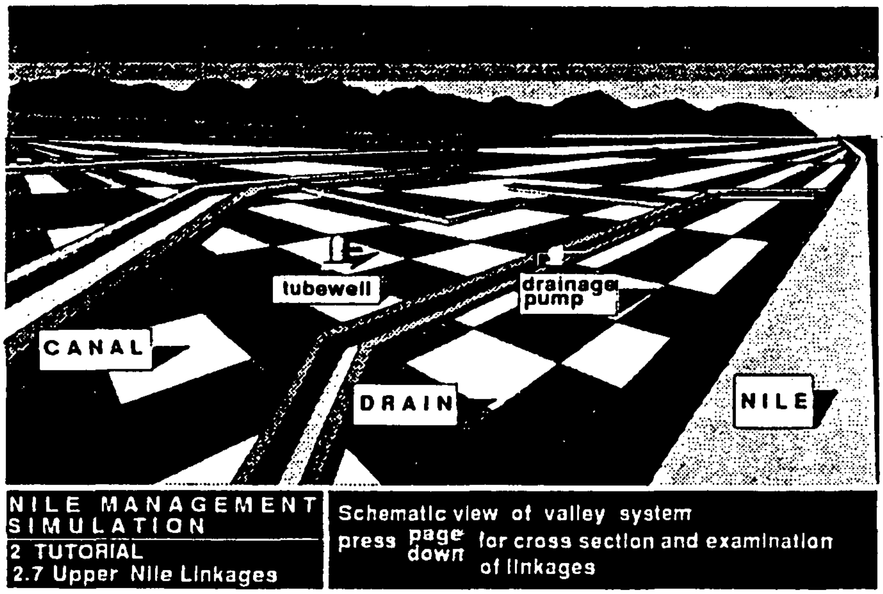

Figure 1.3. Sample screen from Nile basin management simulation (Dempster et al., 1989)

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 Eo. 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 ETo (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 ETc and this reference ETo is made through formulating crop coefficients kc (=ETc/ETo), 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 Eo or ETo 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 ETo and ETc 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.

```
                MAIN MENU CROPWAT (5.7)
   ------------------------------------------------
      PROGRAM OPTIONS:
   ------------------------------------------------
      1.   ETo 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.

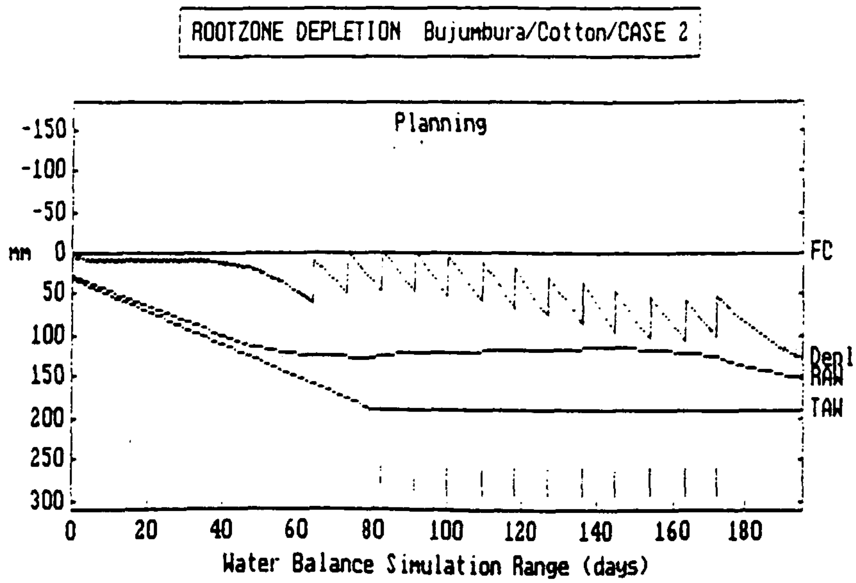

Figure 5.2. Root zone depletion for a case in IRSIS (Raes et al., 1988)

*** 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 (**IRRTURNS**). 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 **WATSCHED**, 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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6. FIELD IRRIGATION

6.1 Surface irrigation

Because the three controlled surface irrigation methods: basins, borders and furrows are the most wide-spread irrigation methods, their design and evaluation have received considerable attention. Their common denominator is the flow of irrigation water over the soil surface during a certain period, so that water can infiltrate and re-wet the root zone. From the moment water is let into the field, it advances gradually to the lower end of the field. Water inflow may be cut off (or "cut back" to a lesser value) before the field end is reached by the water front, at the moment it reaches that point, or some time later. Also, the far end may be open (leading to tailwater losses) or blocked (leading to ponding). All this indicates that there is a wide variation in practising surface irrigation. The basis is, however, that a certain point in the field knows a moment that the surface water arrives (the advance time) and a moment when there is no more water on the surface (the recession time), the difference between the two moments defining the intake opportunity time: the time during which water can infiltrate into the soil. For general descriptions of the various surface methods, many texts are available, but e.g. Booher (1974) and Kay (1986) provide relatively simple descriptive overviews.

Basin irrigation distinguishes itself from the other methods by a zero gradient and an often longer ponding phase in relation to the water advance phase. It also shows an almost instantaneous recession: the entire field falls dry at about the same moment, due to the level topography. In the USA terminology, basin irrigation also includes low longitudinal gradients and one speaks of level basins to make the distinction (compare Dedrick et al., 1982). In hydraulic terms, one tries to obtain a high water application efficiency (average depth required over average depth applied) and a uniform distribution over the field (comparing bottom end infiltrated depth to top end infiltrated depth). Small basins, with a short water advance phase and a long ponding phase, can have very high application efficiencies and uniformities, but may otherwise be uneconomical (required labour for levelling, obstructions by bunds, required field canal density, etc.). There is a possible distinction between (i) many traditional smallholder basin irrigation systems, which have (too) small basins, where the water utilization is a secondary concern, and (ii) large-scale basin irrigation, where especially the uniformity of water distribution over the large basins is a major concern. Design methods have primarily been concentrating on the large-scale type of basin irrigation systems.

Border (-strip) irrigation is characterized by the sloping land surface in the longitudinal direction and the zero gradient across the field. For the purpose of sideways spreading, one often sees a head ditch or a small section with a zero slope at the head of the field. Borders also have a relative great length/width ratio as compared to the traditional basins. Water control is more critical than with level basins, since infiltration takes place between water advance and recession, in the absence of a ponding phase. Thus, very careful levelling and inflow handling is required to avoid poor water distribution uniformity. Flow rate selection and/cut-off timing are more critical than in level basin irrigation. Design criteria include the width and the length of the border strip, the longitudinal slope, the stream size and the application time, although width and slope are to a certain extent dictated by existing conditions. Other factors like infiltration rate, application depth and surface roughness cannot normally be modified and are soil and crop dependent. In practice, border length, flow rate and application time are the variable design parameters available to ensure uniform application.

Furrow irrigation is different from the two other surface irrigation methods in the easier handling of cross slope in a field and in that it does not wet the whole soil surface, but rather uses shallow, narrow-spaced field "channels" to transport the water slowly from the upper to the lower end of the field, thereby not only counting on vertical downward infiltration, but also on horizontal, sideways wetting of the soil, and some upward capillary rise. The method is especially suitable for row crops as it requires mechanized land preparation (levelling and ridging) anyhow. Crops are planted on the side(s) of the ridge to avoid salinity effects. Design criteria include furrow width, depth and shape and furrow length, slope of the furrow, inflow rate and application time. Mechanization, crop density and soil texture (wetting) determine furrow spacing and furrow shape, so that, hydraulically, furrow length, inflow rate and application time remain the basic engineering design variables. Field application efficiency and distribution uniformity are important parameters for the hydraulic performance of a furrow irrigation system, and efforts to improve on these in-field parameters include the use of cut-back flows and the application of surge flow. Re-use of tailwater has also been introduced where water is scarce to improve water use efficiency on a farm, scheme or project basis.

This short description of the major controlled surface irrigation methods may suffice to demonstrate that surface irrigation has been and still is very much concerned with efficient and uniform water distribution over the field. There has thus been a strong emphasis on the two most important parameters in surface irrigation, i.e. infiltration of water into the soil and the advance of water flowing over the soil surface. Infiltration received substantial attention over a long period leading to may infiltration formulas (Green & Ampt, Kostiakov, Philip, SCS intake families and the like; compare ASAE, 1983).

At the same time, hydraulic engineers tackled the formulation and description of shallow water flowing over relatively rough surfaces. The basic hydrodynamic Saint Venant equations produced obstacles for analytical solutions, but numerical solutions became easier with the advance of the computer (see: Strelkoff & Katopodes, 1977). This led to a renewed interest in the hydraulics of surface irrigation, in the application of hydrodynamic theory in the analysis of surface flow (cf. Bassett et al., 1981; Walker

& Skogerboe, 1987) and the development of computer programs for design and analysis of such systems.

6.2 Surface irrigation programs

Microcomputer programs dealing with surface irrigation date back less than 10 years, although work on mainframe computers started another decade or so earlier. They are based on a set of two governing equations: the continuity equation and the momentum equation (i.e. the Saint Venant equations). According to the way in which these basic equations are applied, three types of models are usually distinguished (see e.g. Bassett et al., 1981):
- without major simplifications: "full hydrodynamic models";
- disregarding the acceleration term in the equation of motion: "zero-inertia models";
- replacing the momentum equation by simpler assumptions: "kinematic models".

Full hydrodynamic models are accurate, but delicate and require considerable computer time; they can be standards against which simpler models can be tested (see Figure 6.1.).

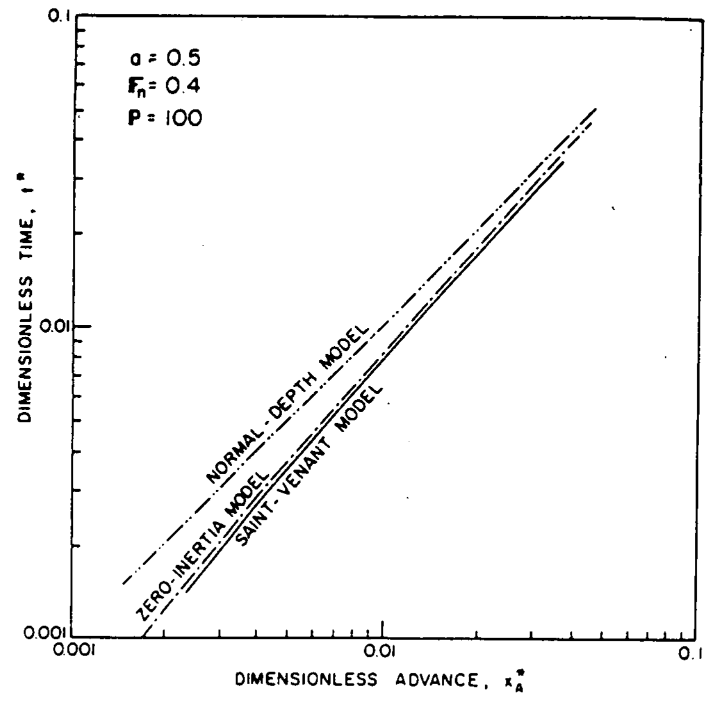

Figure 6.1. Inter-model comparisons (Basset et al., 1981)

The zero-inertia models, however, have received much more attention, especially since the publication by Strelkoff & Katopodes (1977). A direct result of this work was the border flow program BRDRFLW (Strelkoff, 1985). There are quite a number of publications dealing with the zero-inertia models, but e.g. Maheshwari et al. (1989) found in Australia that the zero-inertia form of BRDRFLW worked very well for analyzing field collected data. Later programs like BASCAD for basin irrigation (Boonstra & Jurriëns, 1988) applied the same zero-inertia approach but used other algorithms and numerical solution techniques (like the Newton-Raphson iteration). An update of BRDRFLW called SRFR was published recently (Strelkoff, 1990). It covers furrows, basins and borders and can be run in full hydrodynamic, in zero-inertia or in kinematic-wave (or normal depth or uniform flow) modes.

Two types of kinematic models have been distinguished (Walker & Skogerboe, 1987). The first kinematic approach assumes a unique relation between flow rate and flow depth. This leads to so-called kinematic wave models, or also uniform-depth models, because the relation between flow rate and flow depth is often uniform flow equation like Manning, Chezy or Darcy-Weisbach.

A second approach to replace the momentum equation assumes a constant average cross-sectional surface flow area over the length of the field, and thus has, in fact, no real relation "kinematics". The latter is also called "volume balance model" (see e.g. Walker and Skogerboe, 1987). An example of a small "volume-balance" based Fortran program for computing uniformity, efficiency and losses in surface irrigation (basin, border or furrow) is mentioned in a standard irrigation textbook (James, 1988) and a similar one in Basic for furrow irrigation design in another textbook (Cuenca, 1989). The FAO program SURFACE (Walker, 1989) is another example of this approach. A brief description the four named surface irrigation programs follows (for details, see Annex 1). We have not tested a Utah State University surface irrigation simulation model SURMOD (USU, 1992), which seems to be able to do roughly the same as the undermentioned SRFR.

Finally, the observation by Walker (1989) is supported, stressing that mathematical treatment of surface irrigation is only one tool in arriving at a good lay-out; other factors like size and shape of individual land holdings, land consolidation programs, farmer preferences, and equipment limitation may have a greater weight. It is good to realize that the mathematical models are only applicable in part of the design process and that uniform water distribution (the core of all discussed models) is only one aspect.

*** BASCAD ***

This is an ILRI program, meant for the Computer-Aided Design of level BASins. It simulates advance and infiltration in a level basin with water reaching the far end of the basin. It can be used to find various design variables, such as basin length, inflow rate and application time, or for the analysis of operational alternatives, depending on the mode in which one is operating. One can run in four modes, the first two produce acceptable estimates of design values (for basin dimensions and flow rate respectively), which can be refined and analyzed in modes 3 and 4. In modes 1, 2 and 3 the required infiltrated depth is realized at the basin end, whereas in mode 4 under- or over irrigation may occur, depending on the input.

The program has been tested extensively against the BRDRFLW program (see below), showing the same results for all practical purposes. Yet, the mathematics of the program are not shown on the screen nor explained in the manual, and one thus is faced with a black-box like operator.

The main advantage of the program is that it is fast and that operation is simple and user-friendly. The most recent version (May 1992) provides clear pull-down menus, help screens and graphical presentation of results. Soil infiltration parameters can be given in different ways, as well as units for all inputs. To enable comparison of alternatives, with yardsticks like application efficiency and storage efficiency, final or intermediate results can be stored in separate or combined files and can be shown on the screen. Some possible uses of the program are indicated in Jurriëns and Boonstra (1991), from which Figure 6.2. was taken.

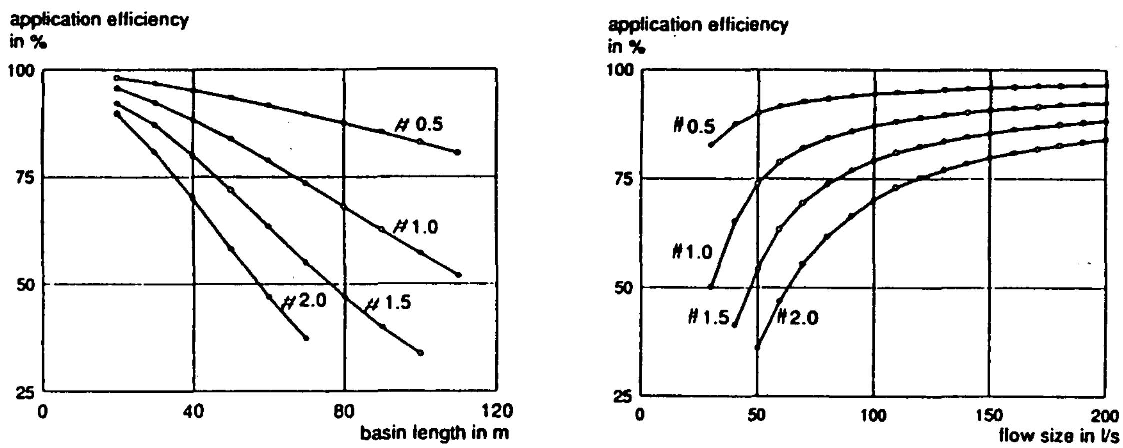

Figure 6.2. Relationships for different soil types calculated with BASCAD runs (Jurriëns & Boonstra, 1991)

*** BRDRFLW ***

This USDA-ARS program calculates the behaviour of the surface stream flowing down an irrigation border with a known infiltration curve. Other physical input data besides infiltration parameters are border length, longitudinal field slope, surface roughness and whether the downstream end is blocked or draining. One subsequently has to specify such management parameters like required application depth, inflow rate and cut-off time.

In contrast to modes 1-3 of BASCAD, the minimum infiltrated depth will not equal the required depth, until a number of iterative runs are made. The program thus clearly is meant for analysis, since design variables must be specified beforehand. The printed results are tabulated figures regarding advance, recession, and run-off as a function of time; application efficiencies and the final water distribution are also shown. The program could assist the designer by evaluating carefully varied series of input data. It is mainly researcher-oriented.

This Fortran program, of which version 7.2 of 1987 was tested, requires a printer to be attached to the computer. It takes considerable run time on the test machine (some 20 minutes) and it takes quite some time to study the manual, before the program can be operated successfully. The manual has a good theoretical background section. The program is now virtually obsolete, since its successor SRFR can do more.

*** SRFR ***

This sequel to BRDRFLW is also a model for surface irrigation analysis, rather than for synthesis and design. It was summarized by Strelkoff (1991), mentioning limitations as well, and there is a manual dating from December 1990 (Strelkoff, 1990). Again, design values like length of run, inflow rate and cut-off time should be given (together with other relevant parameter values), and the program will yield the ultimate longitudinal distribution of infiltrated water and the volume of run-off. The main differences with its predecessor are (i) that it addresses all three types of surface irrigation, (ii) infiltration, bottom slope and roughness may be varied over the field length, (iii) inflow can be input as constant, as surges or as a hydrograph, (iv) infiltrated volumes between stations are now computed continuously (and not after calculating advance and recession curves at the end of the run) and (v) time and distance step sizes are determined automatically, depending on the specified number of (computational) sections in which the field length will be divided. Running the program requires going through a preparatory program and running time is still about 20 minutes on the Compaq test machine (without a math co-processor). The promised plotting facilities appeared not to be generally applicable and the output remains a long list of figures.

Summarizing, the program is still very much researcher-oriented, with a pre-occupation for physical and mathematical theory, typical for the development stage in an academic environment. Appearance and user-friendliness have not been important considerations, apparently, but work on a more comfortable user-interface, especially for input and out, is said to be in progress.

* SURFACE *

This program belongs to FAO Irrigation & Drainage paper 45 (Walker, 1989), but can also be obtained from Utah State (USU, 1992). It illustrates Chapter 5 of Walker (1989) on surface irrigation design based on the volume balance design method. It can deal with sloping basins, with open-ended or blocked borders, and with three types of furrow irrigation, i.e. traditional systems, systems with a cut-back system and systems with a tailwater recirculation facility.

Again, this is mainly an analysis program, into which values for design variables like length of run and flow rate are entered, together with slope, application depth, flow geometry, surface roughness and infiltration characteristics. Output then produces a list of possibilities for e.g. border width, unit flow, advance and cut-off time and application efficiencies. There is no separate manual.

6.3 Pressurized irrigation programs

"Pressurized irrigation systems" is a term which combines sprinkler and drip irrigation, which are characterized by a piped water supply and distribution network, through which water does not flow under gravity but under above-atmospheric pressures of some 200-1000 kPa. The piped distribution network is the subject of another chapter (Chapter 9). The field irrigation aspects of sprinkler and drip irrigation systems are, in line with the above surface irrigation systems, mainly concerned with distribution. Extensive research has been done on the subject of water distribution under stationary and moving single emitters (drippers or sprinklers), showing influences of pressure, opening size and external conditions (especially wind and evaporation).

Sprinklers are still tested in factories and in research stations for their distribution pattern, using catch cans in a grid pattern, whether or not according to standardized procedures (as e.g. prescribed by the ASAE in 1969). Efforts have been made to describe sprinkler distribution patterns as triangular, elliptical, truncated triangular, etc., which would facilitate the mathematical computation of field uniformities resulting from certain lateral spacings and sprinkler spacings on the lateral. This overlapping could be easily simulated once the distribution for a single sprinkler is known. Uniformity coefficients such as those of Christiansen or Wilcox-Swales could then be calculated, or other frequency formulations like e.g. pattern efficiency, gamma and beta distributions (compare e.g. Heermann & Kohl, 1981; Karmeli et al., 1985; Pair et al., 1983). Such procedures may easily be facilitated by the use of a small computer program, an example of which is CATCH3D, made at Utah State University.

For moving sprinklers, such as in a center-pivot system, the path of travel of each sprinkler can be described mathematically and assuming a known single distribution pattern, a resulting field distribution and uniformity could be calculated (disregarding wind and motion influences).

For drip irrigation the water distribution question has received somewhat less attention, also because uniform wetting of the whole soil is not intended, irrigation intervals may be very short, and because emitter non-uniformity may add considerably to the variation in infiltrated depth. Reference can be made e.g. to numerical solutions of the water flow under trickle irrigation by Lafolie et al. (1989). Readily available computer programs for practical purposes were not immediately found, but would be available in Israel and the USA. At this point in time we do not have any such program available. The integrated design package IRRICAD 5, to be released in 1993 from Lincoln University, New Zealand, would probably contain distribution information, among many other features. A French package PB2DIAM, which calculates a micro-irrigation field lay-out, may be relevant CEMAGREF (1992).

*** CATCH3D ***

A small Basic program which builds up a 3-dimensional data file of catch can data obtained from single sprinkler tests or from lateral line tests. It then allows sprinkler spacings, in multiples of the catch can grid, to be simulated. Uniformity and distribution data for these simulation are calculated and resulting three-dimensional overlap pictures are shown and can be printed (Figure 6.3). It is an example of a simple, straight-forward program which facilitates bothersome computations and which allows both graphical and numerical output. The latest is version 4.4 (USU, 1992).

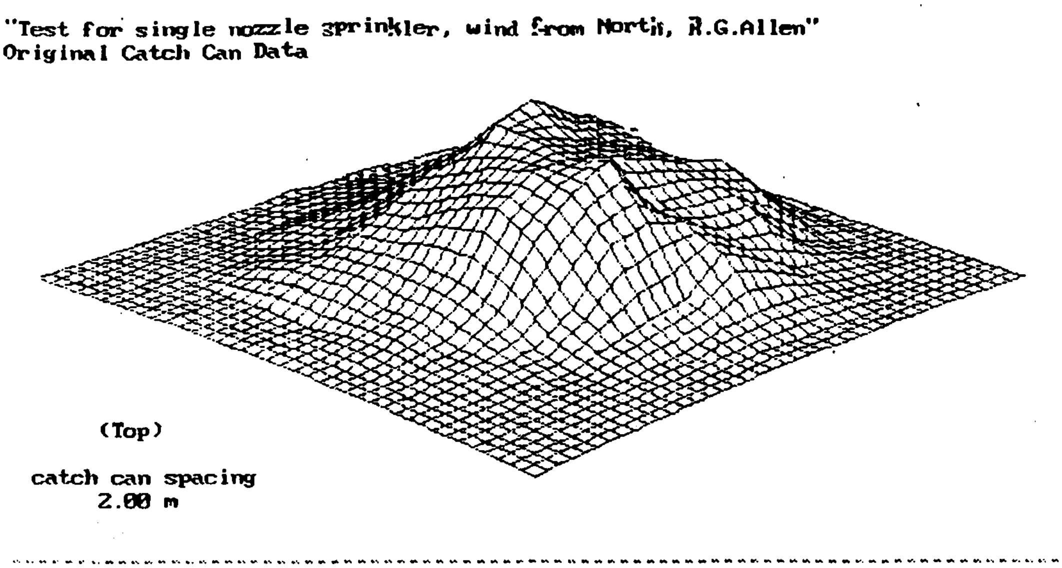

Fig. 6.3. Example of graphical output with CATCH3D

6.4. Other programs

We should mention that we have tried to test two other basin irrigation programs, **BASIN** and **BICAD** (Annex 1). BASIN was made at the USWCL in Phoenix, USA and dates from September 1990. There are Basic and Fortran files available on the disk and apparently pull-down menu's are to be followed for obtaining design values for level basins. It would need thorough polishing before it could be issued for general use. Another problem seems to be that it is entirely built around a concept of designing for maximum lengths. BICAD, a Border Irrigation Computer-Aided Design program, was made in Australia (University of Melbourne) in 1990. No manual or any other information was available and errors occurred on the test machine for our version. Apparently, there is an updated version called BICADAM, with a manual, but we do not have it.

There are more surface irrigation programs: e.g. CEMAGREF in France, among others also developed a surface irrigation program called **RAIEOPT** (CEMAGREF, 1992). It determines the hydraulic performance of furrow irrigation for a chosen flow rate. Finally, we received a comment copy of the Leuven program **FISDEV** (Annex 1) for Furrow Irrigation Systems Design and EValuation. The program as such seems to work, but there are deficiencies and inconsistencies. There is a draft manual, which helps to understand a few programming ideas, but which needs a better introduction and thorough editing. It is described by Zerihun & Feyen (1992) and would be published in 1992; it is available at BF 1000.

The above-mentioned programs are mainly concerned with above-ground water flow and use existing water infiltration functions. Program **SWM II**, however, simulates water infiltration under furrow irrigation, using a two-dimensional finite element transient water flow model. It has instructive graphics and is described by Vogel & Hopmans (1992).

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7. CANALS AND CANAL NETWORKS

7.1 Open channels

Most irrigation schemes in the world have a distribution network that consists of open channels, i.e. water conveyance canals with a free water surface (in which there normally is atmospheric pressure). Water flow in and the design of single canals or canal networks have, therefore, always been a major interest for irrigation engineers. In this area of open channel hydraulics, various types of flow can be distinguished, as outlined in the standard work by Chow (1982). The simplest computations are for steady uniform flow and are often based on the well-known Manning formula:

$$Q = v * A = (1/n) * A * R^{2/3} * S^{1/2}$$

The reciprocal of the Manning roughness coefficient n is also called the Strickler coefficient Ks or the Manning factor kM. Usually, the bottom width and the (normal) water depth often are the two design variables. In cross-section computations then a desired Q is given, n (or Ks or kM) must be specified, while the side slope of the commonly used trapezoidal shape must be input, together with the bed slope S. Because the section parameters (width and depth) cannot be calculated directly, previously nomographs were used, but these days the computer is a helpful tool by executing the iterations (see e.g. small simple programs in standard irrigation textbooks by James, 1988 and Cuenca, 1989). Specifying the freeboard then allows one to calculate the top width of the canal as well, and the total excavated area. Water or bed levels in respect to the ground level then allow cut and fill volumes to be calculated.

The design of channels for uniform flow is relatively straightforward for non-erodible channels, such as lined channels and those excavated in firm foundations such as rock bed. The roughness, the channel bottom slope and the side slopes, the freeboard and costs aspects are the factors to be considered, in addition to a minimum permissible velocity so that no deposition of silt occurs. In erodible channels, the most common earthen channels, there is also a maximum permissible velocity to be considered, i.e. the maximum that will not cause erosion. This is an additional consideration, for which sometimes also the tractive force is calculated and assessed. Attempts have been made to define an average non-silting non-scouring velocity, based on work in the Punjab, later replaced by Lacey's (also India-based) regime theory and other approaches (see for a review: Lacey, 1969). The regime equations require some indicator for the silt particle size as an input and result in wide and shallow canals. In countries with heavy sediment laden irrigation water such as India and Pakistan regime theory formulae are still applied.

Although practical irrigation engineers usually work with uniform flow only, other flow types are dealt with as well for special conditions. In non-uniform steady flow, depth and cross-sectional area of flow vary from one cross-section to another, and this pattern is constant (steady) in time. Local accelerations can be neglected in this type of flow. The non-uniformity can be in the form of gradually or rapidly varied flow (compare: zero-inertia approach in surface irrigation). Gradually varied flow is characterized by water profiles which are usually referred to as "backwater curves". Such water profiles are required to analyse situations occurring during operation and deviating from design.

Rapidly varied flow takes place over very short distances as for instance at the entrance or exit of a canal, or at an obstruction like a bridge, a weir, a cross-regulator or an offtake. Also the change from shooting water to tranquil flow, via a hydraulic jump, is an example of local rapidly varying steady flow and lends itself to computation (water depths, head loss, location).

Unsteady flow in open channels may be characterized by the changes in an inflow hydrograph shape as it propagates along the channel. One normally observes an attenuation of the wave as it propagates downstream. The phenomenon is complex and analytical solutions are limited. However, for computerized calculations the basic differential equations of motion (or the momentum equation) and the continuity equation (together also called the St. Venant equations) can be applied and simplified in various ways and degrees, depending on the aim and the flow type. Over the past decades various techniques for solution of the set of equations have been developed such as finite difference schemes, the Preissmann scheme etc. This specialized issue is reviewed and discussed e.g. by Strelkoff and Valvey (1991) and Liu et al. (1992). Non-steady flow calculations are important for flood routing and urban drainage computations but until recently were used in irrigation on a small scale only. Due to increased computing power, application of unsteady flow models in irrigation canal programs has rapidly gained popularity in recent years. It was a major issue at the 1991 ASCE Hawaii Conference (Ritter, 1991) and featured high during a 1992 Montpellier Workshop on mathematical modelling for irrigation canal operation (CEMAGREF/IIMI, 1992).

7.2 Types of programs

There is a wide variety in types of canal programs. A program can deal with a single canal or with a branched or looped canal network. It can deal with choosing alignments or lay-outs, with hydraulic calculations only, or it may include aspects of earthwork and costs as well. For the installation of larger canal systems, network planning programs may exist. However, this chapter is limited to programs that calculate or simulate flow in canals. As seen above, the hydraulic calculations may concern various flow types. Uniform flow usually only calculates levels, flows, or canal dimensions, whereas the non-steady models simulate flow and level variations over time and place.

Programs for networks are rather complex, because they normally include non-uniform unsteady flow calculations for a large number of canal sections, and many and various irrigation structures, under different operational control rules. They are thus more integrated programs, combining single canal flow simulation, flow through structures, wave propagation, etc. This means that more data need to be stored and accessed, that computations are numerous and need to be fast (co-processor needed), and that graphics require considerable memory capacity.

In the above mentioned Hawaii and Montpellier proceedings a discussion is slowly emerging on whether canal programs should be based on steady or unsteady flow. Arguments for the latter are that steady flow hardly ever occurs in real irrigation networks and that the theory is now well-established. Others point at the calibration problem (e.g. Holly & Merkley, 1991) and argue that the use of unsteady models requires a tremendous amount of data collection which may makes them rather unpractical. Additional problems are related with the varying and continuously changing roughness coefficients and canal dimensions.

There is also no agreement on which program should be used for what purpose. At both occasions it was concluded that no program was known to be in practical use for real-time control, and that most programs so far are used for comparing and testing scenarios and what-if questions (CEMAGREF/IIMI, 1992). Even these programs need to be tested thoroughly Contractor and Schuurmans (1991), and be made more user-friendly (Burt & Gartrell, 1991; Clemmens et al., 1991a) to be useful for the average engineer.

As for the followed classification of programs for single channels and open distribution networks, it is realized that there is some overlap between the canal network programs and the management programs discussed in Chapter 10. The present chapter on canals only discusses programs dealing with hydraulic calculations and design, whereas the programs in Chapter 10 also include other aspects such as historic database management (climate, operation), crop water requirements, scheduling, etc.

7.3 Programs for single channel design

In the world of theoretical hydraulics, in hydraulics laboratories, universities, etc., computerized computations of all kinds of hydraulic phenomena have been practised for a "long" time. Numerous programs must exist all over the world for various types of canal hydraulics computations. Because we are not familiar with this world, we make no reference to such programs, with two exceptions on basic hydraulics. Subsequently, we further mainly discuss programs that have been developed by irrigation engineers for specific application in irrigation. The two exceptions are given as examples of the numerous small programs in Fortran or Basic that have been included in various hydraulics textbooks over the past 3-7 years.

One example is the computation of backwater curves, according to the standard step method, which is presented (as program "Channel") in Douglas et al. (1985). For non-steady flow we mention another example from the same reference: a computer program

("Waves") calculating wave attenuation in an open channel of circular or rectangular cross section. Other numerical solutions that apply the method of characteristics for this type of flow are also found nowadays (cf. Thompson, 1987).

With respect to programs for design of single canals for irrigation (or drainage) one could further distinguish two types:
- uniform flow calculation of wet cross section for given flow or of capacity for given dimensions, by various formulae (Manning, Chezy, regime formulae, etc.);
- calculation of total sections, excavation and fill volumes, costs, etc.

In the irrigation educational sphere we can mention three (internal) programs from the Agricultural University at Wageningen and the International Agricultural College Larenstein in Velp (CANAL (!), CID and NESTOR). In addition, there is a well-documented Manning-based program from Delft University of Technology (PROFILE). From the consulting engineers there are internal programs like CANALDES, LACEY and REHAB, while DORC (for regime canals) stems from the research sphere.

*** PROFILE ***

This simple program (version 1.0) calculates unknown hydraulic parameters in the Manning/Strickler formula for trapezoidal channels, using a tabulated data sheet (see Figure 7.1).

STRICKLER FILE: a:\section2.can DATE : 01-01-1990

Q m^3/s	h m	ks-(1/n) m^1/3/s	b m	m (v:mh)	s 10^ -3	n (b/h)	v m/s	T N/m^2	E W/m^3
5.000	2.00	45.00	1.40	2.0	0.10	0.7	0.46	1.96	0.45
5.000	2.10	40.00	1.40	2.0	0.10	0.7	0.42	2.06	0.42

F1-HELP F2-SAVE F3-RETR F4-CLEAR F5-INFO F6-PRINT F8-DOS F10-QUIT

Figure 7.1 Sample calculation sheet in Profile (Hebermann & Schuurmans, 1991)

Most computations are straightforward, but for the determination of water depth, bed width and side slope for a given flow size, Newton-Raphson iterations are applied. Sample values for Ks are provided, but they do not give sufficient guidance, especially not for small earthen channels.

The manual (Hebermann & Schuurmans, 1991) is very explicit, although the editing could be improved. It is a nice small program for a small task. Possible improvements could be to include suggested values for b/h values, for permissible velocities, for side slopes, etc., and the inclusion of other channel shapes. It was made at the Irrigation Section of the Faculty of Civil Engineering in Delft.

*** CID ***

Version 1.0 calculates irrigation and drainage channels for uniform steady flow using Manning's formula. Two canal shapes are allowed (rectangular, trapezoidal) for lined or unlined sections. Four calculation options are: (i) normal situations, (ii) minimum slope, (iii) minimum earthwork volume, and (iv) minimum earthwork cost. There are numerical and graphical results which can be printed (see Figure 7.2), including cross sections, longitudinal profiles and earthwork quantities and costs.

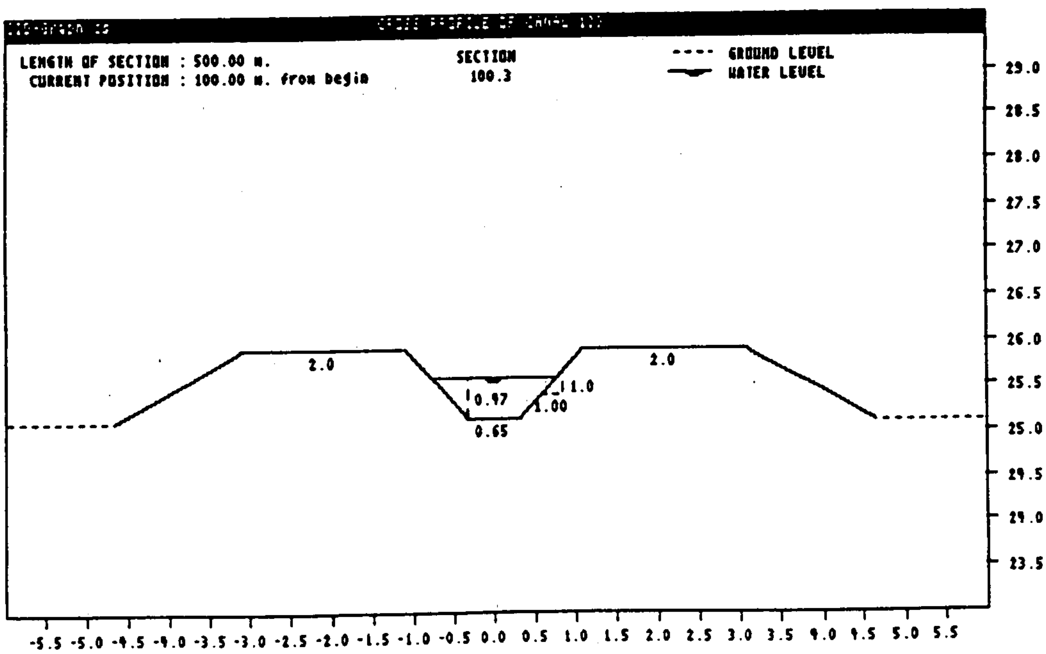

Figure 7.2 Example of a cross-section in CID graphics (Swennenhuis, 1989)

It is a small user-friendly program, which can be learnt quickly. The program was apparently made for students of Wageningen University and Larenstein College, and the language and the editing of the manual (Swennenhuis, 1989) could be improved.

*** DORC ***

This is a software package from Hydraulics Research, Wallingford (UK), with a number of routines that assist in the design of regime canals, i.e. unlined canals with sediment-laden water. The most common methods dealing with alluvial channel design are included, such as regime methods, tractive force, rational methods, and Manning, while also alluvial friction predictors and sediment transport for sand and silt can be rapidly calculated. It is an easy-to-use tool and computations are made quickly with this small program. Experience and judgement of the designer are still required, however.

*** Other programs ***

The **NESTOR** program for non-uniform flow requires a math co-processor. It was apparently written for demonstration to Dutch students at IAHL, Velp. The Dutch language is a drawback for wider distribution. Another non-completed program for non-uniform flow (**COBRA**) is used at the IHE, Delft, but was not available for testing.

CANALDES, LACEY, REHAB are three in-house programs in Euroconsult's "Land & Water Toolkit" (Schellekens et al., 1992). **REHAB** (not the game of Chapter 4) calculates cut and fill volumes in the rehabilitation of irrigation and drainage canals. It simulates the hand method by "counting squares" of overlapping old and new cross-sections in hundreds of places. Input is quite cumbersome, but the use of graphics is a nice feature. **LACEY** calculates a stable, non-scouring, non-silting canal cross-section according to the regime theory. Iterations are used to find bottom width, water depth and mean velocity. **CANALDES** is in fact a package of four small programs, one for calculating cuts and fills, one for drain excavation volumes only, a third one for canal design using Manning's formula for trapezoidal channels and a fourth to calculate backwater curves for gradually varied flow. The direct step method is used (Chow, 1982), which is only applicable to prismatic channels. The above three Toolkit programs must be classified as still under development.

CANAL is a small program for calculating cross-sections of trapezoidal channels using Manning's formula, under development at the Department of Irrigation and Soil Conservation of the Agricultural University at Wageningen. It was not included in our tests (not to be confused with the USU program CANAL).

7.4 Programs for open distribution networks

The following canal programs are generally more elaborate programs, partly because of the large number of canal sections that can be simulated, but also because of the inclusion of control structures and offtakes with their hydraulic characteristics. We mention a few which we have tested, and some others which are described in the literature.

*** CANAL ***

The model was developed at Utah State University (USU), and was described by Gichuki (1988a), who also wrote a manual for the Fortran version (Gichuki, 1988b).

The Pascal version (Merkley, 1987) is currently supported by USU. It simulates canal flow in a branched network, with trapezoidal shaped canal cross-sections. It can calculate (non-)uniform (non-)steady channel flow and includes a hydraulic roughness calibration program, and a pump characteristic curve-fitting program. The data input and the simulation parts are physically separated. There are three operation modes: one interactive and one pre-set fixed user-specified setting of control structures, and one with automatic gate scheduling. There are adequate graphical and tabular screens available, both during simulation and after completion.

The program is available for USD 65 outside the USA (USU, 1992). A new version, correcting the shortcomings mentioned in Merkley and Rogers (1991), is under preparation.

*** DUFLOW ***

An extensive program, developed jointly by Delft University, the governmental Tidal Water Division, and the International Institute for Hydraulic and Environmental Engineering, provides a user-oriented package for unsteady flow computations in networks of open water courses. Apart from uniform and non-uniform flow calculations, it can address e.g. propagation of tidal waves in estuaries, flood waves in rivers and operation of irrigation and drainage systems. Free flow in open channels is simulated and control structures like weirs, culverts, siphons and pumps can be included. A simple rainfall-runoff relationship is part of the model. The program can be used for large river systems, but also for simpler irrigation and drainage networks, for which input hydrographs can be specified. Both graphical and numerical output are available. The most recent (1992) version 2.0 includes a water quality module.

Learning to operate the program fully requires at least a few days, although the manual is thorough and well-prepared. Program logic and menus are clear, especially with some assistance from the manual. The program was tested by the ASCE Task Committee (Clemmens et al., 1991b). Application under various conditions is increasingly documented. The distribution and support is done by ICIM in Rijswijk, The Netherlands, and the cost of version 2.0 is NLG 750.

*** Other programs ***

In the 1989 Southampton conference and in the 1990 ICID Congress, reference is made to a computer simulation of manually operated irrigation systems which are typical for Alberta, Canada, referred to as ICSS, Irrigation Conveyance System Simulation (Manz, 1989, 1990). The program was also presented at the Montpellier Workshop (Manz and Schaalje, 1992). There is a core program which deals with the specific canal hydraulics and subroutines representing different hydraulic structures and other characteristics may be added as required. The strength of the model is said to be the relation between theory and actual physical canal characteristics and operational practices. It is said to have been successful in both research and training environments. It was initially written in Fortran 5 for a mainframe computer but has now been made applicable for microcomputers.

The **MODIS** package for Modelling Drainage and Irrigation Systems was developed at Delft University of Technology (Schuurmans, 1991a), and was based on a river modelling package called Rubicon. It is a user-friendly computer model which can calculate the non-uniform unsteady flow phenomenon in controlled irrigation systems and compute operation performance indicators. MODIS was evaluated by the ASCE Task Force (Schuurmans, 1991b) on technical merit, modelling capabilities and user considerations. The price is about NLG 25,000, which is far above the possibilities of our target user.

SIC stands for Simulation of Irrigation Canals. The program was developed by CEMAGREF (Montpellier) in co-operation with IIMI in Sri Lanka. IIMI mentioned its development in its publications since 1988 (IIMI, 1988a; IIMI, 1988b; IIMI, 1989). More information was provided at the 1992 ICID conference in Budapest (Beaume et al., 1992), and at the Montpellier Workshop (Beaume & Malaterre, 1992). It appeared that the program has two separate modules for either steady or unsteady flow in tree networks. The model was tested (but without calibration), mainly in evaluating various delivery schedules, on a 25 km stretch of the right bank main canal of the Kirindi Oya scheme in Sri Lanka, as described by Rey and Wijesekera (1992). In Pakistan (Habib et al., 1992) SIC appeared to be best at main canal level, where physical control opportunities were better than at secondary level. Further detailed information on the program was not provided. The latest version dates from May 1992 and costs FF 80,000 (CEMAGREF, 1992), which in our terminology means that it is not available to the common irrigation practitioner.

Other programs mentioned at the Montpellier Workshop were **SYMO** (Manguerra et al., 1992), and **CANALCAD** (Holly & Parrish, 1992), which is based on CARIMA (see below), and **SIMWAT** (Manzanera, 1992). Most of these programs were either rather site-specific developments, or still under test, with no clear indication of making them suitable and available for other potential users.

The ASCE "Task committee on irrigation canal system hydraulic modelling" reported that it examined only those programs which could model user defined canals and were readily available, which appeared to be six programs (Clemmens et al., 1991a). Three of them were discussed above (CANAL, DUFLOW, MODIS); the three remaining are: **USM** (Rogers & Merkley, 1991), **SNUSM** (Gooch & Keith, 1991) and **CARIMA** (Holly & Parrish, 1991). For a description and evaluation of these programs reference is made to the respective articles. They reveal that all programs have serious shortcomings in the field of user-friendliness, they are cumbersome to handle the input data and take considerable skills and time to learn. In general, the committee concludes that "models for the prediction of unsteady flow in irrigation canal networks are in their infancy of development. While significant advancements have been made, there is much more progress to be made before they can be routinely used by practising engineers" (Clemmens et al., 1991c).

There are undoubtedly more programs, in various stages of development. But looking for readily available programs, the above listing seems to be rather complete. Only two more programs are briefly mentioned: One is **LYMPHA**, an open distribution network model, developed for the Province of Gelderland (The Netherlands) by the Department of Hydrology, Soil Physics and Hydraulics of the Agricultural University at Wageningen. The Fortran program has an extensive manual, regrettably in Dutch (Kors & Promes, 1990). The other is **MIKE 11**, developed by the Danish Hydraulic Institute. The information contained in a brochure on the program package suggests much similarity with DUFLOW. The program was not available and could therefore not be tested.

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8. PIPE NETWORKS

8.1 Pipe flow

Although the majority of the conveyance of irrigation water is by open channels, closed conduits or pipes also play an important role in water transport, especially in pressurized irrigation systems like sprinkler and drip irrigation. However, pipes may also be found in other irrigation methods, either as short sections (such as culverts, syphons, gated pipes) or in longer supply sections, e.g. over difficult terrain, over high-seepage sections or otherwise as buried supply lines. In such applications, pressures are normally lower than in sprinkler and drip irrigation systems, which leads to different materials being used. In situations where water, land, and labour are scarce and expensive, the advantages of buried pipes like no seepage losses, no loss of land, low maintenance, and possible automation may outweigh the high installation cost.

Similar to open channel flow, irrigation water flow through pipes is a standard component of irrigation engineering. The hydraulics of pipe flow have been studied for a long time and quite a number of empirical and more physically-based formulas have been developed e.g. to relate flow rates to pipe diameter, head loss and material properties. Although laminar flow occurs (e.g. in long path emitters in drip irrigation), most practical problems of irrigation water flow in pipes have turbulent flow conditions. For steady incompressible flow through pipes, expressions like the Weisbach-Darcy formula have been developed, in which a friction factor appears. For this factor often the Colebrook-White formula is used (see Labye, et al., 1988), for both smooth and rough pipes, and to ease its solution, the Moody diagram is often used. In a way similar to the procedure for solving Manning's equation, the use of nomographs like the Moody diagram to find pipe diameters is no longer necessary if a small computer program that performs iterations is available (compare program CBW in Douglas et al., 1985).

Apart from the theoretically more correct Darcy-Weisbach formula with the Colebrook-White equation, in irrigation design often more empirical formulas are used, such as the Scobey or Hazen-Williams equations, or the Manning equation, all with properly adjusted material constants. The Hazen-Williams equation is the most common relation between friction loss (hf), pipe length (L), pipe diameter (D) and discharge (Q), which could be written as (using g= 9.8 m^2/s):

$$Q = 0.278 * C(HW) * D^{2.63} * (hf/L)^{0.54}$$

in which C(HW) is the Hazen-Williams pipe coefficient, which is tabulated in various handbooks (e.g. Pair et al., 1983). Again, instead of using nomographs (Pair et al., 1983) or tables (Finkel, 1982), a simple computer program can easily solve practical design problems like finding minimum diameters (because of the cost) at acceptable head loss for a certain section.

It is a relatively easy operation to program the inclusion of available pipes with details such as materials to choose from, marketed diameters, strength (allowable pressure) and the prices.

8.2 Pipe networks

The simple problem of finding an appropriate diameter for a certain pipe section (similar to finding a cross-section for an open channel stretch) often is only a part of the design process of a pipeline system or network. Such a network could start at a pump, where a main line conveys the pressurized water to the irrigation site. There, branches and sub-branches may spread out, which feed portable or fixed sprinkler laterals, or drip lines. Local head losses are then included as well (entrance losses, obstructions like bends, valves, enlargements, etc.). Hydraulically, such a system is mainly governed by the required pressures and discharges at the outlet points (drippers or sprinklers), which may only vary within set limits (such as 20% per lateral, e.g.) from the design specifications. The design work then normally consists of securing these Q and P values through the proper choice of pipe material and pipe diameter, the possible use of valves and boosters, and, ultimately, the required pump capacity. Apart from hydraulic considerations, topographical details (elevations, system lay-out) are required as well (cf. Weizman, 1986).

The system lay-out is governed by many non-hydraulic factors and is far less easy to simulate in a computer program, although there are major CAD programs written to deal with this issue. However, what we are concerned with here could be described as fixed networks, i.e. networks for which the lay-out has already been determined. This also means that it has been decided beforehand whether the system is branching (like a tree) or if it is looped (ends are linked; inflow from more directions possible).

It is clear that irrigation could borrow from the experience in drinking water distribution networks, an area where the use of mathematical models for design, operation and analysis has advanced considerably, not only for large water supply systems run by Water Boards on mainframe computers (cf. WATNET and GINAS, described by Wright & Cleverly, 1988). Microcomputer versions have been made more recently, also for developing countries (Thorley & Wood, 1988). Relatively early application of microcomputer programs in improved planning and design of water supply systems happened in Israel (Kadar, 1986), but also in developing countries, as illustrated by a set of UNDP/World Bank programs, briefly mentioned below (UNDP/WB, 1987). These could be useful for irrigation networks as well.

Networks are represented mathematically by reaches and nodes. Each reach is characterized by the flow rate and the change in head and each node is characterized by the flow rate entering and leaving it. For a network operating at a given time under steady state flow and with set boundary conditions, node equations (based on continuity) and reach equations (based on head losses) can be written.

For single source, branching networks, only the reach equations need to be solved (e.g. using Hazen-Williams). In this case, optimization by linear programming could yield the best alternative network, both hydraulically and economically (cf. Karmeli et al., 1985). Kamand (1987) described the use of Critical Path Analysis for optimizing branched pipe networks and Haghighi et al. (1987) mention the application of the Finite Element method.

For looped networks, however, more powerful techniques are required, such as the Hardy-Cross approximations or the Newton-Raphson iterations. Algorithms have been developed to ensure convergence of the iterative procedures. For a simple example of the Hardy-Cross procedure, see the program "Hardyc" in Douglas et al. (1985). The use of a network solver, i.e. a set of computer programs that provide the solution (flows, pressures, operating points of pumps and valves) for a pre-defined network under pre-defined operating conditions is described and illustrated extensively by Karmeli et al. (1985). They could be used both for planning and design and for operation of existing networks. Avni (1986) also mentions the use of a network solver in Israel.

8.3 Programs for network calculations

We have mentioned a number of references to drinking water supply networks and to piped irrigation distribution network programs. Standard irrigation textbooks nowadays start to include small computer programs, as we have mentioned before, and James (1988) includes a relatively extensive Fortran code for the calculation of pressure distribution along sprinkler or drip laterals, submains and mains. This program has not been tested.

We have also indicated above that the boundary between (drinking) water supply networks and pipe networks for pressurized irrigation systems is not very strict. We therefore include in this short description a brief overview of the UNDP/WB water supply programs. Apart from this, FAO (s.a.) have issued a pipe optimization program (we called it OPTIPIPE in the comment forms), which is a cost versus diameter program for a branching network. We then also briefly discuss two small in-house programs from a Netherlands consultancy firm, DRIPSPRI, HAZEN-W, from Schellekens (1992), and mention a few other references to programs for pipe networks in the literature.

* UNDP programs *

These programs relate to drinking water supply. At the end of 1985 ten small computer programs were made for a UNDP project on development and implementation of low-cost sanitation, executed by the World Bank. Of these 10 programs, five could be useful for piped irrigation as well. **HEADLOSS** computes the head loss in a defined pipe length using the Hazen-Williams equation.

MINTREE uses a minimum spanning tree algorithm to find the shortest path connecting the nodes of a primary branches system of a looped network. Both run under a machine-resident Basic version. They are quick and short. The programs **BRANCH** and **LOOP** are compiled Basic programs.

BRANCH uses a linear programming algorithm and the Hazen-Williams equation for the optimal least cost design of branched distribution networks. LOOP uses the Hardy-Cross analysis and the Hazen-Williams formula to provide flow rates, velocities and head losses for a given network, with HI and LO indicators. Alternative design can be quickly compared, also in terms of cost. Both work nicely. The **FLOW** program is similar to LOOP, but is written in Fortran and is based on Newton-Raphson's method for solving non-linear equations and either Manning or Hazen-Williams. The program is rather inflexible in input/output handling.

*** OPTIPIPE ***

This is our name for a FAO program meant for optimizing pipe diameters, for which also a 68-page manual was prepared (FAO, s.a.). According to the relevant literature (Labye et al., 1988), the program must assist in finding the least-cost alternative for a branching pipe network in irrigation, by selecting the suitable diameters according to a method described by Labye. Unfortunately, the copy of the program seems to have serious difficulties: in ascending the network the program aborts due to a subscript out of range and on descending the network the same happens because of an "input past end" message. The manual is also not very clear at certain points (starting; running the example). The program and the manual seem in need of thorough revision.

*** Other programs ***

The small **HAZEN-W** program (Schellekens et al., 1992) calculates head losses in m/km and velocities (in m/s) for specified input including discharge and pipe diameter. **DRIPSPRI** assists in dimensioning sprinkler laterals or drip feeder lines, with their multiple outlets. Slope, outlet spacing, emitter number, design pressure and discharge per emitter, pipe diameter and the first/last deviation must be specified. Actual heads and discharges per opening are tabulated as output. The program (Schellekens et al., 1992) follows Perold (1977). There is also a small program called **TRICKLE**, which accompanies a Hungarian book on drip irrigation (Balogh & Gergely, 1985); this program calculates required head, pressure distributions, maximum number of emitters, etc., depending on the chosen option and available input data.

Thorley & Wood (1989) describe a program **SIMNET**, a pipe network model for potable water distribution systems, which can also be used for pressurized irrigation water networks. CEMAGREF (1992) also have a program for studying the behaviour of a pressurized distribution network called **ICARE**, which can be used for exiting or planned systems; the data input uses another program called **XERXES-RENFORS** (they are costing FF 20,000 each). Life cycle costing and hydraulic analysis are combined to determine least cost pipe sizes in a branching pipe network program called **NETDES**, which originates from Utah State University (USU, 1992). Pressurized irrigation system networks are also dealt with extensively by **IRRICAD**, a complete modern design program for conventional sprinkler irrigation, for micro-sprinkler systems and for drip irrigation systems, which is in the final stages of development at the Agricultural Engineering Institute at Lincoln University, New Zealand. The program handles a wide range of topics, from lay-out and pipe design to bill of quantities and cost estimates.

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9. STRUCTURES

9.1 Irrigation structures

Structures in irrigation systems can serve many purposes and can take many forms. USBR (1983) classifies the most common irrigation structures as follows:
- conveyance structures (e.g. inverted syphons, drops);
- regulating structures (e.g. checks, division boxes);
- protective structures (e.g. wasteways; cross drainage);
- water measurement structures (e.g. flumes, weirs);
- energy dissipators (e.g. baffled outlets, stilling wells);
- transition, erosion and sediment protection structures;
- pipes and pipe appurtenances;
- safety devices.

The relatively better documented among these are the conveyance, the regulating and the measuring structures. The smaller type of farm structures are discussed e.g. by Robinson (1983). Another useful classification is given by Manz (1987). Most conveyance structures can be designed in practice with relatively simple hydraulic formulae, while the flow regulating and measurement structures are hydraulically and mathematically more complicated.

Measuring and regulating structures can be classified according to their operation (fixed, open/closed, stepwise or gradually adjustable, automatic), their hydraulic properties (non-module, semi-module, module) or their function. The latter leads to distinguish:
- upstream water level control structures (e.g. barrages, cross-regulators, horseshoe or duckbill weirs, checks);
- downstream water level control structures (such as Neyrtec automatic gates);
- structures for controlling/regulating flow rates (e.g. constant head orifice, regulating flumes, Romijn weirs, undershot gates);
- flow dividers, such as divisors, division boxes, Neyrtec modules);
- structures for measuring flow rates (e.g. Parshall flumes, broad-crested or sharp-crested weirs, propeller meters).

Many of these structures, especially the smaller type, are discussed by Kraatz & Mahajan (1975). Discharge measuring structures are extensively treated in Bos (1988).

Structures for measuring and/or regulating flow rates are specifically concerned with the relation between the observable water depth and the wanted discharge. For non-module structures both upstream and downstream water levels are important, whereas for semi-module ones only the upstream water level counts (as long as they are not submerged) through the creation of critical flow in the control section. Formulas have been developed for this Q-H relation for many standard structures and tables have been listed (e.g. Bos, 1988).

Such tables could be conveniently replaced by computer programs in which the relevant formulae have been entered. Bos et al. (1984) published an early computer program for this purpose regarding long-throated measuring flumes, which was updated and extended by Clemmens et al. (1987); a further update will introduce design aspects as well.

9.2 Programs for weir design

All structures mentioned above need to be designed: their location and the materials need to be chosen, strength and stability determined and dimensions calculated. One would therefore expect to find design programs for a multitude of structures, in the more modern fashion probably including CAD/CAM drawing facilities. However, surprisingly few readily available programs for structure design were found so far in the irrigation area; a possible lead into road construction was not followed up. Actually, the FLUME program version 2.4 (for the design of long-throated flumes) was one of the few programs that could be tested; the other two (BCWEIR and BCW) are dealing with the same topic and the same structure.

*** FLUME ***

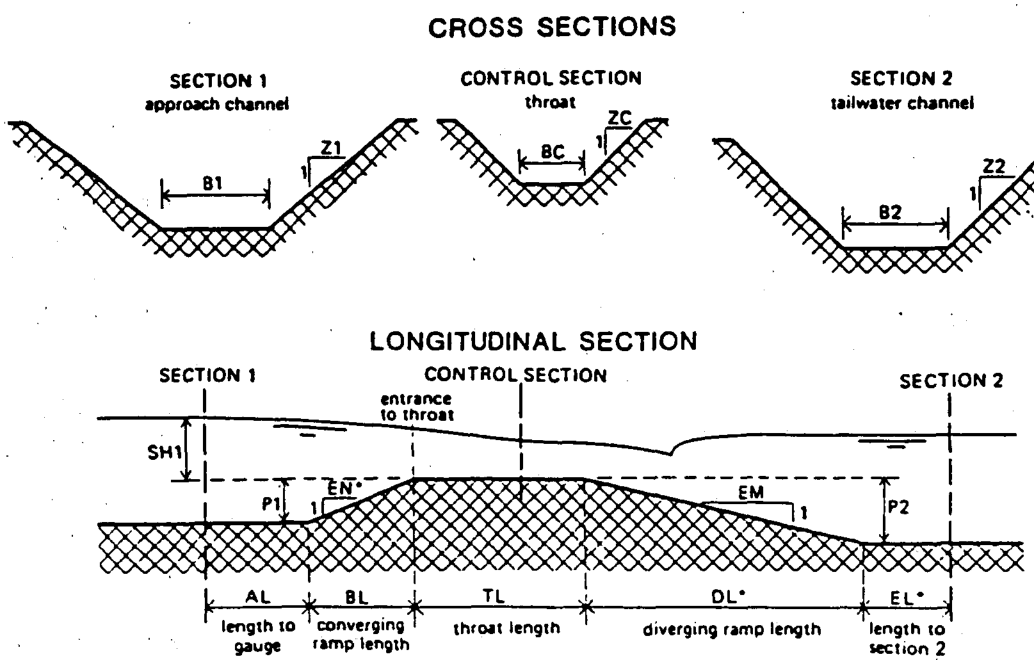

Figure 9.1. Input data for FLUME (Bos et al., 1984; Clemmens et al., 1987)

Long-throated flumes were discussed in detail in Bos et al. (1984), where also a Fortran IV computer program (dated 1983) was mentioned (based on Repogle's 1975 mathematical model) to determine accurate stage-discharge relationships for this type of measuring flumes. Input data for the computer program are shown in Figure 9.1. In Clemmens et al. (1987) the same model FLUME is described and the accompanying program (version 2.4 of 1989) was tested.

The input/output arrangements are fixed, which is typical for older Fortran programs: data forms have to be filled carefully beforehand: the manual is quite useful in doing this (it is thus not a "stand alone" program).

The program does calibration and analysis, not design. No graphics or plotting facilities are included; comparisons must be made through comparing long lists of tabulated data. The manual contains a good section with the simplified basic theory. An update (version 3.0) is currently under preparation, in which the design aspect is more prominent, the user is guided by menus, help is provided on-screen, interactive data entering is present, and extensive graphics are applied. This new version, to appear in 1993, is addressing some of the more critical remarks made on the test version.

*** BCWEIR ***

This program for the design of broad-crested weirs was developed in a water resources management and training project in India. The initial manual (Parrida & Bell, 1991), containing the source code, states that they adapted an existing 1975 mathematical model for the broad-crested weir flume of Repogle to a Basic program which was meant as in-service training and irrigation management material for State training institutes and universities and practising professionals.

In 1992 a supplement to the manual was produced, and a new version of the program was issued, with more options, with guiding menu's and with simple graphics (Wiser & Pattanaik, 1992). Input of initial data leads to the calculation of a minimum sill height, then follows a re-run with new values of sill height and length. A rating table (Q-H) can be produced for design values or known dimensions, which can be printed for use in the field. Manning calculations for the downstream end can be performed. BCWEIR is based on the same type of structure and on the same type of mathematical model as FLUME, mentioned above.

*** BCW ***

A similar program as BCWEIR exists at Utah State (USU, 1992). It is a fully text-based program (no graphics are used) which calculates stage - discharge ratings for broad-crested weirs in rectangular, trapezoidal and triangular sections. This simple but apparently correct calculation program is based on the theory of long-throated flumes and broad-crested weirs of Bos et al. (1984). There is no manual, but rudimentary on-screen Help is available. BCWEIR can do more than this program, and with FLUME around, the need for this BCW package is limited. RBC is the Spanish version of BCW.

*** Other programs ***

A drop structure design program (**HADES**) is still being developed by Hydraulics Research Wallingford, UK. At the same place, computer programs are being made for the design of sediment control structures (Lawrence & Atkinson, 1989); one is ready (**DACSE**). This is a program for Design and Analysis of Sediment Extractors that was recently completed at Hydraulics Research in Wallingford and is available at UKP 500. It is said to be used to design several structures in the Philippines. Lawrence & Atkinson (1989) mention that design and performance prediction models for three types of structure are being developed at Wallingford: (i) sediment control structures at irrigation intakes; (b) sluiced settling basins, and (iii) canal sediment extractors. DACSE addresses this third type.

A few small in-house programs are available with the Euroconsult (Land & Water Toolkit (Schellekens et al., 1992). It contains a number of small routines for instance for design of a weir or of an orifice or culvert. For the latter both a circular or a square profile can be entered. A third choice is the design of a drop structure with stilling basin referred to as "Indian fall". The required input is shown on the screen; the stilling basin can be designed separately. The volume of earth work can also be requested. These small programs are not meant for or ready for wider distribution, but they illustrate an apparent need, and in-house attempts to fill a vacuum.

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10. IRRIGATION SYSTEM MANAGEMENT

10.1 Defining the subject

Although terms like "irrigation water management", "irrigation system management" and the like have become widely used, their meaning is not very strictly defined. Jurriëns and de Jong (1989) presented a systematic review of literature on the subject, including a discussion on terminology and a suggestion for a consistent framework of irrigation water management and related subjects, the latter to a large extent in line with a discussion by Small and Svendsen (1990). Such a discussion is not the subject of this publication. So we only briefly indicate here the field of irrigation system management to explain which type of programs are reviewed in this chapter.

The programs discussed below mainly deal with i) individual existing schemes (thus not with management of the irrigation sector at national level, and also not with design of new schemes), ii) with executive or operational management (thus not with the office- or agency management, including its organizational and administrative/financial management), iii) with the technical water component and related management tasks (thus not with commercial, social or agricultural components and tasks), iv) the main system (thus excluding water distribution and water use within tertiary units).

The water tasks involved in this system management then include water distribution (through main, secondary and sub-secondary canals) and delivery (to the tertiary inlet). Other water tasks like water supply (making water available from river or reservoir), maintenance of the water control system and drainage are not covered by the programs discussed below.

These tasks have to be planned, operated (implemented) and monitored, being the three essential components of management. Pre-season planning is done to determine how much water has to go where and when. During implementation of this plan (operation) the system is monitored and changes can be made either because actual operation deviates from plan, or because plans have to be adjusted due to for instance rainfall or drought. Monitoring includes data collection on e.g. flow rates and canal water levels and meteorology, their analysis, interpretation and resulting action. Further monitoring or evaluation is needed to assess the final results of the irrigation season, and may include data on cropped areas, yields, water use, efficiencies, etc.

It is obvious that microcomputers could be of great assistance in the water-related tasks mentioned above, in planning as well as in operation and in monitoring. They cannot only access relevant databases and carry out the many required computations quickly and accurately, but appropriate software can also be used to simulate alternatives and answer "what if" questions, e.g. in planning allocation and delivery schedules (see also: Burton, 1990).

If accurate databases are present (with canal system information, soils and climate data, historical cropping patterns, water deliveries and delivery performance data), microcomputers can be used effectively to steer the operational aspects of larger irrigation systems. With also an effective current data collection system, gate settings can be adjusted within a short time, and in very sophisticated automated systems real-time process control would be possible (cf. Phene, 1986). It must be emphasized that such operational benefits can only be expected if correct data are collected (because garbage in = garbage out) and if systems are under stress.

10.2 Types of programs

In the preceding chapters it was not difficult to see what a program would address and contain: level basins belong to surface irrigation, measuring flumes come under structures, single canals or networks are also clear. For programs discussed in the present chapter this is somewhat more difficult, because their function can differ considerably, although they all have the above defined system management tasks in common. They are more synthesized packages, integrating some of the earlier discussed components, such as crop water requirements, scheduling, canal flow, structures, etc.

It is difficult, however, to distinguish different models for planning, operation, or monitoring. Some planning models could also be used for operation, operation models can also include monitoring modes, and various mixtures thus can exist. One possible distinction is that there are general irrigation system management programs as well as scheme-specific ones. The latter have often been developed for actual use in a particular scheme, and cannot be applied elsewhere, even with other input data. Apart from actual planning, operation and monitoring, they can also be used for on-the-job training of local personnel, but their educational value in other environments is limited. Such programs can have a link with some of the earlier mentioned irrigation games, in particular the programs NILE, SAIDIYA and MAHAKALI (Chapter 4).

The more general system management programs contain the framework and a number of modules required for system management, and can work with any normal set of conditions and do any normal (programmed) task. They can, in theory, be applied in any irrigation scheme, if the proper data are entered, although there are limitations in practice. They can also be used for general training purposes, in which answering what-if questions and simulating the effect of various actions form part of a learning process.

With regard to planning, there are some "allocation" or "scheduling" models, that calculate amounts of water to be given to certain areas, at specific locations and moments in time. Such allocation models only address a limited portion of system management.

As for operation, the models can include simulation of canal flows and levels, whereby the strictly hydraulic models discussed in Chapter 7 are included in an integrated package. Some programs only work in terms of water depth or volumes or delivery rates without simulating hydraulics of flow in canals. Besides actual operation, these models can also be used to understand the system and to identify its possibilities, constraints and sensitivities.

Operational programs can include a monitoring part for immediate feed-back, or monitoring can be done separately, with or without a computer program. In this respect one should distinguish two types of monitoring as outlined above: real time monitoring and seasonal evaluation.

10.3 Programs for irrigation system management

The simpler operations like straightforward water allocation to tertiary units in a not-too-big scheme could be facilitated using spreadsheets. Bailey (1985) gives an example of a spreadsheet used for pre-season planning purposes in the Gezira Scheme in Sudan, which could also be used for monitoring. Bullock & Burton (1988) mention the use of a spreadsheet for the day-to-day scheduling of main system supplies in the Brantas delta near Surabaya in Indonesia. A simple spreadsheet used at the Institute for Irrigation Studies at Southampton was tested (MAINSYST).

Slightly more complex situational models for irrigation water management are described by Makin (1990) for the Kraseio Scheme in Thailand, while other scheme specific models were developed for rice in Kenya (RICEID) and for water management in the Nile delta (SIWARE from the Staring Centre, Wageningen). Narayanamurthy (1988) mentions a general model for preparing the operational plan, i.e. the water releases and distribution through the canal system. More extended packages would need many options, and maybe a possibility to add modules or delete others (e.g. Sagardoy, 1991). Of these larger packages we shall mention WASAM and OMIS and INCA in some detail, and CAMSIS and UCA in passing.

*** INCAdemo ***

This is a recent irrigation software package for Irrigation Network Control and Analysis, developed at Hydraulics Research Ltd., Wallingford, UK. The package itself (not the demo) is an integrated program built around a generalized database and is running under WINDOWS.

It is suitable for the entire range of system management. The demo uses an existing database for the Kraseio scheme in Thailand (see also: Makin, 1990), and includes network data and maps, information on soils, crops, and climate. It can be used for computing water requirements, preparing cropping patterns, making irrigation schedules, setting target flows at control points, et cetera. Extensive use of graphics, pull-down menu's and other user-friendly features make the program very attractive, also for relatively inexperienced computer users.

The program applies recent computer technology (hardware and application software) and costs approximately UKP 3000. The hardware requirements and the price place it outside the reach of our normal target group, if no special funding is available. Figure 10.1 shows one of the screens (in black and white, regrettably).

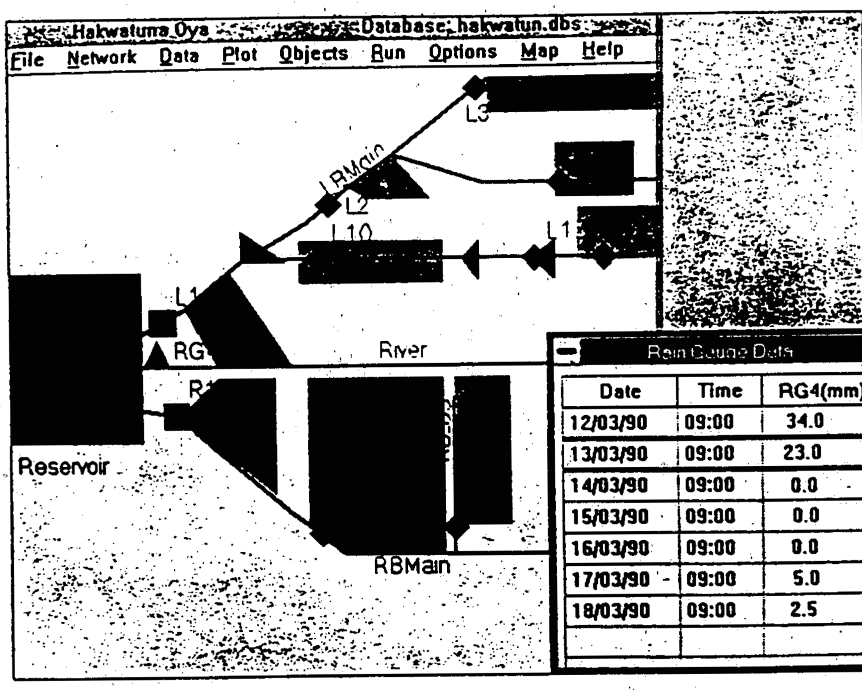

Figure 10.1. Example of a screen from the INCA package

*** MAINSYST ***

This is a Lotus 1-2-3 allocation spreadsheet in which either a field water use factor (in l/s.ha) is specified or the fixed water supply at the source. The spreadsheet then calculates the discharges up or down the conveyance system and specifies flow rates at each tertiary unit and, for the first case, the requirement at the source. It uses the "relative area" method for various crops/crop stages instead of varying the unit discharge (IIS, s.a.). It is basically an allocation program. There is an unsophisticated manual (IIS, s.a.) and it is apparently being used in training. Relevant references regarding this program are Bullock & Burton (1988) and, on a more general note, Goldsmith et al. (1988).

Although the MAINSYST spreadsheet is for a specific situation in Indonesia, the idea could be borrowed for other locations as well. It was developed at the Institute for Irrigation Studies at Southampton University, UK. It is simple but good introductory training material to show the basic possibilities of spreadsheets in irrigation, which also includes simple graphs.

*** OMISdemo ***

The demonstration disk for this program, which deals with Operation and Management of Irrigation Systems, shows that the actual program facilitates activities like planning a cropping pattern, processing monitoring data, prepare half-monthly operation schedules and simulate alternative operation decisions. The demonstration disk points at the integrated structure of the program and its user-friendliness. It is menu-driven and has attractive graphic displays.

Verhaeghe & Van der Krogt (1990) describe its application in the Cidurian Scheme, Indonesia. It was developed by Delft Hydraulics Laboratory for an engineering consultancy firm and is available at a price above NLG 10,000. This means that it is normally outside the financial reach of our target group. It is difficult to judge how the program would perform or how much needs to be adjusted in other locations. The OMIS model package has been introduced in Indonesia, Egypt, India and Nepal, and Schuurmans & Van der Krogt (1992) describe experiences in Egypt and Indonesia. The following management tasks are supported by the program: planning a cropping pattern at the start of the season, operating the canal system during the season, and evaluating the performance at the end of the season. An hydraulic module, providing operational instructions, has recently been added. No further testing of the actual OMIS program was done.

*** RICEID ***

This is a simple Rice Irrigation and Drainage program (in QuickBasic 4.5) for a specific situation in Kenya, where a 6000-ha rice scheme was faced with a number of management decisions like the introduction of double rice cropping and a possible extension of the area, while temporary water shortages were noticed at times. Starting from a fixed water management schedule at field level, weekly irrigation and drainage requirements at scheme level were simulated for 30 years of meteorological data and for various planting date and staggering options (Ndiritu, 1989). The model is rather site-specific and no attempts at wider distribution, user-friendliness or the use of graphics were made. The output consists of long lists of figures. It may have illustrative value for educational purposes.

*** WASAM ***

This is an early (1987) Water Allocation, Scheduling And Monitoring package that was used in the daily water management of large-scale irrigation schemes in Burma and Thailand (Van Vilsteren, 1987). It is set up around historical data and an intensive actual data collection system at different points in the network.

It allows for calculation of expected flows and for monitoring actual flows at various levels (main canal, laterals, smaller canals and ditches). As such it clearly is an operational tool. It was made by Euroconsult for specific projects and was written in Basic. It has rudimentary graphics as shown in Figure 10.2. The tested version did not have a main menu, which made meaningful evaluation difficult. It appeared to be a suitable local working tool, but would require updating to be given wider distribution. This is currently being done at Euroconsult and the new program will become available in 1993.

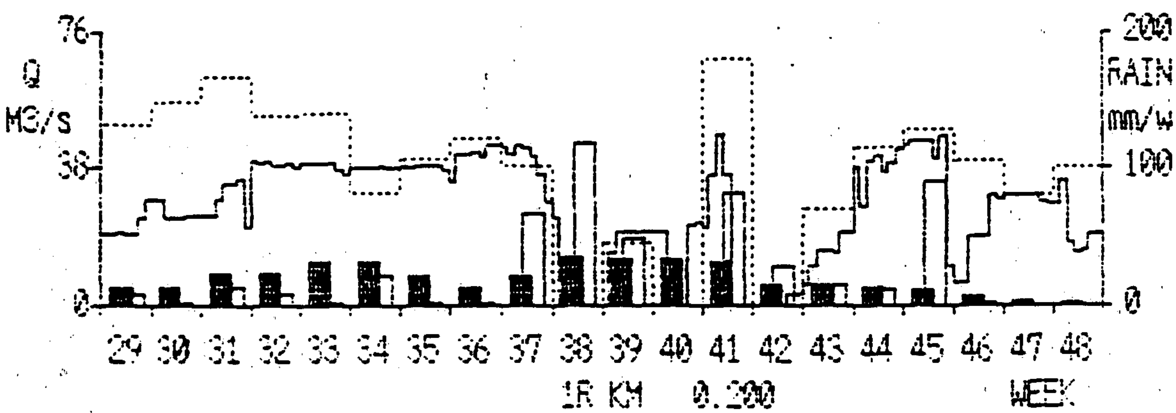

Figure 10.2. Example of WASAM graphics (Van Vilsteren, 1987)

10.4 Other programs

A Computer Aided Management and Simulation of Irrigation Systems package (**CAMSIS**) has been developed at the University of Southampton (Burton, 1986, 1988). It is described to be an interactive package incorporating high-resolution colour graphics. It is primary used for the operational stage of an irrigation scheme, although it could be useful for planning and design, and for educational purposes, as well. The CAMSIS package was written in Fortran 77 and actually contains a number of sub-programs. The program apparently underwent further development and testing since 1988, and is said to be complete soon and would available on a personal basis. The program, in whatever version, was not available for testing and evaluation.

Sagardoy (1991) describes the setting up of a Computerized Irrigation Management Information System (**CIMIS**) at the FAO in Rome. In this draft report he describes the guiding principles, the hardware and software requirements and probable training needs. The structure of the CIMIS system is discussed, rather than the actual databases and calculation modules. In a further paper (Hatcho & Sagardoy, 1992), the same menu-driven system of integrated databases is described. The nine intended modules of CIMIS will take some time to complete, but the water distribution option seems to be ready. It can deal with (a) planning, simulation and optimization, (b) daily operation, and (c) evaluation and monitoring, the three basic management aspects introduced above.

In Maharashtra, India, a USAID project assisted the Irrigation Department with a computerized Management Information System (**MIS**), which was successfully introduced in 30 minor irrigation systems (Sheng & Holden, 1992). A database management system (DBMS) and models for irrigation management are included in the package. The DBMS requires a minimum data set, and can produce standard reports and answer flexible queries of the manager. The irrigation models are based on Lotus 1-2-3 spreadsheets, each in a separate module, and are formed after routine daily (previously: manual) practice. Although this particular case is rather site-specific, the conceptual framework for this system seems worth following elsewhere.

In Thailand, a water allocation and distribution program called **WADPRO** has been developed and tested in the same area as WASAM (described above). The purpose was to estimate the weekly requirement at the tertiary and secondary levels of the irrigation system for a single season. Lowland paddy, upland crops, soil parameters and rainfall are included in the model. A comparison with WASAM and actual canal flows indicated low canal flow rates; WADPRO showed that higher rates and shorter operation times were possible (Kemachandra & Murty, 1992).

At Utah State University a Unit Command Area model (**UCA**) was developed (Keller, 1987). It consists of two integrated sub-models, i.e. one for on-field maintenance of the water balance, and another for water allocation and distribution. The on-field sub-model predicts consumptive use, crop growth and yield in response to irrigation events and weather conditions for all field in a unit command area. The distribution and allocation sub-model allots water from the UCA turnout to individual fields according to the aggregate field demand and rules governing the share system. The models attempts to integrate technical and socio-economic aspects in the management decisions.
The fields of a unit command area are individually characterized by soil type, crop rotation, access to water supply, size, etc. The integration of the two models leads to the aggregate UCA demand, which roughly is the optimal supply hydrograph. Actually available water supply is compared and, if lower, allocation and distribution is adjusted. Seasonal statistics on many parameters normally conclude a model run. The program was not available for testing and evaluation. A sequel to this UCA model is now circulating as **ILM**, the Irrigation Land Management Model, which was used by Steiner & Walter (1992) to analyze effects of allocation and scheduling rules on equity and productivity in irrigation systems.

The name of the **SIWARE** program stands for SImulation of Water management in the Arab Republic of Egypt and was developed at the Institute for Land & Water Management Research at Wageningen, The Netherlands in co-operation with the Drainage Research Institute in Egypt (El-Din El-Quosy et al., 1989). It is intended for application in arid areas on a regional or national scale, i.e. to analyze water management alternatives for irrigated agriculture, with a bias towards drainage. The package contains a number of modules (e.g. DESIGN, WDUTY, WATDIS, FAIDS, EVA, SAMIA, REUSE). The package was not available for testing.

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11. DRAINAGE

11.1 Drainage for agriculture

The subject of drainage may be as wide as irrigation, and a separate inventory of existing microcomputer models in drainage would be warranted. However, a drainage chapter is certainly not out of place within the chosen major context of irrigation. We shall therefore, for our purpose, be mainly concerned with drainage as related to irrigation, although any delineation is rather arbitrary. We exclude flood control, urban drainage and similar more civil engineering types of drainage and natural drainage from agricultural watersheds.

A further distinction can be made between main drainage (the external water conveyance, pumping) and field drainage (the actual removal of excess water from the agricultural plots). We shall be mainly concerned with field drainage in this chapter. Some aspects of main drainage, like open channel hydraulics, are very similar to irrigation (discussed in Chapter 7) and we shall also exclude pumps (which may appear in Chapter 12).

Field drainage concerns either surface drainage or sub-surface drainage. Surface drainage is concerned with the safe removal of excess water over the soil surface (e.g. through interceptor drains, the construction of cambered beds, grassed waterways, tail water collectors, paddy spillways). Sub-surface drainage systems are installed to prevent negative effects of high groundwater tables on crops in the root zone (aeration; salinity) and the layer just below it, from where, especially in arid areas, water and salts can move into the root zone by capillary rise, leading to salinisation. This process can be split into the following more detailed areas of interest:
- drainage system variables influencing the groundwater table;
- water table depths influencing growth factors; and:
- growth factors influencing crop production.

Drainage of agricultural land is inter-disciplinary, but computational aspects mainly concentrate on soil physics and chemistry, hydrology and hydraulics, crop production, although planning, construction, economics and financing are important as well. Leaving the latter aside, hydro-technical aspects dominate for the irrigation and drainage engineer.

Because the depth of the groundwater table is not constant, its characterization is not straightforward: averages, critical and optimum depths, and cumulative exceedances of certain levels have been used, especially in areas where short term fluctuations are relatively small and long term seasonal effects are more important, i.e. for the steady-state situation. Rather rapid recharge of groundwater is inherent to irrigation, which has led to development of non-steady state drainage considerations.

Sub-surface drainage systems may consist of open ditches, mole drains or pipe drains, or a combination. All have their specific applications, but design aspects are based on solutions of groundwater flow problems.

Apart from the specified drainage objective, one could distinguish the following design variables in sub-surface drainage (Oosterbaan, 1987):
- the discharge rate and the required water table depth (criterion variables);
- hydraulic conductivity, depth to the permeable layer and drainable pore space (environmental variables); and:
- drain type and material, drain spacing and drain depth (engineering variables).

Hooghoudt, Ernst, Donnan, Kirkham and others have provided analytical relations between such variables for steady-state situations, mainly found in temperate areas, while the De Zeeuw & Hellinga formula or Kraijenhoff-Maasland are used for non-steady state, i.e. for fluctuating water tables. The (modified) Glover-Dumm formula is often used for irrigated situations, where a saw-toothed groundwater hydrograph is superimposed on a seasonal base pattern (Luthin, 1957; ILRI, 1974; Smedema & Rycroft, 1988).

Although this is more important for humid areas, the design discharge is an major concern for many drainage systems. This leads to various types of rainfall-discharge relationships and models, which would lend themselves quite well to automatic computation. Statistical analysis of observed discharges, unit hydrographs and reaction factors involve extensive calculations, while also the more empirical rational formula and the curve number method can be easily programmed (Smedema & Rycroft, 1988).

If drainage is mainly meant for salinity control, leaching phenomena, capillary salinisation, and water and salt balances can be simulated relatively simply, leading to models that will predict long-term effects of certain drainage interventions and salinity management measures. Such drainage systems need not only be limited to pipe drainage, but could also take the shape of well drainage, which opens up another area for numerical modelling, especially concerned with hydrogeology (cf. Boonstra & De Ridder, 1990).

There are numerous other drainage problems that lend themselves to computer modelling and simulation, among which can be named: seepage (under canals, through dams, in polders), soil ripening and subsidence upon reclamation (in peat and clay soils), chains of paddy fields, sluice drainage in tidal areas, re-use of drainage water for irrigation, and management of water levels in polders and other drainage areas.

11.2 Some programs for land drainage

As stated above, there is a wide variation of areas within the land drainage field, where model development has taken place. We have not attempted to cover and classify this entire area, but we mention only a few models that have come to our immediate attention in the following sections.

Among them are single-purpose programs like CANALCAD for automated design of irrigation and drainage canals, a simple drainage canal design spreadsheet (DRAINCAN) and an tool to assist in processing hydraulic conductivity measurements (AUGER), and drain spacing formula calculation programs as e.g. used by Euroconsult.

There are more integrated models, of which an American model for humid areas is mentioned, that was developed in the mid-1970s and that was adopted by the USDA-SCS (DRAINMOD). In passing we mention an integrated drainage design program that is being developed in Leuven, Belgium (DRAINCAD).

Then there are quite a number of drainage-related models which deal with water flow in the soil which were developed at the Institute of Land and Water Management Research (now Staring Centre) in Wageningen, of which we only mention a collaborative effort with Leuven University, Belgium (SWATRER) and a related model (SWACROP). We specifically exclude models made for specific purposes, such as for existing Water Boards and Water Supply Companies in The Netherlands.

In the area of tubewells and groundwater flow there are also a wide variety of models available (see e.g. Makin & Goldsmith, 1988; and: Ghassemi et al., 1989, for an example from Australia), and we will only mention SGMP and SATEM. Then we briefly discuss a salt balance model developed at ILRI (SALTMOD) and a program for the re-use of drainage water in a chain of irrigation schemes (REUSE).

11.3 Single-purpose programs

There are a number of simple in-house programs used by Euroconsult in Arnhem, The Netherlands (Schellekens et al., 1992), which include AUGER, KLM, TKB and TIDE. **AUGER** will calculate the hydraulic conductivity from auger hole measurements below the groundwater table, based on Van Beers (1971). The formulas found with the program appear to be some 20% different from the use of graphs. Program **TKB** (Toksoz-Kirkham-Boumans) provides steady-state solutions for drainage of multi-layered soils. Conductivities and layer thicknesses need to be given, plus two from three design parameters: spacing, hydraulic head and discharge; the remaining value is then calculated. There is also a small program **TIDE** which is said to calculate the amount of water flowing into or leaving an polder for one tidal period, but the test version did not work properly. There is a similar program **KLM** which also calculates the Ernst and Hooghoudt drain spacings. These small programs appear to need some more polishing before they can be issued to third parties. A few similar drain spacing programs are available in educational institutions in The Netherlands (Agricultural University, International Agricultural College Larenstein, and ILRI for its International Course on Land Drainage), but they are not suitable for issue.

*** DRAINCAN ***

This is a spreadsheet to be used in Lotus 1-2-3, which is based on Manning's formula and which will calculate the water depth of a trapezoidal secondary drainage canal with fixed b/d ratio, side slope and Manning factor. It will also provide bed levels and calculate earthwork volumes using the average end area method, for a maximum of 20 sections. The program and the manual (Runcie, 1987) show more about the construction of spreadsheets than about the design of drainage canals and earthwork quantities involved, although it will do the job. Similar written programs mentioned earlier (Chapter 7: CID, PROFILE) will do the same job and may have better graphics (see also Annex 1).

*** SUBDRAIN ***

This is an older program (Bottcher et al., 1984), that is especially useful for teaching and demonstrations regarding subsurface pipe drainage systems. The drainage system consists of parallel and equally-spaced laterals connected at any angle to one or both sides of a single main line. Based on the topographic features of the drainage area, the program computes the mainline configuration, drain spacing, drain diameters, drain depths, water table elevations, and the total cost of the system. The colour graphic displays may have been advanced in 1984, but they now appear rather outdated. The program is straightforward (hence the inclusion under single-purpose programs) and can handle simple situations only (in contrast with DrainCAD, mentioned below).

In addition, there is a software package for the automated design of irrigation and drainage canals (**CANALCAD**), recently developed at the Center for Irrigation Engineering in Leuven, Belgium, which is available at BF 10,000. It requires Lotus 1-2-3 for calculations and AutoCAD for drawings. We have not tested this program because it requires AutoCAD and an A-1 size plotter.

11.4 Soil moisture flow programs

There is a group of programs that were developed initially at the Staring Centre at Wageningen, The Netherlands. They are mainly based on soil moisture flow through the upper soil layers, which are agriculturally important. They are generally based on moisture flow in the unsaturated zone between a relatively shallow water table and the soil surface, for which the Richards equation is important. Relations between capillary conductivity, suction and moisture content need to be input. The water balance of the root zone forms the basis of the considerations. Around this core, other modules are introduced, such as a sink term for moisture extraction by roots, evaporation from the soil surface, etc. This SWATR, SWATRE, SWATRER sequence of programs is represented by SWATRER. By including a crop growth model (CROPR), an integrated model for water management effects on yield is obtained (first called SWACRO, now SWACROP). More details are given by Feddes (1988).

* SWATRER *

This is a soil water model that solves the Richards equation for moisture flow in unsaturated soil and includes water uptake by roots. As such it can act as a "bridge" between saturated flow (below the water table) and the atmosphere in the soil-plant-atmosphere continuum. It applies a finite difference technique with an explicit linearization (Dierckx et al., 1986). It is often used in combination with other models to make an overall assessment of e.g. drainage and irrigation on crop production possible (see Van Wijk & Feddes, 1986; Figure 11.1). SWATRER is a follow-up of SWATRE (Belmans et al., 1983).

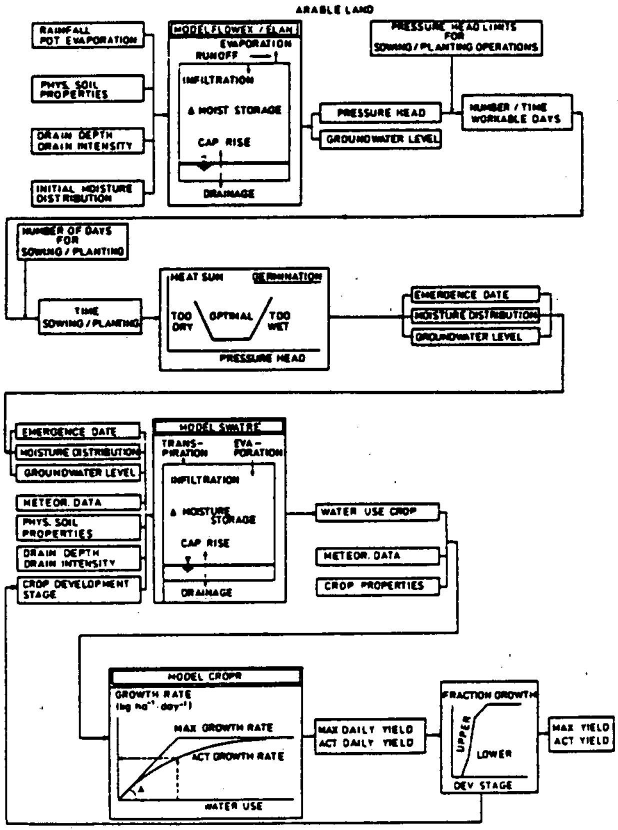

Figure 11.1 Integrated model approach for water management effects on yield (Van Wijk & Feddes, 1986)

It is slightly difficult to judge its validity and usefulness for non-soil physicists, but it appears more a research tool than an application program, also because of the extensive set of data required. The use of Ritchie's evaporation model and the Curve number method to estimate some of the water balance terms looks slightly dated. Although drainage was not a major target of the program, the program can be used to test several drainage options; it is undergoing further testing e.g. in Pakistan.

*** SWACROP ***

This model (Feddes, 1987; Kabat, 1988) combines the SWATRE and CROPR models (mentioned in Figure 11.1) and is based mainly on work by Feddes et al. (1978). It is written in standard Fortran 77 and uses a number of ASCII files for input, which require quite detailed data to be present, as indicated in the March 1989 instructions for input. It is a simulation model of the water balance of a cropped soil, in which different types of boundary conditions can be set, including the possibility of irrigation and drainage and the calculation of crop yield. In the 1989 version the only possible crop is potatoes; other crops are said to be under development. Execution time without a co-processor is rather long. The program applies batch processing: a fixed input format is processed without further steering into a fixed output format. There are no possibilities for on-screen evaluation of results, either by comparing runs or by included graphics, but a further small program called BALANCE will do this now (Wesseling, 1992).

*** DRAINET ***

Hundertmark (1990) describes a set of two simulation models, DRAINET R and DRAINET S, which solve the Richards equation for unsaturated soil moisture flow and the Laplace equation for saturated flow simultaneously in different ways. Both are based on finite differences and they simulate the dynamics of recharge and discharge processes in good agreement with measured soil water potentials; simulated drain discharges required a correction factor. The R version is for homogeneous, the S version for inhomogeneous soils. Hourly rainfall data are required to take full advantage of the models. We did not test these models.

11.5 Groundwater and salinity programs

*** SGMP ***

This Standard Groundwater Model Program (SGMP) predicts the effects of man's interference with existing groundwater systems, such as new irrigation schemes, changed groundwater abstractions, and artificial recharge. The model is devised for saturated flow and can handle single aquifers (SGMP1) or two-layer systems (SGMP2). Numerical iterative or elimination methods are used to solve the finite difference equations. Simple plots are made in a special file. SGMP1 was originally developed for punched card processing and details are described in (Boonstra & De Ridder, 1990), but is now available in microcomputer version; it is written in Fortran IV. A later addition is the inclusion of a second aquifer and the corresponding Fortran 77 version is SGMP2. In both programs there are four sub-programs to be run consecutively (data input, calculations, printing results, plotting results).

As with all mathematical models, the accuracy of the input data is crucial, which is stressed in the accompanying book. The appearance and the input/output handling are rather dated, but the program functions are still useful. Efforts are underway to combine SGMP with SALTMOD (see below) into a regional salinity model (Rao et al., 1992).

* SATEM *

This is a small package containing Selected Aquifer Test Evaluation Methods, which help in determining the hydraulic characteristics of water-bearing layers from pumping tests (Boonstra, 1989). The four sub-programs treat the most common methods, i.e. JACOB, HANTUSH, PARTIAL, and RESIDUAL, each applicable for specific aquifer and data conditions. Diagnostic plots of drawdown data appear on screen and are manipulated by the user until a satisfactory agreement with theoretical formulas is obtained. The program is a nice, small tool for a clearly defined job. It should actually be used in combination with Kruseman & De Ridder's (1990) publication, where more methods are described.

* REUSE *

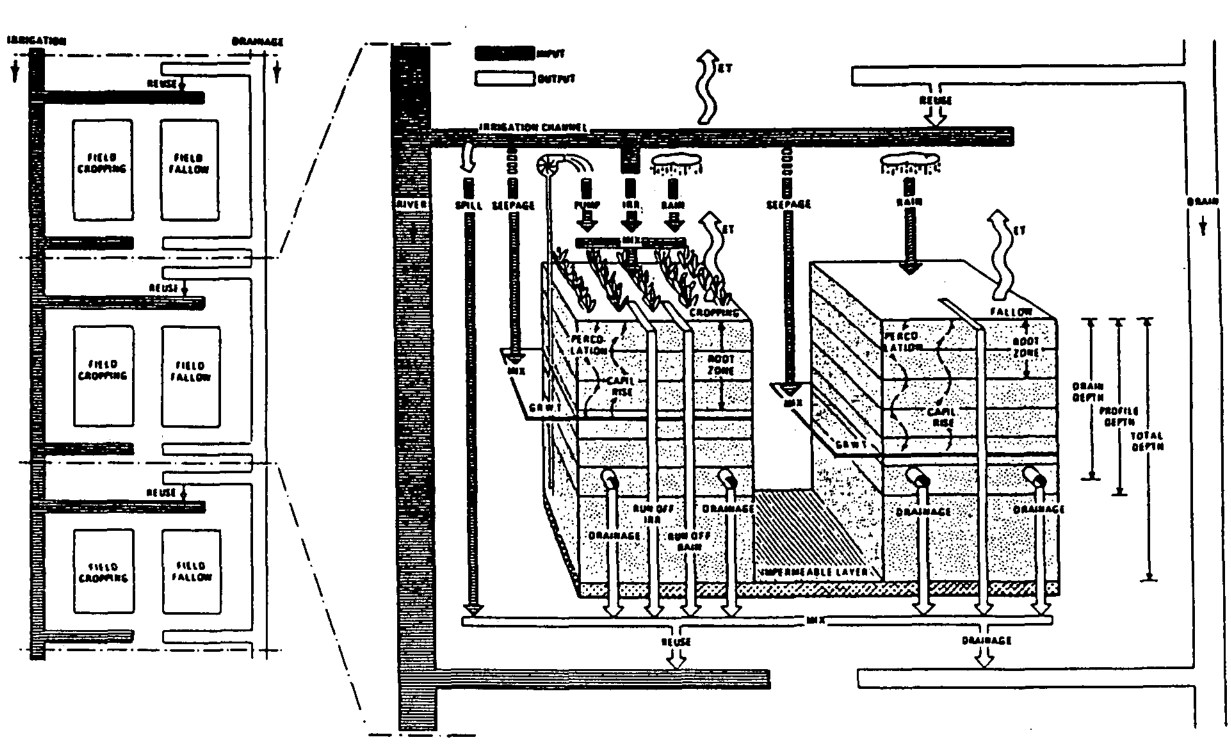

Figure 11.2 Schematic lay-out of the simulation basin in REUSE (Hoogenboom et al., s.a.)

This program simulates water and salt balances in a series of schemes in a river basin under different climatic and water management conditions (see Figure 11.2). The climatic variables include precipitation and evapotranspiration, while the management aspects cover irrigation efficiencies, reuse of drainage water, the water supply to the basin and its salt content. The program is written in Turbo-Pascal and requires the exact preparation of an input file, according to a supplied example. Calculations are then done per time step, per project, per sub-period and per period, after which the results can be viewed in an output file. There are no possibilities to steer the input, the calculations or the output via the screen or otherwise. The model is relatively simple and well-structured, with a concise manual. It could be useful for training and for regional salinity studies. It is said to have been tested in Egypt and in Pakistan (Hoogenboom et al., s.a., Smedema et al., 1992).

*** SALTMOD ***

This is a program to predict long-term developments in salts contents in soil, groundwater and drainage effluent in irrigated land. It also computes the depth of the groundwater table and the drain discharge. Various hydrologic conditions, water management options and cropping schedules can be simulated. A carefully prepared input table is internally converted to an output table, which needs to studied separately. A provided sample data set works quickly, even without a co-processor. The program would require thorough polishing to make it user-friendly, because now a careful study of the manual (Oosterbaan, 1992) and related theory is required before the program can be operated sensibly. Efforts are made to integrate SALTMOD with SGMP into a regional salinity model (RSM), and provide it with more up-to-date user interface and make a complete user manual available to other users of the program.

11.6. Integrated programs

*** DRAINMOD ***

This program has been under development and testing for a long time (since the 1970's) and it incorporates basic knowledge about steady-state drainage conditions in humid areas. Approximate methods are used to quantify water balance components of the soil profile, such as subsurface drainage, subirrigation, infiltration, evaporation and surface run-off. Hourly precipitation data and daily temperatures need to be input, apart from a long list of other general and specific data. Many drainage aspects can be summarized by the program over shorter or longer periods (Skaggs, 1980). The program seems to work properly with sufficient guidance from the manual (Workman et al., 1990). It has been widely tested and adapted (e.g. including a financial option for maximizing farm benefits, Prasher & Moindarbary, 1989).

One must devote sufficient time to cover the basic theory so that meaningful data can be entered. There is an irrigation option available in the program which seems to have limited application. The program looks a good illustrator for existing sub-surface drainage knowledge in humid areas.

*** DRAINCAD ***

The Irrigation Engineering Centre at Leuven University (Belgium) developed a drainage design software package (DrainCAD) that is based on the use of AutoCAD and Lotus 1-2-3 (Liu et al., 1990). Maps are digitized into AutoCAD, drain spacing formulas of Hooghoudt and Glover-Dumm can be chosen in Lotus worksheets, and the drainage lay-out is plotted again in AutoCAD. The main drainage system is then designed using a Lotus spreadsheet, and AutoCAD assists in drawing longitudinal profiles and cross-sections of canals (Figure 11.3). There are possibilities to connect geographical information systems like ARC/INFO with DrainCAD via a relational database interface (Mallants et al., 1991). The package is available at BF 10,000. The hardware and software requirements could make this package somewhat exclusive for occasional use in institutions that are not concentrating on drainage design. Drainage design offices would probably welcome it. We did not test this program.

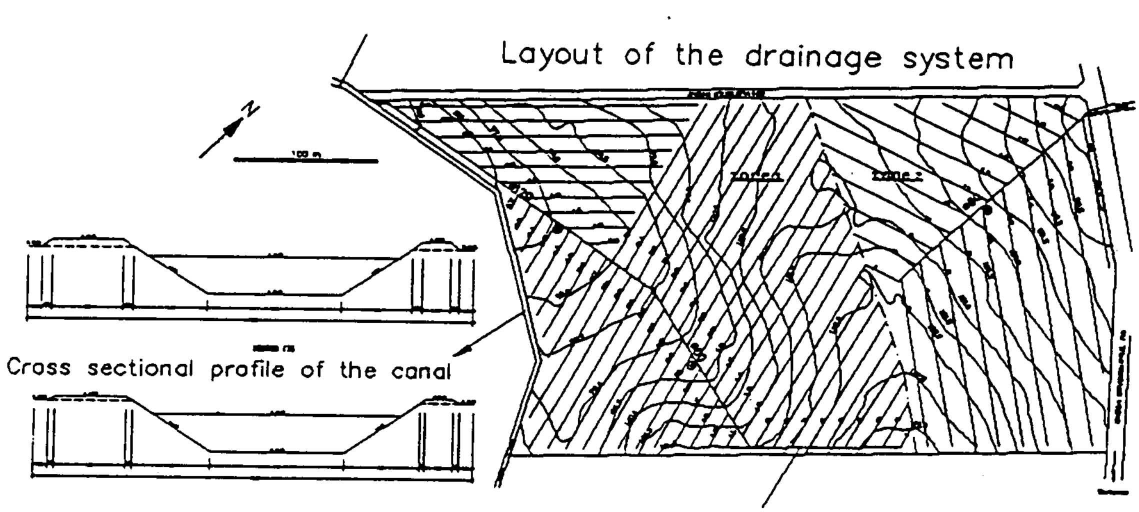

Figure 11.3 Example of graphics in DrainCAD

Although not available as a published package, we finally mention the computer-aided design of drainage networks as done in Egypt, described by Camel et al. (1991). Computer programs now facilitate data processing, computation of discharges, calculation of installation depths and the position of manholes in the collector system. It is noteworthy that no complete computerization was attempted, because a weighing of advantages and disadvantages led to the conclusion that drawing the lay-out could still better be done manually.

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12. OTHER PROGRAMS

12.1 General remarks

Irrigation is an applied science (some say: an art), which incorporates aspects of many other disciplines, such as:
- hydraulics;
- hydrology;
- meteorology and climatology;
- soil science;
- land use planning;
- agronomy;
- civil and mechanical engineering;
- sociology and economics;
- management science;
- project planning;
- ecology and public health;

to which list, seeing the subject of our publication, a bit of computer science should possibly be added. Anyhow, it is not surprising that one encounters many computer programs which are dealing specifically with any of these disciplines (or others), but which have a direct or a more remote connection with irrigation.

In our search we have avoided to look for such partly related software, because the focus would become too wide and the number of programs and references unmanageable. This does not mean, however, that the contents of Chapters 4-11 cover all software that would be potentially interesting and useful for irrigation purposes. To name only a few clearly related topics with definite computational aspects which we have not treated:
- specific irrigation scheme design and drafting programs like MIDAS, which is mentioned below (although this is a core subject of irrigation);
- pumps (capacity calculation, selection, management, operation, etc.), for which there must be numerous computer programs (cf. Wells et al., 1983; Beieler, 1987);
- land levelling, which involves relatively simple but repetitive computations (such as programs LANDLEV and LEVLGRAM in USU, 1992); we mention TOPOCAD below; but general application packages like Lotus 1-2-3 and SURFER (from Golden Software, Inc.) can also be useful for this purpose;
- surface run-off calculation methods, including rainfall-runoff transformations and soil and water conservation models (cf. e.g. ASAE, 1988);
- meteorological and hydrological data processing, including analysis and forecasting (e.g. program RAINBOW, mentioned below; cf. also: Dahmen & Hall, 1990);
- crop growth models (see e.g. Jones & Ritchie, 1990; Hanks & Ritchie, 1991);
- project planning programs including Linear Programming, Critical Path Analysis, and other operations research techniques;

- simple agro-economic calculations like economic and financial internal rate of return, net present value, etc. (compare e.g. a program called MECENE of CEMAGREF, 1992);
- land use planning using Geographical Information Systems (GIS) and related computerised techniques (cf. Badji & Mallants, 1991);
- computerized automation of actual water delivery, i.e. real time control of canals, pipelines and pumping plants (cf. Zimbelman, 1987).

If one is searching for hydraulics and hydrologic programs, a relatively early American overview is given by Waldrop (1985), which is followed by other, more recent summaries. It may also be useful to mention the SAMWAT database for models in water management (Heikens et al., 1991), although it is almost exclusively geared towards models developed in The Netherlands, by government institutions and by private engineering firms. There are models dealing with groundwater, with surface water (including quite a number of urban storm runoff programs), with rainfall-runoff relations, and with agricultural production models. Extensive descriptive formats for such models have been developed, but it is difficult to judge to what extent the models can be used in developing countries, the more so because many models are kept "in house" or are protected by a high selling price. The earlier mentioned DUFLOW program is a notable exception. The International Ground Water Modeling Center in Delft (The Netherlands) or Golden (USA) could be a useful source of programs if one is looking for links of irrigation with geo-hydrology (IGWMC, 1992).

The above enumeration illustrates that there is much more to irrigation than the areas mentioned in Chapters 4-11 and that there are undoubtedly many more relevant and interesting programs than the ones we have listed. As a sample we will discuss a few in the next sub-chapter. Undoubtedly, many others have escaped our attention up to now because of the limited search period or because they are only scantily described in the literature. The search horizon could probably be widened in a possible follow-up study.

12.2 A few more programs

Four rather arbitrarily chosen programs are briefly discussed below, viz. TOPOCAD, for processing topographic data; RAINBOW, a handy tool for the quick analysis of rainfall records; MIDAS, a top-of-the-market minor irrigation design and drafting package under development, and SIMYIELD, which simulates crop performance under irrigation. Only RAINBOW and SIMYIELD were tested (Annex 1).

* TOPOCAD *

This is a recent software package (version 1.3 dates from January 1991) that is used for the processing of topographic data and the calculation of the plane of best fit in land levelling. It combines Lotus 1-2-3 land levelling computations, with SURFER applications to generate contour lines and related maps, and AutoCAD to modify drawings generated by SURFER. Hardware (20 MB hard disk, mouse, co-processor) and software requirements are thus a bit above average. The package is available from the Center for Irrigation Engineering at Leuven, Belgium at BF 3000.

*** RAINBOW ***

A computer program that tests the homogeneity of hydrologic records (see Figure 12.1), executes a frequency analysis and makes a probability plot of hydrologic data. It uses normal, log-normal and Gumbel distributions only. It was written in Turbo Pascal and applies special user screens. After an initially slightly confusing first screen, the program can be quickly learned, even without the manual. The manual (Anon., 1990) is generally good, but should be edited properly. It performs a simple task quickly and nicely.

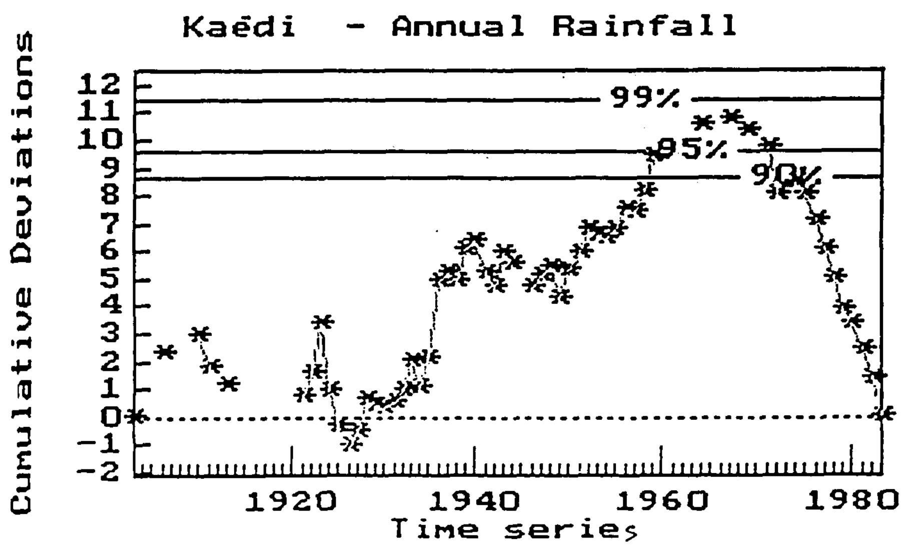

Figure 12.1. Rescaled cumulative deviations graph in RAINBOW (Anon., 1990)

*** MIDAS ***

The Minor Irrigation Design Aid Software was originally developed for Zimbabwe, but is now under test in Kenya as well. It makes use of a digital terrain model and a customized computer aided design package (AutoCAD) to facilitate a number of aspects in irrigation design. It was intended for the design of small surface irrigation schemes (< 500 ha), but is flexible enough to be extended. This design aid package runs on an IBM compatible microcomputer with at least 640 kB of RAM and a math co-processor.

A digitizer and a pen plotter are necessary for the mapping and a colour graphics display is recommended. The following steps are covered (Skutsch, 1991):
- processing and input of survey information;
- sketching of canal layout;
- design of field layouts;
- check on peak water requirement;
- check on drain capacity;
- defining the canal network;
- generation of ground profiles;
- canal design;
- detailed design using hydraulic structures from a library;
- production of structure inventories;
- production of working drawings using pen plotter.

A commercial version was planned for the end of 1992, and would probably be available in 1993.

*** SIMYIELD ***

A program that simulates crop yields under irrigation, described by Narayanamurthy (1988a). It is said to be a design and management tool, which would allow to evaluate different planning and management options in term of final yield ratios (actual/potential). The program leans heavily on FAO Irrigation & Drainage Paper 33 (Doorenbos & Kassam, 1979) and on Paper 24 (Doorenbos & Pruitt, 1977). The program is based on the water balance of a layered topsoil, for which the terms are estimated using standard and rather strongly simplified procedures. One advantage is that the program runs through sets of daily rainfall data and thus avoids estimating effective precipitation. Program structure, data input and output and file handling are nicely arranged, although screen interactions are simple and somewhat dated. SIMYIELD handles dry-footed crops and there is a separate program for flooded rice called RICEYLD (Narayanamurthy, 1988b). This is a simplified version of the main program due to the absence of an unsaturated zone and the presence of a simple yield relation.

There is a certain resemblance between SIMYIELD and some of the programs mentioned in Chapter 5 ((Water requirements and scheduling), but there are also water management aspects (Chapter 10) and design and planning aspects (no specific chapter). This shows the difficulties of making a rigid classification of existing irrigation programs.

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13. PRACTICAL SOFTWARE USABILITY CRITERIA

13.1 Introductory remarks

Having run the programs mentioned in the previous chapters, as listed in Annex 1, the question arises if criteria can be developed for software that is appropriate for the irrigation practitioner. That question of software quality and criteria for quality is the subject of this chapter. The contents are a mixture of a limited number of references, some floating initial ideas about what a good program is from the user point of view, and experiences with the tested programs.

When discussing software criteria, it should be established who decides the quality aspects to be evaluated, even if one tries to avoid personal preferences as much as possible. It is possible to distinguish between various groups of people who can judge software quality, such as the developer, the maintainer, the buyer and the end user. Each of these may have a different perception of what is important in terms of quality. The developer and the maintainer fall in the category of software engineers, which is outside our present scope. We would be more interested in what the end user (which in our case is also often the buyer) would consider to be the necessary qualities of a good computer program.

It is possible to distinguish 15 software quality factors, which can be grouped into two categories of the user's operational and maintenance needs (Deutsch & Willis, 1988). Leaving the maintenance needs aside, the two major concerns of the user regard functionality and performance. Deutsch & Willis ascribe four software quality factors to each of these two concerns, viz.

Functionality:	Integrity	How secure is it ?
	Reliability	How often will it fail ?
	Survivability	Can it survive during failure ?
	Usability	How easy is it to use ?
Performance:	Efficiency	What resources are needed ?
	Correctness	Does it comply with requirements ?
	Safety	Does it prevent hazards ?
	Interoperability	Does it interface easily ?

In this concept, stemming mainly from the software engineering discipline, we would be mostly interested in the Usability factor, which deals with the initial effort to learn, and the recurring effort to use the software for its intended purpose. Usability can e.g. be enhanced or degraded by the naturalness of the user interface, the readability of the documentation, the logic of the program structure and the number of keystrokes required for a given command.

When discussing usability, there is an obvious link with the target group of the software. We have called this group the irrigation practitioner in Chapter 1. This means that a solid training in irrigation is present, and that only a rudimentary knowledge of microcomputers is assumed, referring to an understanding of the limitations of computer use and a basic notion of equipment and application packages. Above all, however, we assume an interest in the application of microcomputers in areas like (1) analyzing research data, (2) writing scientific research or monitoring and evaluation reports, (3) solving design and operational irrigation problems, and (4) providing education and training. We, moreover, assume that we talk about professionals who do not have access to the latest computer technology and rely on hardware and software that is readily available and of proven performance. This requirement would probably be standard in many smaller institutions, especially in developing countries.

The question of irrigation software criteria was also addressed by Rogers et al. (1991), who were to evaluate unsteady flow models for irrigation canals, so as to be able to provide guidance to potential users on the use and limitations of the same. Program capabilities, application and usefulness were investigated. They distinguished three groups of criteria, viz. technical merit, modelling capabilities, and user considerations. The technical merits concerned e.g. computational accuracy and numerical solution criteria, which do not concern us now. Also, modelling capability aspects like system configuration, turnouts, etc. are outside our scope. However, the user considerations mentioned by Rogers et al. are interesting for our discussion. They state that a computer model is valuable only if the user can apply the model effectively, for which the following aspects are important:
- *user interface:* the interaction between user and computer influences the problem-solving efficiency. Effective data management, consistent terminology, flexibility through interactive execution mode, numerical and graphical output are mentioned as important concerns;
- *documentation and support:* written documentation, a user's manual, example input files and output, a case study, interactive help functions and error diagnostics, source code availability, technical support by the developer are listed as contributing to useful programs;
- *direct and indirect costs:* the purchase price of the software and required hardware and additional software can be considered as direct costs; often more important, however, are (indirect) labour costs for learning, for data entry and operation, and for interpretation of results. The latter can be minimised by appropriate documentation and user interface.

In this context of usability and user considerations, we concentrate on four aspects, which are discussed below in some more detail, i.e.:
- hardware requirements;
- user-friendliness;
- the manual;
- availability.

It is realized that criteria are not to be considered in isolation, and are not only determined by the user group but also by time. The latter means that many remarks made below may be subject to change within a number of years, if the fast developments in microcomputer technology and use we have seen up to now are anything to go by. With such reservations, let us look at the four above aspects in more detail.

13.2 Hardware requirements

Irrigation programs are written for a particular hardware configuration, which not only concerns the computer itself, but also the peripheral devices like monitor, disk drives, printer, etc. Let us consider which requirements could currently be considered normal and which are excessive for our previously defined target group.

* *The microcomputer:*
The program should be suitable for IBM microcomputers or compatibles; either XT or AT (286, 386 or 486) machines. The currently common maximum requirement may specify a 286 machine or a 386SX, although the 486 is gaining ground rapidly. Clock speeds are not normally indicated as hardware requirement; 16, 20 or 25 MHz should be sufficient.

* *The disk operating system:*
The standard disk operating system that is required should be Microsoft DOS (MS-DOS) and should not have to exceed version 3.3 (or the equivalent DR DOS or PC DOS). Requiring version 4.01 is still considered asking too much, although version 5.0 (especially useful for WINDOWS applications) has already been in use for some time now.

* *The internal memory:*
The maximum required internal (random access) memory (RAM) is 640 kB, which was the standard a few years ago. Asking for 2 MB or more is asking too much of the common user we have in mind. This virtually excludes the use of WINDOWS.

* *The hard disk:*
Specifying that a hard disk with 20-40 MB capacity should be present (with at least 1 MB free) is not a particularly excessive requirement, but specifying that 60 or 100 MB is required is not yet realistic. Hard disks are also characterized by access time, but specific requirements do not normally occur.

* *The co-processor:*
For our standard user, the need for a math co-processor (8087 for the XT, 80287 or higher for an AT) would almost be asking too much. One might say that it comes in handy (and speeds up computations), but the program should also run within a reasonable time without it.

* *The monitor:*
Even if a program was developed for use on a colour monitor, it should also be suitable for monochrome displays (either through colour filters, providing suitable device drivers, selecting proper colour settings, etc.). The maximum screen resolution that could currently be requested is VGA (640x480), which will also handle programs based on the earlier Colour Graphics Adapter and Enhanced Graphics Adapter monitors. Requiring Super VGA or higher resolution is still asking too much. The program itself should preferably identify which type of monitor is available and set its switches accordingly. If not automatic, a SETUP for the proper screen type selection should be available. A mouse is not normally an explicit requirement.

* *The printer:*
If a printer is required, a standard 9-pin matrix printer (like an Epson LX-800, STAR LC-20 and the like) should be sufficient, although 24-pin printers are rapidly becoming more common. Specific plotters can be nice for printing graphics, but should not be required as a standard outfit. The fact that a printer is required to run a program is considered a slight anomaly. In principle, one should be able to do virtually everything on screen, and input data and results (tables, graphics) should be stored in files. One can then decide whether or not to print from these files later. It means that such input and output files should contain meaningful data, with recognizable headings, etc. They should be retrievable by most universal packages like LOTUS, Harvard Graphics, etc. for further processing.

* *The floppy disk drive(s):*
The presence of a second floppy disk drive (3.5" or 5.25") should not really be necessary (one sometimes sees: A: for the program disk and B: for the data disk). The 3.5" drive is rapidly taking over from the 5.25" drive. Programs should preferably be stored on double density diskettes, to avoid handling problems which may occur with high density ones.

* *Other devices:*
Digitizing tablets, plotters and other devices may be occasionally required by some programs based on drawing programs like AutoCAD. This is not considered a normal requirement. CD-ROM players, digitizers and multi-media kits are still for the future.

13.3 User-friendliness

This is a generally used but loose term, although it has a more specific contents in software engineering circles. As software users, we distinguish the following aspects of user-friendliness of irrigation programs:

* *"Stand alone":*
The program should stand on its own: a new user should not need the manual to find his way around in the program under normal conditions. In practical terms, this often

means a menu-driven program, with logical and clear options/choices at the various levels. These days (following the increased use of a mouse) this often means the use of pull-down menu's. The structure and the logic of the menu's should be such that the standard user, with knowledge of the subject, almost automatically finds his way. Help screens provide explanation in different situations (where the manual was needed previously), preferably context-sensitive.

* *Screen lay-out:*
The importance of the monitor and what appears on it as the communication interface with the user can hardly be over-emphasized. Programs should not have crowded screens with excessive information, nor should they be devoid of any guidance (especially for new users). In most programs there are more levels, and especially a new user wants to know at which level he is, which file he using, what his possibilities are (including a Quit and Exit or an Escape) and what the consequence of a certain choice would be. Standard but salient catch words, uniformity in lettering, colour and location of certain information (status bar, instruction bar, etc.) should provide ease of operational security and confidence.

* *Standard basic actions:*
There should be well-considered system in the basic movements on the screen, such as moving the cursor with the four arrows, contracting highlighted choices with <Enter>, leaving a menu with <Esc> (or possibly with F10), the presence of Help under F1, etc. Most of these standard movements are borrowed from the more widespread general application packages like WordPerfect, Lotus 1-2-3 and dBASE. Also the presence of defaults and range limits (avoiding errands into the unknown) are helping the unskilled user to easily find what he wants, instead of discovering this by time-consuming trial and error.

* *Fool proof:*
The program should have thorough protection against hitting the wrong key accidentally and ending up with a messed up program, loss of data and a computer that is "hanging". As much as is practically possible, the program should be fool proof. A carefully selected set of error messages may also be helpful in this respect, although it should not be overdone.

* *Interactive data input:*
Data input, an important aspect in the numerical programs in scientific applications, should be structured in an inter-active way, often requiring a special user interface. This requirement avoids that users must count columns and enter blanks and data in a separately specified format, as was the case in many early Fortran programs, which were converted from punched cards input. The program should offer highlighted and commented data fields on screen and should not bother the user with where exactly it stores the entries. Data entry is the main contribution from the user, but it should be made easy, self-explanatory and quick by the program.

* *File handling:*
In the same way as the program should facilitate data input, it should also make file handling easy. There should be no need to leave the program (and e.g. go to MS-DOS commands) to update, save, delete, rename or copy input or output files which are needed during program execution or during initial analysis of output. A good program foresees the most common requirements and has them "in house"; it also means that not every odd wish is catered for as this could easily clog the program and thus lead to confusion.

* *Graphics:*
The use of graphics for the evaluation of results could also be considered part of the user-friendliness. It is often faster and easier to compare the outcome of two different runs graphically than to do this comparison by looking at data tables. Even though tabulated data would be required for further processing, on-screen graphical viewing adds to the ease and the speed of evaluating what you (and the program) have done. Good graphics, lettering and other techniques can render an enormously important communication dimension to a program.

13.4 The manual

There should always be a manual accompanying a program, even though we said above that it should not be necessary for normal operation of the program. But it is required to document the objectives, target groups, relevant current developments, the methodology and the process of program development, the background theory, the use of approximations and constants. It should also explain the use of the program step-by-step and point out any less common uses. At least one worked example should be included, the data of which should already be available on the distribution disk. Its usefulness is mainly as a reference guide for more interested user groups and evaluators. We are intentionally ignoring the fact that for the author a separate system engineer's manual (and other documentation) may be needed for program maintenance and further development: the common user should not be bothered with these details. Without explaining each and every basic computer handling detail, a good manual should contain at least the following, although not necessarily in this order.

* *Introduction:*
An introduction, in which the following topics are covered: a brief history of the program, the program language, the aims of the program, the intended target group, what the program can do and what it cannot do. The minimum required and the recommended hardware configuration (PC, RAM, FDD, HDD, Monitor, Printer) and disk operating system (and minimum version number). If necessary, a few general programming remarks may be made. The files present on the distribution disk should be listed and a contact address for further information and possible comments should also be given. A short description of the structure of the manual should conclude the introduction.

* *Background theory:*
A concise section in which the subject matter of the program is reiterated. This theoretical background is mainly meant to instill confidence in the reader that theoretical concepts have been followed which are valid and up-to-date. Of course, references to more detailed theory can and should be given, but a first evaluation should be possible without having to go to such references. This section would include a number of basic formulas used in the program, a consideration of boundary conditions and ranges of values for which the program solutions are valid. The inclusion of some tables or ranges of relevant input values is often useful. The choice of any numerical solutions should be explained and any approximations or the use of controversial constants defended. Such a chapter is not only a matter of scientific accountability, but may also serve educational purposes and assist others to further explore the chosen roads.

* *Program structure:*
An appropriate summary and explanation of the structure of the program, with its various menu's, levels and options. There should be a short explanation of each feature on the screen in a logical sequence. It is often useful to separate this explanation from the actual use of the program. It can also serve to give reasons why certain choices were made.

* *Running the program:*
Instructions for the use of the program. One could probably start with installation procedures and then mention general screen movement and other conventions: cursor movement, <Enter> to accept, <Esc> to go up one level, F1 for Help, etc. Then an explanation would follow on how to start, which screens are showing up, main program choices, menu options, data input, error messages, etc. This is the documented equivalent of actually starting up the program and running it by following the screen instructions.

* *Example case:*
At least one sample problem or case study, which illustrates the normal use of the program. This not only concerns the use of menu's, choosing options and reading Help, but the case study should also be designed in such a way that most features are shown without confusing the (first) user. Although this could be a useful exercise, data input should not be necessary (if it takes more than a minute or so) and data files should be available on the distribution disk. Including a simple first example and a slightly more complex second one is normally a good strategy.

13.5 Availability

Although this may seem a rather superfluous point, it still is important for a good program that it is available to the intended target group. This means that it should be adequately advertised, it should be sent quickly when ordered, the price should not be prohibitive and there should be a contact person at a fixed address.

Although other categories are possible, one could distinguish between:
- public domain software;
- software developed by public educational & research institutes;
- packages developed by consultants for specific clients;
- packages from publishers and other commercial institutions.

Development costs of all but the simplest computer programs are high and even supplying public domain software costs money (for copying, handling and postage; even bulletin board programs often suggest a contribution). Educational and research institutes mainly operate on public funds and they normally do not charge development costs. The current move towards a withdrawing public sector and the need for government bodies to generate income lead to increasing costs for software packages. Apart from the financial aspect, there is also the psychological barrier in giving away a lot of time and effort to someone else, who could benefit from it in an unethical way. Publishers and consultants charge high prices for their programs in a bid to recover the development costs: they work on a purely commercial basis.

Asking a price (be it high or low) brings about questions of protection of the software package against illegal copying. This could be done by including a copy lock, by allowing a very limited number of copies, by including an expiry date, etc. Institutions (libraries, government institutes, industries) have to respect the copyright, but checking unofficial use is not an easy task, especially not in developing countries. As such, a high price is already prohibitive for restricting normal circulation, but to stop illegal copying requires other protection measures.

For our earlier defined target group, availability often simply means: price. Generally speaking, exorbitant prices cannot be afforded, except under special project funds. A price of USD 5000 for a program is then very high, whereas up to USD 100 would often be affordable. Larger government institutions, and firms working in the private sector, can more easily find money for computerization, and a software budget accompanying the purchase of hardware may more easily accommodate relatively high prices for a program. In such cases a few thousand US dollars for a program may seem completely reasonable. For individuals however, price often remains a major obstacle towards availability.

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14. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

14.1 Summary

In this publication we set out to make an inventory of readily available microcomputer programs for the irrigation discipline. After a few introductory chapters, over forty readily available programs were discussed according to a convenient classification into nine sub-areas. In addition to test-run programs, a limited number of literature references to programs were included. Let us first summarize the findings per sub-area and then proceed to list some more general points.

In the Games chapter we noted that the non-computer-based games discussed either have a strong manager focus (JUBA), a project planning bias (RIVER WADU), or an unspecified farmer orientation (SIMBOL). Only the Irrigation Management Game (IMG) has a slightly stronger engineering component. The River Wadu and the IMG may be useful for irrigation engineering courses, especially for team building and related skills. Of the four discussed computer-based games, one game partly aborted (WYEGAME). A second has very nice graphics, but lacks a more general training purpose (SUKKUR). A third (IRRIGAME) does not make the irrigation decisions very clear and is geared towards American conditions, while a fourth (REHAB) also stresses the group experience rather than the irrigation knowledge. It seems useful to follow up on the Mott MacDonald programs NILE and MAHAKALI with their superb graphics.

The Water requirements and scheduling chapter showed that there is a variety of programs dealing with computations of crop water requirements, mainly based on a reference evapotranspiration, although some other relations also occur in American programs. These programs are either single purpose (ETREF, CRIWAR, CRWTABLE), or embedded in scheduling programs (CROPWAT, IRSIS). Such programs also form the basis for various other irrigation scheduling programs which are in use in various countries, either commercially or as an extension service. FAO's CROPWAT has the advantage of a wide dissemination.

The Field irrigation programs have benefited greatly from work by Strelkoff and Katopodes on zero-inertia models. An earlier analytical border flow program (BRDRFLW) got a sequel (SRFR), which is more versatile, but lacks user-friendliness. A useful and user-friendly tool for design and analysis exists (BASCAD), while similar programs did not work properly on our test machine (BASIN, BICAD). Volume-balance approaches are also used, especially in programs from Utah State University (SURFACE, SURMOD). A program for furrow irrigation (FISDEV) is under development at the Center for Irrigation Engineering in Leuven. Pressurized irrigation programs were few and concentrated on spray patterns and hydraulics (CATCH3D). BASCAD and CATCH3D are easy-to-learn practical tools, most others are meant for experimental analysis.

The programs on canals and canal networks included a few simple design tools for steady flow based on Manning's formula (CID, PROFILE, CANAL). Every educational institution seems to develop its own program for this purpose and versatility rather differs. Available mature models which also consider non-steady flow in canal systems seem not to be widely available (CANAL, DUFLOW, MODIS), although more programs have been developed "in house" (CARIMA, LYMPHA, SAMWAT database). DUFLOW is good, but has irrigation only as a sub-set. A French model (SIC) developed in connection with the IIMI is simply too expensive for our target group, as is a Dutch model (MODIS).

Pipes and pipe networks programs appeared to be relatively obscure: very few were available and did not even work (OPTIPIPE). Apparently they either are simple diameter calculations belonging "in house" (HAZEN-W, DRIPSPRI), or are not publicly available, such as network solvers used in Israel. A strong connection with the drinking water supply discipline was noted (UNDP), where many networks are simulated or operated using computers (WATNET). An upcoming New Zealand program looks promising for pressurized system designers (IRRICAD).

Under Structures, in fact only one program (FLUME) was found for the analysis and design of broad-crested weirs, with some similar but simpler programs based on the same theory (BCW/RBC; BCWEIR). Design programs used for silt trapping structures were mentioned to be in use at Hydraulics Research in Wallingford.

The Irrigation system management chapter revealed that simple allocation could be done using spreadsheets (MAINSYST), which are also effective for information system management (MIS). The more complex operational and management models (OMIS, INCA) are attractive, but expensive affairs, outside the budget of our target group. The large databases necessary and the interactive communication ask for larger memory, faster access, and generally more modern technology (INCA). A more modest approach has been used in Burma and Thailand (WASAM), but the program requires upgrading, while other attempts are still under development (CAMSIS, CIMIS). There is considerable scope for effective computer use in this area.

The Drainage chapter indicated that there are a few "internal" single purpose programs available (AUGER, DRAINCAN), that some soil moisture based programs have been developed but are not easy to transfer (SWATRER, SWACROP), that in the groundwater area some useful tools have been made (SGMP, SATEM), and that salinity programs are mostly still under development (SALTMOD, REUSE). The number of integrated programs seems to be limited (DRAINMOD), and design programs are require additional software (DrainCAD).

It was finally mentioned that there are undoubtedly more programs than we have described, especially also in areas more or less closely related with irrigation, such as hydrology and meteorology. Further, a minor irrigation design program under development was mentioned (MIDAS), as well as a relatively simple planning simulation package from India (SIMYIELD). They did not fit in our simple pragmatic classification chapters.

14.2 General conclusions

We concede that a total of forty-odd test-run programs may be a relatively small sample of potentially useful irrigation software, available worldwide. There is, in addition, a logical bias towards our immediate surroundings: what is available at greater distance is more difficult to see. However, within the limitations of time, money, and knowledge, this is what we could readily obtain. And on the basis of this sample, we shall draw conclusions, which we hope will have a more general dimension. To a certain extent, we find support in the literature (referred to in previous chapters) for this wider applicability of many of our conclusions.

As far as the subject areas are concerned, we can conclude that there are some overlapping efforts in water requirements and irrigation scheduling, where seemingly similar programs are appearing in various places, often based on FAO Irrigation and Drainage Papers 24 and 33. Such an overlap is also apparent in canal models, which has already led to the advice to direct efforts towards improving existing models rather than creating yet another model. In irrigation system management models there is a similar danger visible, although developed software packages are, so far, rather site-specific. A proper co-ordination of efforts apparently does not exist.

Areas which are rather under-represented in the availability of computer programs seem to be pipes and pipe networks and irrigation structures. For irrigation structures there is virtually only one type of weir coming out of our survey. For pipes and pipe networks there are also very few programs mentioned, but the impression was obtained that pipe network computer software for other than irrigation purposes could be useful, and that pressurized irrigation network programs are made in more commercial environments. A more definite conclusion is not possible.

With the usability criteria, as outlined earlier, in the back of our mind, we further see that the test-run programs reveal the following state of affairs:

- *hardware requirements* and the need for additional software are limiting in a few cases only;
- the *user-friendliness* of many programs is deploring, as exemplified by:
  - a considerable number of programs require an extensive and time-consuming study of the manual before the program can be operated;
  - some irrigation programs do not have a proper screen lay-out with menu choices, lack standard guidance like on-screen Help and error messages, use odd key strokes, and are not fool-proof;
  - many of the Fortran programs do not have interactive data input, but require cumbersome and inflexible filling of ready-made data forms;

  . some programs have no file handling system, leaving the less-experienced computer user with a confusing task;
  . functional graphics to ease data input and the quick analysis of output is completely absent in many programs;
  . many older programs apparently are not maintained or updated to make them more friendly for today's user;
- the *manual* is problematic for quite a number of programs: either absent completely, or poorly written and edited, or lacking basic parts like theoretical background, program logic, installation routines, sample cases;
- the *availability* of a number of programs also creates difficulties: the purchase price is sometimes too high, in other cases programs are described in the literature but not marketed, or they are only meant for internal use, or constantly under development.

It is also striking that a number of available programs do not work at all or abort during test runs.

Apart from the subject area of irrigation software, one may distinguish various purposes like research, analysis, design, and training and education. It appears that many programs or simulation models bear the imprint of the individual researcher, who has great attention for the conceptual, scientific and theoretical detail. Although this is completely justified, there is much less attention for the subsequent step of preparing a program or a model for wider distribution and marketing. The researcher's hesitations (program under development, needs improvement, etc.) are clearly visible in quite a number of cases and irrigation software centres, with attention for publishing and dissemination (and hence user orientation) are still scarce. Computer-aided design programs for irrigation are relatively few in number, although an increasing number of tools (small programs which assist in a design detail) are available. Most design programs are relatively recent, i.e. dating from the past few years. It further appears that very few programs (except some games) were developed for the sole purpose of education or training, and computer-assisted instruction in irrigation is still in its infancy. Of course, some programs can be used for more than one purpose, but this multi-purpose character is often assumed afterwards rather than intended from the start.

The situation is not completely negative, however, since there are also programs that have adequate attention for the user interface, that have a complete and clear manual, and that are easily available at a reasonable price. It is remarkable, that especially the relatively simple single-purpose programs have a positive score on the above counts and are appropriate for their task. In addition, one sees a group of appropriate, more comprehensive and complex programs arriving on the market, which are based on modern software engineering principles, criteria and techniques, but which are often rather expensive. The "middle of the market" seems to receive relatively less attention.

Overseeing these rather critical remarks, we may conclude that there is a surprisingly small number of irrigation programs that are up to standard, complete, available, quickly to learn, and easy to use for our target group. It looks as if many programs on the market were made for one specific purpose and then, as an afterthought, made available to other interested parties, without further adjustments. Of course, it could be useful to learn from other attempts, but relatively little seems to have been done in the way of user considerations. In some cases the programs demonstrate little structured programming, while in other cases software engineering is overshooting our target group. A general consensus on the need for quality software production, and how to realize this, seems to be missing.

As far as the production and maintenance of irrigation software is concerned, there also seem to be three or four institutions which are developing and marketing more than the incidental microcomputer program (Logan, Leuven, Wallingford and CEMAGREF). There is a second echelon, where reasonable programs are produced, but in lower numbers and frequency (FAO, Delft Hydraulics, USWCL, ILRI, etc.). Despite critique on some of their programs, the few main centres seem to head in the right direction of placing computer software development for irrigation on a professional and more structural footing. This does not mean that the occasional program originating from other institutions cannot be useful, but there often is a lack of a standardized approach. The "ideal" defined in Chapter 13 is not normally reached in such cases. We hope that more overviews such as this one may assist in more attention for uniformity, usability and other standards in the production and marketing of irrigation application programs.

In the process of developing adequate quality software for practising irrigation engineers, we may conclude that we are apparently still in the early stages of development. Part of this may be due to fast-changing developments in computer technology. But, despite great strides forward in the necessary knowledge over the last five years or so, the great range in quality of currently available programs and the rudimentary institutional build-up for the subject of irrigation software indicates that there is a long way to go before appropriate programs are produced and published as matter of routine.

14.3 Recommendations

Stemming from the foregoing summary and conclusions, and from some more general considerations given earlier in the report, the following suggestions are formulated in connection with irrigation-practitioner oriented microcomputer software:

- More institutions should consider putting some extra effort into applying finishing touches to "internal" programs, written with a lot of effort, so that they are made easily usable by others in the same irrigation field;
- More contact between various institutions dealing with irrigation software seems required: a network or a model centre could help. The existing collaboration between Leuven/Wallingford/ILRI is a step in the right direction;
- Standards and criteria for the production and maintenance of irrigation software should be formulated and adhered to as much as possible. Criteria outlined in this publication could serve as a starting point for development of usability aspects;

- The development of training/education modules via the CAL/CAI system is an area which should be more energetically explored; applied education science and irrigation could meet to advantage in this respect;
- The collection and preparation of a set of simple, single purpose calculation aids for irrigation should be followed up. The term computational irrigation is relevant, while terms like a "tool box" may be applicable;
- The development of Expert Systems in irrigation for improved decision support should be stimulated;
- The use of GIS and other information systems in irrigation should become more widely discussed and possibilities for its application more widely explored;
- Inventories like the current one should be improved, extended and repeated/upgraded at regular intervals;
- The preparation of a thorough annotated bibliography on the topic of this publication could be a useful addition to the knowledge base;
- The applicability of software from irrigation-related or even further removed disciplines should be better and more fervently explored;
- Training in the application of irrigation computer software should be increased so as to avoid duplication and unnecessary programming work;
- The awareness of the perspectives, possibilities, perils and pitfalls of computer use in irrigation research, design, management and training should be an integral part of professional education and training.

Finally, we would like to repeat our call from the first chapter: any comments, corrections or additional information would be very much welcomed and will be taken into account in any possible future edition.

ANNEX 1. DESCRIPTIVE FORMS

Serial no.	Program	Mentioned in:	
1.	BASCAD	Ch. 6	Field irrigation
2.	BASIN	Ch. 6	Field irrigation
3.	BCWEIR	Ch. 9	Structures
4.	BCW/RBC	Ch. 9	Structures
5.	BICAD	Ch. 6	Field irrigation
6.	BRDRFLW	Ch. 6	Field irrigation
7.	CANAL	Ch. 7	Canals
8.	CATCH3D	Ch. 6	Field irrigation
9.	CID	Ch. 7	Canals
10.	CRIWAR	Ch. 5	Scheduling
11.	CROPWAT	Ch. 5	Scheduling
12.	CWRTABLE	Ch. 5	Scheduling
13.	DORC	Ch. 7	Canals
14.	DRAINCAN	Ch. 11	Drainage
15.	DRAINMOD	Ch. 11	Drainage
16.	DUFLOW	Ch. 7	Canals
17.	ETREF	Ch. 5	Scheduling
18.	FISDEV	Ch. 6	Field irrigation
19.	FLUME	Ch. 9	Structures
20.	INCAdemo	Ch. 10	Management
21.	IRRIGAME	Ch. 4	Games
22.	IRSIS	Ch. 5	Scheduling
23.	MAINSYST	Ch. 10	Management
24.	NESTOR	Ch. 7	Canals
25.	OMISdemo	Ch. 10	Management
26.	OPTIPIPE	Ch. 8	Pipes
27.	PROFILE	Ch. 7	Canals
28.	RAINBOW	Ch. 12	Other
29.	REHAB	Ch. 4	Games
30.	REUSE	Ch. 11	Drainage

Serial no.	Program	Mentioned in:	
31.	RICEYLD	Ch. 12	Other
32.	SALTMOD	Ch. 11	Drainage
33.	SATEM	Ch. 11	Drainage
34.	SGMP	Ch. 11	Drainage
35.	SIMYIELD	Ch. 12	Other
36.	SRFR	Ch. 6	Field irrigation
37.	SUBDRAIN	Ch. 11	Drainage
38.	SUKdemo	Ch. 4	Games
39.	SUKKUR	Ch. 4	Games
40.	SURFACE	Ch. 6	Field irrigation
41.	SWACROP	Ch. 11	Drainage
42.	SWATRER	Ch. 11	Drainage
43.	UNDP	Ch. 8	Pipes
44.	WASAM	Ch. 10	Management
45.	WYEGAME	Ch. 4	Games

Program 1: BASCAD

▸ *what it does:*
BASCAD simulates advance and infiltration in a level basin with water reaching the end of the basin. It is based on the zero-inertia approach to solving the Saint Venant equations and applies Newton Raphson iteration for solving resultant non-linear equations. This happens in a 'black box'. One can input certain data and view the resulting design parameters. The program can be run in four modes, with an increasing number of input variables. It produces acceptable design values in modes 1 and 2 and indicates consequences of any changes in modes 3 and 4. The latest version (2.0) introduces pull-down menu's, on screen help, interactive data input and improved file handling.

▸ *made where:*
International Institute for Land Reclamation and Improvement (ILRI), P.O. Box 45, 6700 AA Wageningen, The Netherlands. Price NLG 28.00 (Publ. 43 + disk).

▸ *what available:*
- A 3.5" disk with an *.EXE file, which cannot be changed (May 1992);
- The manual: Boonstra, J. & R. Jurriëns, 1988. BASCAD, a mathematical model for level basin irrigation. Publ. 43, ILRI, Wageningen;
- Jurriëns, M. & J. Boonstra, 1991. Level basin irrigation: some examples of design and operation. In: Annual report 1991, ILRI, Wageningen: 8-20.

▸ *what required:*
IBM PC/XT/AT with MS-DOS operating system.

▸ *written in:*
Basic; Fortran. Shell for version 2.0 in Pascal.

▸ *remarks:*
- Version 2.0 has an installation routine;
- The floppy is protected and can only be copied three times;
- The name ....CAD is misleading, as it suggests design drawings like AutoCAD (compare DRAINCAD, which has such graphics);
- The mathematics of the model are not explained in manual; adding such a brief section would be useful for many training institutions and would instill more trust than the mentioned black-box operation;
- Previous versions had some additional drawbacks, but are no longer sold;
- Pull-down menu's, graphics of advance time and infiltrated depth, and the storage possibilities for the output (e.g. as a track record) are present in the 1992 update (version 2.0).

Program 2: BASIN

▸ *what it does:*
Determines design variables in level basin irrigation, using one design screen, showing the variables involved and the unknown calculated. Infiltration, roughness and the design question have to be specified before the program is run. Then the units are specified and an output is chosen.

▸ *made where:*
USDA-ARS US Water Conservation Laboratory, 4331 East Broadway, Phoenix, Arizona 85040, USA

▸ *what available:*
A copy of the program on a 3.5" diskette, containing 14 files, the most recent one of September 1990, but the program has not been formally released. A user's manual is apparently in preparation.

▸ *what required:* not stated.

▸ *written in:*
Turbo Pascal, although a *.BAS file indicating Basic and a *.FOR file indicating Fortran are present on our diskette.

▸ *remarks:*
- No information is provided on the screen on program structure and program logic or on operating sequence;
- Apparently, pull-down menu's are to be followed from left to right; changed values entered are not seen until calculations are made;
- The system may stall completely (re-start) if an out-of-range value is entered; the user must therefore be sure to enter acceptable values;
- By selecting Execution/Calculation a view of an output file may be obtained, although this may not be immediately clear;
- Program seems to be made to do the same as BASCAD, except by using pull-down menu's; the pull-down efforts need to be improved considerably (ought to be fool-proof);
- Program seems to focus on finding maximum length of run;
- Program needs thorough polishing to alleviate the above problems.

Program 3: BCWEIR

▸ *what it does:*
This program assists the designer in the design of broad-crested weir (BCWEIR) flumes and produces rating curves for given channel dimensions. It uses theory developed by Repogle and others, and has four main features: (i) initial data leading to an initial sill height, (ii) a re-run with new sill height and length, (iii) running the rating table from design values or known dimensions, and (iv) printing summary design and rating tables. The latest version adds more profile shapes and some computer graphics.

▸ *made where:*
Water & Power Consultancy Services (India) Ltd. and Louis Berger International, Inc., 213 Ansal Chambers-II, 6 Bhikaji Cama Place, R.K. Puram, New Delhi 110066, India

▸ *what available:*
- A 3.5" disk with a version dated 1 September 1992;
- The manual: Parrida, B.P. & W.C. Bell, 1991. Manual on computer-aided design of broad-crested weir flume. Techn. Rep. 52, Water Res. Man. & Training Project, LBII/WAPCOS, New Delhi;
- Wiser, E.H. & A.B. Pattanaik, 1992. Supplement to Technical Report no. 52. Water Res. Man. & Training Project, LBII/WAPCOS, New Delhi.

▸ *what required:*
An IBM PC XT computer with >= 640 kB RAM, running under MS-DOS 3.x. Monochrome or colour monitor. One serial and one parallel port.

▸ *written in:* Basic.

▸ *remarks:*
- Typing bcw starts the program and shows a logo screen;
- The program is menu-driven and mnemonics can be used;
- A new weir can be designed or a rating curve made for an existing weir;
- Simple graphics and lettering are used, but work alright;
- Program choices and structure look logical;
- Manning formula solutions are also available in the package, mainly intended for testing the tailwater depth;
- The worked example in the Supplement to the manual is useful;
- The latest version is only available as compiled file; there is a source code listing of the former version in Technical Report no. 52;
- Program seems to work properly and may be useful, without being sophisticated.

Program 4: BCW/RBC

▸ *what it does:*
The program produces stage-discharge ratings for broad-crested weirs and is used for design and calibration of broad-crested weirs for open-channel discharge measurement. The program is interactive with a built-in data editor. Results can be sent to a disk file or directly to a printer. The English language version is called BCW (there is also a Spanish version called RBC).

▸ *made where:*
Software Engineering Division, Biological and Irrigation Engineering, Utah State University, Logan, Utah 84322-4105, USA. Available from USU at USD 20.00 plus shipping and handling.

▸ *what available:*
- A 3.5" disk with a version 2.2 dated May 1991 (file BCW.EXE);
- There is no manual. For literature see: Bos, M.G., J.A. Repogle & J.A. Clemmens, 1984. Flow measuring flumes for open channel systems. Wiley, New York.

▸ *what required:*
An IBM PC or PS/2 compatible computer with > = 256 kB RAM, running under MS-DOS 3.30 or higher. No special graphics or colour card required. A printer is required for hardcopy output.

▸ *written in:* Not stated.

▸ *remarks:*
- The program starts by typing bcw;
- There is a short Help available on screen for each of the 8 menu options;
- Only trapezoidal cross-sections can be handled (with rectangular and triangular shapes as special cases thereof);
- The program is fully text-based; there are no graphics;
- Data entry is easy and computations are quick;
- It looks as if BCWEIR can do more; moreover, FLUME seems to make this simple BCW program rather obsolete.

Program 5: BICAD

▸ *what it does:*
This program for Border-Irrigated Computer-Aided Design calculates the design variables in border irrigation systems, i.e. mainly border length and width, slope, flow rate and application time. Inputs are infiltration constants, surface roughness and depth to be applied. The program can be run in a simple, approximate and quick regression mode or in an accurate process mode. Results can be plotted.

▸ *made where:*
University of Melbourne, Dept. of Civil and Agricultural Engineering, Parkville, Vic. 3052, Australia, by Dr. B.L. Maheshwari (for The Rural Water Commission of Victoria).

▸ *what available:*
A 3.5" disk with version 1.0, dated 10.04.1990, containing the *.EXE file B1.EXE and two more files. Clemmens (pers. comm.) mentions that the program is now called BICADAM and that there is a manual. We did not have that available while testing.

▸ *what required:* not stated.

▸ *written in:* not stated.

▸ *remarks:*
- Program starts by typing b1, after logging to a:;
- Intro screen does not show on Compaq;
- Using a fictitious data set of reasonable values, running in the regression mode produces a run-time error M6201 - MATH and a - **: DOMAIN error. Program stops;
- Action required: obtain and test most recent version for proper evaluation.

Program 6: BRDRFLW

▸ *what it does:*

The program predicts the behaviour of the surface stream flowing down an irrigation border, with a known infiltration curve. Other inputs are; border length, slope, roughness and downstream boundary condition (blocked or draining). Management parameters like required application depth, inflow rate and cutoff time are also needed. Resulting parameters are advance, recession, and runoff as functions of time, plus the ultimate distribution of water. The model runs under the zero-inertia formulation, or the kinematic-wave model, or a hybrid of the two.

▸ *made where:*

Theodor Strelkoff for: US Water Conservation Laboratory, 4331 East Broadway, Phoenix, Ariz. 85040, USA

▸ *what available:*

- A 3.5" disk with an executable file B07M.EXE, a data file and a README file; version 7.2 of March 1987;
- The source codes in Fortran of the seven constituting files, dated March 1987 (version 7.2);
- The manual: Strelkoff, T., 1985. BRDRFLW: a mathematical model of border irrigation. USDA, ARS-29, Phoenix, 104 pp.

▸ *what required:*

- IBM PC AT or 386 or compatible (there is a version for machines with a math co-processor: then the executive file is B07M7.EXE, which we do not have);
- A (wide carriage) printer had to be attached to the PC, otherwise the program did not run (even if README.NOW was followed).

▸ *written in:* Fortran 77

▸ *remarks:*

- Start program by typing B07M after logging to a:
- Example of handbook is printed till ZERO INERTIA ....; on the Compaq Deskpro 386N it takes about 17 minutes before the rest of the output is produced;
- Program is not user-friendly: you need to read most of the manual to know what to do to run the program; the input/output arrangement is typically Fortran and hence inflexible;
- Manual is quite elaborate on theoretical background of the zero-inertia and kinematic-wave approaches;
- Long processing time is a drawback, although a math co-processor would help (then B07M7.EXE required, which we do not have);
- Program is now virtually obsolete, since its successor SRFR has taken over (1991), which can do more than only borders (also basins, furrows) for more conditions.

Program 7: CANAL

▸ *what it does:*
This hydraulic model simulates unsteady flow conditions in canal systems that branch out like a tree, with the canals having a trapezoidal cross-section. In the test version there is a maximum of four branches at nine reaches each. Reaches are separated by control structures and each reach can have up to nine turnouts. There are three operation modes, i.e. (i) interactive user-specified control structure operation, (ii) pre-set control structures and (iii) operational supply setting through automatic gate scheduling. There are extensive graphical screen displays of flow profiles and other situations, while tabular numerical information is also available.

▸ *made where:*
By F.N. Gichuki (the Fortran version) and G.P. Merkley (the Pascal version), Dept. of Agric. & Irrigation Engineering, Utah State University, Logan, UT 84322-4105, USA. Available from G.P. Merkley via USU at USD 50.00 + 15.00 postage.

▸ *what available:*
- A 1991 version of the CANAL program on a 3.5" HD disk (Pascal version);
- F.N. Gichuki, 1988. (1) Development of a branching canal network hydraulic model. WMS II report 72; (2) User's manual for the Fortran version of USU main system hydraulic model. WMS II report 73. Logan, Utah;
- G.P. Merkley, 1987. Users manual for the Pascal version of the USU main system hydraulic model. WMS II report 75. Logan, Utah;
- G.P. Merkley & D.C. Rogers, 1991. Description and evaluation of program CANAL. In: Ritter, W.F., Irrigation and Drainage, ASCE, Hawaii: 390-396

▸ *what required:*
IBM AT machine or compatible, EGA card, high resolution colour monitor, 80287 co-processor, minimum 640 KB RAM and a hard disk. DOS version 3.1 or higher.

▸ *written in:* MS Pascal 3.31 with assembly language routines for screen display.

▸ *remarks:*
- The DOS path name has to be adjusted in the CDAT program first;
- In the CDAT program (a separate .EXE file) input files are created, and edited; there is a sample case (file LNOR);
- After leaving CDAT, typing CANAL (a separate .EXE file) starts the simulation;
- There is a clear manual (WMS 75), with background and operating instructions;
- There is an attractive choice between graphics and tabular data for a wide range of variables; a simulation can be interrupted for interactive changes;
- The Pascal version is now supported by USU; a new version with variable computation time steps (now: 5 min.) would be available at the end of 1992;
- A math co-processor is needed to produce reasonable run times.

Program 8: CATCH3D

▸ *what it does:*
This is a sprinkler overlap program, which simulates the water application uniformities of rectangular sprinkler patterns by overlapping catch can measurements from a single sprinkler test of from a lateral line test. The catch can grid must be square and only patterns that are multiples of the catch can grid can be evaluated. Resulting calculated values include uniformity coefficient, distribution uniformity, application efficiencies of the low half and the low quarter and catch can efficiencies. Overlapping patterns can be shown and plotted graphically.

▸ *made where:*
Dr. R.G. Allen, Dept. of Agricultural and Irrigation Engineering, Utah State University, Logan, UT 84322-4105 (copyrighted). Available at USD 39.00 + 15.00.

▸ *what available:*
- A 3.5" disk with *.DOC, *.BAS, and *.EXE files for CATCH3D and for the derived 3-dimensional plotting program 3D (by the same author); a number of data files (*.DAT) are present for demonstration; we have version 3.3 of 1988;
- No manual is present but the documentation in the *.DOC files should suffice.

▸ *what required:*
IBM-PC XT or AT under MS-DOS with CGA or EGA screen.

▸ *written in:* Basic

▸ *remarks:*
- Program works OK with test data CATCH3D.DAT;
- Although a program like SURFER may yield similar graphics, it is nice that all kinds of uniformity parameters are calculated;
- A simple and useful program e.g. for educational purposes;
- Especially the 3D plotting facility is a nice feature for research reports, etc.
- We did not look at other data files like DONUT, SIDEROL, etc.

Program 9: CID

▸ *what it does:*
Calculates irrigation and drainage canals for uniform stationary flow using Manning's formula. Canals may be trapezoidal or rectangular and lined or unlined. Calculations are made per canal section, i.e. per stretch with constant canal dimension variables. Four calculation options are present, i.e. for normal situations, for minimum slope, for minimum earth work volume and minimum earth work cost. Both numerical and graphical results are produced and can be sent to a printer or a file for future use.

▸ *made where:*
COMPAS, a combined initiative of International Agricultural College Larenstein, Laarweg 6, 6882 AA Velp and The Department of Land & Water Use of the Agric. University, Nieuwlanden 11, 6709 PA Wageningen, both in The Netherlands. Author is Ir. J.B.M. Swennenhuis. Restricted availability.

▸ *what available:*
- One copied 3.5" disk with version 1.0 (for 4 graphics cards);
- The manual: Swennenhuis, J., 1987. CID - a program for the Calculation of Irrigation and Drainage canals. IAHL/Velp, Agric. Univ./Wageningen

▸ *what required:*
- IBM PC/XT/AT with a minimum of 512 kB RAM;
- Floppy disk drive 5.25" (for original disk);
- Either HGC, CGA, EGA, AT&T graphics card;
- Epson MX, RX, FX compatible printer.

▸ *written in:* Not stated.

▸ *remarks:*
- Type EGACID to start after logging to a:
- Help facility is reasonably extensive; nicely under F1;
- Graphics are a nice feature, but X-section not very informative and top of embankment not shown on longitudinal section;
- Program logic and chosen keys for action are quite OK;
- Program easy to use, even without complete manual;
- Made for college level students, with simple graphics and no interactions;
- Language of manual (and occasionally on screen) needs some editing;
- Print out of graphs is not impressive;
- General impression is: nicely made small program; user-friendly and easy to grasp.

Program 10: **CRIWAR**

▸ *what it does:*
The program calculates CRop Irrigation WAter Requirements of a cropping pattern of up to 40 crops in an irrigation command area using the modified Penman method, as described by Doorenbos & Pruitt (1977). It corrects the crop water requirements in a simple way for the effective precipitation. Input data can be stored in a file and output is automatically tabulated in an output file. The user is prompted to answer simple questions appearing on-screen. Weekly or monthly data are calculated.

▸ *made where:*
International Institute for Land Reclamation and Improvement, P.O. Box 45, in co-operation with Institute for Land and Water Management Research, P.O. Box 35, 6700 AA Wageningen, The Netherlands

▸ *what available:*
A 3.5" disk with 3 *.EXE files and a TXT directory containing 103 text files with screen messages, dating from 1988. Total size = 345 kB;

▸ *what required:* IBM PC XT will do; second drive if size 5.25" XT (for output).

▸ *written in:* Fortran

▸ *remarks:*
- Was supposed to be ILRI publication 46, but was never published;
- Based on Doorenbos & Pruitt (1977) modified Penman equation;
- Loading the program after the initial 3 screens takes long (without a message);
- Meteorological data input is in fixed units (temperature in degrees C, rain in mm, wind in m/s, etc.); not flexible (like e.g. L&W:PENMAN);
- Prompting for the date (!), and for input data, choices, etc. now appears outdated (program originally dates from 1986);
- Most incorrect entries indeed produce a warning;
- There is no manual, but it is not needed to run the program;
- Usefulness now expired, with more versatile programs like CROPWAT, IRSIS and similar programs on the market;
- A few minor improvements have been made in a 1991 version, but these do not change the remarks made above.

Program 11: CROPWAT

▸ *what it does:*

The program calculates crop water requirements from climatic data using the Penman-Monteith approach, and subsequent irrigation requirements, using crop data. It also allows the development of irrigation schedules for different management conditions and produces scheme water supply data for varying cropping patterns.

▸ *made where:*

Land and Water Development Division, Food and Agriculture Organization, Via Terme di Caracalla, 00100 Rome, Italy (M. Smith).

▸ *what available:*

- Version 5.3 from Oct. 1988.; the 5 *.BAS files were hidden on the 5.25 disk; in total 64 files;
- FAO, 1988. Manual for CROPWAT (version 5.2) May 1988. FAO, Rome. 45 pp.
- FAO, 1988. Guidelines for using CROPWAT. India: National Water Management Project, Workshop Walamtari, 9-13 May 1988. 55 pp.
- Smith, M., 1992. CROPWAT - A computer program for irrigation planning and management (+ disk with v. 5.7). Irr. & Drain. Paper 46, FAO, Rome, Italy

▸ *what required:*

IBM PC XT or AT or compatible, with a minimum of 360 kB RAM. The used version 5.7 has a size of about 703 kB in 238 user files. For direct start-up from the HD 5.25" disk in I&D Paper 46, MS-DOS 3.2 or higher is needed.

▸ *written in:* Basic

▸ *remarks:*

- Start from disk, type CROPWAT or install on hard disk first using INSTALLH;
- There are 3 data directories: CLIMATE, with *.PEN and *.CLI files, CROPS (with *.CRO files), and FIELDS (with *.SOL and *.FLD files); check printer setting and proper paths first;
- Manual is sometimes needed to explain screen choices;
- Accuracy of ET calculations difficult to evaluate; no data compared with other similar programs as yet;
- Practical applicability of irrigation scheduling and scheme water supply sections difficult to evaluate; certainly useful for training;
- Program runs correctly and menu switching is alright;
- Addition of graphics would enhance scheduling section;
- CLIMWAT meteorological data set not tested (not yet received from FAO).

Program 12: CWRTABLE

▸ *what it does:*
This spreadsheet allows up to five different cropping patterns to be specified for a total of 52 periods (e.g. weeks, to make one year). Water requirements are then calculated from input data such as reference evapotranspiration and crop factors, which are thus not calculated by the spreadsheet.

▸ *made where:*
M. A. Burton at the Institute of Irrigation Studies, The University, Southampton SO9 5NH, UK. Limited availability.

▸ *what available:*
- A 3.5" disk with three IIS spreadsheet programs, among which: CWRTABLE version 1.0;
- A 15-page manual: Spreadsheet program nr. 1 - Cropping pattern crop water requirements; IIS, Southampton, Nov. 1987.

▸ *what required:*
IBM PC with 384 kB memory with colour or Mono screen. MS-DOS 2.1 or higher; Lotus 1-2-3 package.

▸ *written in:* Lotus 1-2-3.

▸ *remarks:*
- After calling Lotus 1-2-3, type /FR and at the prompt type A:\CRWTABLE\ to obtain either the empty spreadsheet (CWRTAB0) or the filled in example (CWRTAB1);
- The main input (ETo) has to come from somewhere else;
- It does simple additions, showing the effect of different planting dates on irrigation water requirements;
- It is a simple spreadsheet, suitable for introducing students to the usefulness of spreadsheets for irrigation calculations, rather than for general issue or use in irrigation project design;
- Manual has a few small errors (e.g. page 10);
- The spreadsheet can be printed in three sections;
- Plots of crop water requirements versus time can be printed with Lotus' PrintGraph menu.

Program 13: DORC

▸ *what it does:*
The software package contains a number of routines which help in the Design Of Regime Canals, i.e. canals with a stable profile as far as sedimentation and scour is concerned. Apart from a range of design methods for alluvial, unlined canals, procedures for predicting alluvial friction and sediment transport are provided. Methods for predicting the transporting capacity of sediments in the cohesive size range are also included. The package includes regime methods, tractive force, rational methods, Manning, alluvial friction predictors, and sediment transport for sand and silt.

▸ *made where:*
Overseas Development Unit, HR Wallingford, Wallingford, OX10 8BA, England.

▸ *what available:*
- A 3.5" disk with version 1.1, dated 1992 as an .EXE file, complete with installation files and a startup routine (DORC.BAT);
- A (draft) User manual (March 1992), 55 pp.

▸ *what required:*
An IBM-compatible microcomputer with > = 640 kB RAM, running under MS-DOS 3.0 or higher. A hard disk is preferred. A line printer, if printed results are required.

▸ *written in:* MS Fortran 5.0

▸ *remarks:*
- The installation procedures are simple and work correctly;
- There is a clear main menu, leading to one or two levels of sub-menu's, after which input data are requested on the top half of the screen and results are shown on the lower half of the screen;
- File handling, data entry and moving around the program are clear and straightforward;
- The manual is clear on program organization, and gives some guidance as to which method to use, but scientific background, formulae used, and coefficients selected are not mentioned (but references are given);
- Experience and judgement of the design engineer is required to select input values and to interpret the calculated output values;
- Screen display is simple and contains numerical information, once the method is selected; available Help refers mainly to units and numerical limits;
- An easy-to-use tool for designing alluvial channels appropriate to transported sediment load.

Program 14: DRAINCAN

▸ *what it does:*
This spreadsheet is to be used in Lotus 1-2-3 and will calculate the water depth of a trapezoidal secondary drainage canal (in cut, with b = 3*d, side slope 1:1.5 and n=0.025) and bed levels using Manning's formula and compute the earthwork quantities using the average end area method, for a maximum of 20 sections. The main aim, however, is educational: to show spreadsheet programmers how to set up, structure and document a spreadsheet program for a familiar irrigation/drainage problem.

▸ *made where:*
Robert Truncie (an M.Sc. student in Irrigation Engineering) at the Institute of Irrigation Studies, The University, Southampton SO9 5NH, UK.

▸ *what available:*
- A 3.5" disk with two more IIS spreadsheet programs and DRAINCAN version 1.0 of 1987;
- A 41-page "Manual", extracted from the M.Sc. thesis of R. Truncie (i.e. Appendix C and Chapter 7).

▸ *what required:*
IBM PC XT or AT. Epson FX 1000 printer using 14" paper. Lotus 1-2-3 release 2 or higher.

▸ *written in:* Lotus 1-2-3.

▸ *remarks:*
- After invoking Lotus 1-2-3, type /FR and a:\draincan\ to have a choice of an empty spreadsheet (DRAIN.WK1) or a filled-in one (SAMPLE.WK1);
- After the logo, and two documentation screens, a separate menu was created (Table View Save Access Quit) above the spreadsheet, for Creating or Updating the Table; for Viewing the longitudinal section of the drainage canal; for Saving/printing the table or graph; for Accessing the spreadsheet construction; and for Quitting Lotus;
- This program and the manual indeed show more about spreadsheet construction in Lotus 1-2-3 than about calculating canal dimensions and earthwork volumes;
- The graphics of Lotus 1-2-3 release 2 are indeed rather rudimentary (View option); there are nicer programs available which do the same (e.g. CID).

Program 15: DRAINMOD

▸ *what it does:*
Based on the water balance in a soil profile, DRAINMOD uses climatological records to simulate the performance of drainage and water table control systems for shallow water table soils. Approximate methods are used to quantify hydrologic components like subsurface drainage, subirrigation, infiltration, evapotranspiration and surface run-off. The model assumes an equilibrium soil water distribution above the water table. Hourly precipitation and daily temperatures are input and daily, monthly or annual summaries can be output of many drainage aspects.

▸ *made where:*
Prof. Dr. R. Wayne Skaggs, Biological and Agricultural Engineering Department, Box 7625, N.C. State University, Raleigh, NC 27695, USA.

▸ *what available:*
- PC version 4.6, dated April 1992;
- DRAINMOD User's manual, edited by: S.R. Workman, R.W. Skaggs, J.E. Parsons & J. Rice, 1990, North Carolina State University, Raleigh; 95 pp.
- R.W. Skaggs, 1980. Drainmod reference report. USDA-SCS, Fort Worth

▸ *what required:*
- A hard disk with 1 MB free space; DOS 3.0 or higher; minimum 320 kB RAM; minimum graphics 640*200 (CGA);
- A math co-processor is recommended;
- Files=20 in CONFIG.SYS; EDLIN to be in the path.

▸ *written in:*
There are Basic and Fortran versions; we have a Fortran version; the DMSHELL is in QuickBasic 4.0.

▸ *remarks:*
- Installation routine works OK (see Manual p. 3-10 and file INSTALL.INF);
- The hourly rainfall data may pose a problem in many locations: not measured;
- Program made for humid climate, steady state; irrigation option available, but does not seem very appropriate;
- Running time without co-processor for simple example (DCNVBN) is 15 minutes, which is rather long;
- The program promises graphs for hydrologic data files; no such (sample) files are present with the package, so no graphs could be checked;
- Test output file was made; can be viewed and printed OK;
- The subject matter is not simple and a careful study of the input data (9 editing screens/files) is required; the manual gives good practical advice; theory is in a reference report (Skaggs, 1980).

Program 16: DUFLOW

► *what it does:*
Provides a hydrodynamic user-oriented package for unsteady flow computations in networks of open water courses. It addresses e.g. propagation of tidal waves in estuaries, flood waves in rivers and operation of irrigation and drainage systems. Free flow in open channels is simulated and canal sections, and control structures like weirs, culverts, siphons and pumps can be included. A simple rainfall-runoff relation is part of the model.

► *made where:*
International Institute for Hydraulic and Environment Engineering, Delft; Rijkswaterstaat, Tidal Waters Division, The Hague; Delft University of Technology. Distribution: ICIM, P.O. Box 5809, 2280 HV Rijswijk, The Netherlands (formerly: Bureau SAMWAT). Price of version 2.0 is NLG 750 excl. VAT.

► *what available:*
- Two 3.5" DS DD diskettes, containing program version 1.1 and examples;
- Spaans, W., N. Booij, N. Praagman, R. Noorman & J. Lander, 1991. DUFLOW, a microcomputer package for the simulation of one-dimensional unsteady flow in open channel systems. IHE, DGW, TUD; Delft. 92 pp.
- Clemmens, A.J. & F.M. Holly, 1991. Description and evaluation of program DUFLOW. In: Ritter, W.F., Irrigation & Drainage, ASCE, Hawaii: 418-424

► *what required:*
IBM-compatible PC under MS-DOS, with 640 kB internal memory, graphics card (CGA, EGA, VGA, Olivetti, Hercules), preferably a math co-processor; two 360 kB floppy drives or equivalent; a hard disk is recommended.

► *written in:*
The non-interactive calculation module is in Fortran-77. The interactive input and output modules in GW-Basic.

► *remarks:*
- After making a directory c:\duflow\ and copying all files thereto, program starts upon typing DUFLOW; subsequently, one must check Setup and Filenames;
- Main program consists of three basic options: Input, Calculations, and Output; Input and Output are logically subdivided in Submenu's;
- Manual is useful, has background theory, program structure, and operation (with example in App. B: Getting started) nicely explained;
- Program runs through example without problems;
- An educational version (with limited possibilities) is available;
- Version 2.0 was issued late in 1992 and contains a water quality module as well; this version was not tested; we used its precursor, version 1.1.

Program 17: ETREF

▸ *what it does:*
This is a package of four computer programs based on FAO's Crop water requirements publication (I&D paper 24, 1977), containing ETREF, calculating the potential evapotranspiration of a reference crop, ETCROP, multiplying ETref with a crop coefficient, ETSPLIT, calculating the potential evaporation and transpiration separately, and DEFICIT, calculating net irrigation requirements.

▸ *made where:*
Center for Irrigation Engineering, K.U. Leuven, Kardinaal Mercierlaan 92, 3030 Leuven, Belgium. Price is USD 45.

▸ *what available:*
- Information brochure on this software package;
- A 3.5" disk with the four programs in source code, in an *.EXE version, all with an input chart *.CHA;
- A copy of the manual: Raes, D., P. van Aelst & G. Wyseure, 1986. ETREF, ETCROP, ETSPLIT and DEFICIT, a computer package for calculating crop water requirements. Lab. Soil & Water Eng., Leuven, 104 pp.

▸ *what required:* IBM PC/XT/AT or fully compatible.

▸ *written in:* Fortran 77

▸ *remarks:*
- The ETREF, ETCROP and DEFICIT programs are a logical sequence to arrive at irrigation project requirements; ETREF and ETSPLIT are useful for a soil-water balance model (e.g. SWATRER);
- Adjustment factor c for ETREF is discussed in Jensen, Burman & Allen (1991); more useful info given there;
- Programs have the typical Fortran input chart, which was OK in 1986, but which looks rather dated now;
- Manual appears is quite elaborate, repeating tables from I&D 24, and adding others;
- Climatological data input sometimes flexible (humidity: 4 possible units), sometimes not (wind speed: m/s only);
- No (sample) climatological data file provided on disk, only one month for Jaca (Spain) in manual: file FT04001 is not provided;
- Same goes for other examples in manual: only blank files are provided; for a sample run they must be filled first;
- Suggestion that daily ETREF values are useful is implied, which is highly questionable.

Program 18: FISDEV

▸ *what it does:*
The program is a tool for the design and evaluation of furrow irrigation systems, based on current surface irrigation theory. It distinguishes three types of systems, i.e. with fixed inflow, with cut-back, and with tailwater re-use, which can be treated separately or in comparisons. Four calculation modes allow to solve for inflow rate, furrow length, application time and minimum infiltrated depth.

▸ *made where:*
Center for Irrigation Engineering, Vital Decosterstraat 102, 3000 Leuven, Belgium

▸ *what available:*
- A copy of the program (45 files) on a 3.5" disk; it is a preliminary version of April 1992 (to become version 1.0);
- A copy of the draft Manual: Zerihun, D. & J. Feyen, 1992. FISDEV, a software package for design and evaluation of furrow irrigation systems. Center for Irrigation Engineering, Leuven, Belgium, 52 pp.;
- Zerihun, D. & J. Feyen, 1992. FISDEV - a software package for design and evaluation of furrow irrigation systems. Proc. 16th Europ. Conf. ICID, Budapest, vol. III: 189-195

▸ *what required:*
IBM XT/AT or compatible with a minimum of 360 kB RAM. Math co-processor and VGA recommended.

▸ *written in:* Turbo Pascal.

▸ *remarks:*
- As this is only a preliminary version, these remarks may not hold for the final product;
- Creating a DB directory tree takes a long time; an installation procedure may be indicated;
- Help screens require editing and are not always clear;
- The file handling facilities easily lead to confusion;
- There is no consistency in the use of Modules and Modes;
- The final version of the manual would benefit from another introduction;
- Chapters 1-4 of the draft manual could be replaced by an improved section on furrow irrigation design and evaluation;
- The manual still lacks a chapter on surface irrigation theory.

Program 19: FLUME

▸ *what it does:*
The model computes stage-discharge relations and energy losses for long-throated flumes and broad-crested weirs. It can accommodate a wide variety of flume and channel shapes and many different input and output units. Input data can entered from the keyboard or be read from a file and, similarly, output can be to the screen or to output files (in tabulated form).

▸ *made where:*
USDA Agricultural Research Service, US Water Conservation Laboratory, 4331 East Broadway, Phoenix, Ariz. 85040, USA (Contact A.J. Clemmens).

▸ *what available:*
- 3.5" disk with FLM24.EXE file (90 kB), source code in Fortran, a README and some data files;
- Manual: Clemmens, A.J., J.A. Repogle & M.G. Bos, 1987. FLUME: a computer model for estimating flow through long-throated measuring flumes. US Dep. of Agriculture, Agricultural Research Service, ARS-57, 68 p.
- Literature (e.g.): Bos, M.G., J.A. Repogle & A.J. Clemmens, 1984. Flow measuring flumes for open channel systems. Wiley, New York.

▸ *what required:*
Not stated (IBM PC XT or AT or 386, with or without a math co-processor).

▸ *written in:* Fortran IV.

▸ *remarks:*
- Program starts by logging to a: and typing FLM24;
- Input data e.g. of example (flume 7) can be either read from data file or typed in from keyboard;
- If typed in from keyboard data appear almost immediately on screen (and, if chosen, in output files);
- No plotting or graphics facilities provided: other plotting programs may import data from output files;
- Program does calibration and analysis, NOT design;
- Manual is quite useful for help in choosing inputs (pages 8-13); extensive examples are given; theory provided (pages 34-57);
- Program shows older Fortran problems with inflexible input/output arrangements; the comparison of runs must still be done by looking at long tabulated data (or by using other graphics packages);
- Hydraulic basis should be OK;
- The program does not stand alone: you need the manual;
- A new version 3.0 has been made and is to be published in 1993.

Program 20: INCAdemo

▸ *what it does:*
The demonstration disk shows in a number of subsequent screens that the Irrigation Network Control & Analysis package is based on a generalized database (in the demo for Kraseio Scheme in Thailand). The database contains, a.o. canal network data, historic rainfall data, info on soils, cropping patterns, canal water levels, etc. The program facilitates data management & processing, irrigation water management, and performance monitoring. Extensive use of graphics, including map zooming, visualizes information quickly and attractively.

▸ *made where:*
HR Wallingford Ltd., Wallingford, Oxfordshire OX10 8BA, UK. Contact: John Skutsch. Available at around GBP 3000.

▸ *what available:*
A 3.5" demonstration disk, which is 770 kB in size including zipped INCA files (unzipped size 220 kB). There is a batch file for installation on c:\incdem.

▸ *what required:*
For the demo 2.5 MB should be available on the hard disk, and a VGA colour screen is required (VGA mono will do). For the real program WINDOWS v. 3.1 is required and an SQL routine licence (GBP 150). An IBM 80386 machine is required, with 4 Mb RAM and a 60 MB hard disk, with a VGA colour screen.

▸ *written in:* not stated

▸ *remarks:*
- After installation to c:\incdem and logging there, typing ST INCA will start the demonstration (see instruction sheet);
- Program seems indeed to be an integrated package, including separate functions like calculating water requirements, preparing cropping patterns, making irrigation schedules, allocating canal target flows, etc.;
- Graphics are indeed nice, somewhat comparable to the Mott MacDonald standard (NILE, etc.), and functional; it is the first package that runs under WINDOWS (hence the 80386 and 4 MB RAM requirement); top of the market; too high and too expensive for our normal target group;
- A wide range of options (pull-down menus) are easily accessible; they seem logically structured;
- Difficult to judge how site-specific the program is; apparently it is (besides Thailand) also introduced in Sri Lanka and Bangladesh.

Program 21: IRRIGAME

▸ *what it does:*
The program asks the user to choose between various input options, such as: advisory services, growing season rainfall, reservoir water availability, type of irrigation system, crop type, crop/soil options, and two agronomic options. It then proceeds to provide weekly climatic data and graphical rooting depth and soil depletion, requesting you to say, week by week, whether or not to irrigate and how much to apply. You can operate at various speed levels. In the end a summary and plotting possibilities are provided. The 'scoring' is not completely clear.

▸ *made where:*
Brian J. Boman, Utah State University and University of Florida, USA, based on earlier irrigation games by J. Parrish & L. M. Mulkay. Available from Software Engineering Div., Biol. & Irrig. Eng. Dept., USU (April 1992) at USD 35.00 + shipping & handling (USD 8.00 in USA, USD 15.00 abroad).

▸ *what available:*
A 3.5" disk with 11 files in 182 kB, including BASICA.COM and GWBASIC.EXE. The IR.BAT does not work on the Compaq. There are 4 other *.DAT files, two (older) Fortran files (.FOR) and two Basic files (.BAS), which seem to be the current ones. References were seen to J. Parrish (1982 and undated), about an On-farm management simulation game and about Irrigation simulation game development, both from USU, Logan.

▸ *what required:*
Not specified; Hercules 720*348 or IBM 640*200 (CGA) to be selected, when prompted. Apparently, any IBM PC XT will be adequate.

▸ *written in:* Basic (new programs), Fortran (the older ones).

▸ *remarks:*
- Type IR after logging to the a: drive, containing the floppy;
- There are apparently climatic data available; it is not clear where they are, for which station, and if they can be changed;
- The provided information before being asked whether to irrigate or not is confusing; the Depletion graph may not have been understood correctly;
- The 13 plotting menu choices at the end are potentially nice, but there is no "score", or "What did I do right or wrong ?";
- It is not immediately clear what the other files (except GWBASIC.EXE and IR1.BAS, which produce IRRIGAME) are meant for;
- The purpose of the game is not clear; there is no manual or any other documentation to assist;
- We may not have tested the most recent version.

Program 22: IRSIS

▸ *what it does:*
The IRrigation Scheduling Information System package addresses irrigation scheduling at field level. For a given climate, crop and soil it offers possibilities to calculate net irrigation requirements or optimum water distribution under limited water supply, to plan irrigation schedules, to evaluate past irrigation schedules, and to plan irrigation actions. Consequences of irrigation schedules are shown in terms of water use efficiency and crop yield depressions. It employs interactive data processing and calculations, using hierarchically structured displays or screens.

▸ *made where:*
Center for Irrigation Engineering, Laboratory of Land Management, Faculty of Agricultural Sciences, Kardinaal Mercierlaan 92, b-3030 Leuven, Belgium. Available at USD 75.00.

▸ *what available:*
- A 3.5" disk with IRSIS version 4.01 in *.EXE form, with drivers, displays and a database;
- Raes, D., H. Lemmens, P. van Aelst, M. vanden Bulcke & M. Smith, 1988. IRSIS - irrigation scheduling information system, vol. 1: Manual (199 pp.) and vol. 2: Displays (71 pp.). Lab. of Land Management, Leuven;

▸ *what required:*
IBM PC/XT/AT or compatible, 640 kB RAM, PC-DOS/MS-DOS 2.xx or higher; minimum 1 FDD, CGA and a monochrome monitor.

▸ *written in:* Turbo-Pascal; interactions with SUSI (Lemmens 1988)

▸ *remarks:*
- The package in fact replaces and extends ETREF, ETCROP, ETSPLIT and DEFICIT, made in Leuven earlier (1986);
- The interaction with displays using Structured User System Interface (a developed by-product of IRSIS) is a nice improvement (for 1988, anyhow, when pull-down menus were not common);
- Works only for uniform soils and dry-foot crops (no rice); capillary rise is not included, nor are leaching, distribution losses or delivery systems;
- Hierarchical structure of displays easy to grasp; Main > Libraries > Members > Inquire/Update > ID/Data/Report > Details (e.g. text, tables, graphs);
- Working through the case study (chapter 4 of the manual) takes a few hours, leaving out smaller details;
- The total package is a handsome scheduling program, but at least a few days are required to become familiar with the terminology, the program logic and the keyboard actions. Comparable with FAO's CROPWAT (Smith, 1992).

Program 23: MAINSYST

▸ *what it does:*

This spreadsheet either works with a given reference crop relative factor (l/s/ha) and calculates the discharge at each tertiary unit and works back up the system to find the total requirement at the source, or starts from a fixed water supply at the source and then distributes this over the respective tertiary unit areas. It uses relative areas for various crops/crop stages, instead of a varying unit discharge (l/s/ha). It is thus basically an allocation program.

▸ *made where:*

M.A. Burton, Institute of Irrigation Studies, The University, Southampton SO9 5NH, UK. Restricted availability.

▸ *what available:*

- A 3.5" disk with PENEWON.WK* worksheets (one empty);
- A manual: Computer programs for management of irrigation systems - Spreadsheets and the relative area method, IIS, Southampton; 24 pp.
- Bullock & Burton, 1988. Spreadsheets for water management - a case study from the Brantas Delta, East Java. Irr. & Dr. Syst. 2: 259-278.
- Goldsmith, Bird & Howarth, 1988. Computerised irrigation scheduling using spreadsheet models. Irr. & Dr. Syst. 2: 211-227.

▸ *what required:*

IBM PC computer with 384 kB memory and Lotus 1-2-3 or QuattroPro software.

▸ *written in:* Lotus 1-2-3.

▸ *remarks:*

- Summary (Manual p. 10) is in columns A-H, rest is to the right; no worksheet PENEWONA.WKT (p. 12) copied, which gives Worksheet file revision out of date error (TWIN = simple and free spreadsheet, like Lotus 1-2-3);
- No Kapongan scheme files present (Manual p.4; Ch. 5);
- Spreadsheet is configured for particular scheme, but idea can be borrowed for other schemes;
- It calculates allocations with either the water supply at the source fixed or with the standard water use fixed (say, 0.4 l/s/ha);
- There are 4 graphs under Names which can be viewed;
- The idea is not revolutionary, but it can form a useful demonstration exercise for the use of spreadsheets for small irrigation problems;
- The sequence of the spreadsheets in terms of level of difficulty/training is: CWRTABLE - MAINSYST - DRAINCAN.

Program 24: NESTOR

▸ *what it does:*
This set of programs calculates steady non-uniform flow in channel sections of various shapes. For a maximum of 30 reaches, water profiles are calculated, i.e. the eight relevant variables are connected. Output is tabulated in a data sheet, but graphical output is also possible. A maximum of 11 different cross-section per canal reach and five structures per section can be included.

▸ *made where:*
G.J. Hunink, Int. Agric. College Larenstein, Laarweg 6, 6882 AA ,Velp, The Netherlands. Restricted availability.

▸ *what available:*
NESTIN, NESTOL and NESTUD executive files for input, as the major program and for (student) demonstration, respectively. Version number is 1.0, dated 1991.

▸ *what required:*
A math co-processor is required; other requirements not specified. The total package fits on a HD floppy only (AT machines or higher).

▸ *written in:* not stated.

▸ *remarks:*
- The programs are apparently mainly intended for demonstration and use by College students and not specifically made for further distribution;
- Input not difficult; calculations seem to work OK;
- The graphics are generally reasonable, but sometimes poor (e.g. printed length profile from NESTUD);
- A major drawback for wider use at present is that everything is written in Dutch.

Program 25: OMISdemo

▸ *what it does:*
The demonstration disk mentions that OMIS (Operation and Management of Irrigation Systems) allows the user to plan a cropping pattern, process monitoring data, prepare half-monthly operation schedules and simulate alternative operations. The demo stresses the integrated structure of the program, its fast data processing, its flexibility and its user-friendliness (menu-driven, graphic displays).

▸ *made where:*
Delft Hydraulics, Division Water Resources and Environment, P.O. Box 177, 2600 MH Delft, The Netherlands, for DHV Consultants, Amersfoort. OMIS itself costs over NLG 10,000.

▸ *what available:*
- Demo disk with 44 files (approx. 716 kB);
- Relevant publication: Verhaeghe, R.J. & W.N.M. van der Krogt, 1990. Modelling of irrigation water management. Delft Hydraulics publication no. 447, Dec. 1990.

▸ *what required:*
For the demo, an IBM AT is required with an EGA card and colour screen; Monochrome screen gives good idea, but maps are not 100%. It says that the OMIS program itself needs an IBM AT with a math co-processor, an EGA card, a colour screen, a hard disk with >= 10 MB storage, and an Epson compatible printer.

▸ *written in:* not mentioned.

▸ *remarks:*
- Demo starts with typing DEMO;
- The general text, and slides of the four main functions, give a good impression of the program's possibilities;
- Graphics shown are indeed of good quality;
- Application and data shown are for the 12000 ha Cidurian Irrigation Scheme (Indonesia), mainly for the overall network, which includes river diversion and a hydropower dam. The smallest irrigation unit is a tertiary unit;
- The operation part includes the organizational setup, (pengamats, mantris and gatekeepers) and deals with monitoring information and new gate settings on a half-monthly basis;
- It is difficult to judge from the demo how site-specific the program is. It would be useful to establish how the actual OMIS would perform under other conditions, in other places. The set-up looks promising;
- The OMIS program is basically an allocation program, taking account of crop data, climatic data, and soil data in various portions of a scheme on a half-monthly basis. It can also handle current information for monitoring.

Program 26: OPTIPIPE

▸ *what it does:*
The program calculates the most cost-effective pressurized irrigation water distribution system, considering pipe diameters only. It is meant as a practical tools for irrigation engineers to assist them in designing a branching pipe network.

▸ *made where:*
FAO, AGLW Service, Land and Water Development Division, Via Terme di Caracalla, 00100 Rome, Italy

▸ *what available:*
- A version of the OPTIMIZING PIPES DIAMETER program, renamed OPTIPIPE by us, dated August 1988 (most recent file) on a 3.5" disk;
- Manual for OPTIMIZING PIPES DIAMETER (FAO and PIT's). Land & Water Dev. Div., FAO, Rome. No year. 68 pp.
- Annex: Use of the programme. pages 233-244 of FAO Irrigation & Drainage Paper 44 (from Labye et al., 1988).
- Literature: Y. Labye et al., 1988. Design and optimization of irrigation distribution networks. Irrigation & Drainage Paper 44, FAO, Rome. Chapter 4: Design and optimization techniques of pressure distribution networks. pp. 89-146.

▸ *what required:*
IBM PC XT or AT or compatible, with minimum 260 kB RAM, and a printer.

▸ *written in:*
Basic, in 11 program modules and many data files for the example. Size is: about 222 kB.

▸ *remarks:*
- Start by typing OPTIPIPE after logging to relevant drive;
- The options appearing at the start are not clear: e.g. do they take you through the example or are you starting a new network ?;
- There are sequential errors in the manual;
- Upon entering the data of Fig. 37 (F1) and Fig. 39 (F2), as mentioned in part II of the Manual, two errors appeared, i.e.:
- On ascending the network (F3) the program aborts (subscript out of range);
- On descending the network (F4) program aborts (input past end);
- Program as we have it does not work properly.

Program 27: PROFILE

▸ *what it does:*
Calculates user-defined unknowns in the Manning/Strickler formula for trapezoidal channels, using a tabulated calculation sheet, which can be written to a file for future reference. The Newton-Raphson iteration is used for unknown water depth, bed width or side slope.

▸ *made where:*
Delft University of Technology, Faculty of Civil Engineering, Sanitary Engineering & Water management, Section Irrigation, P.O. Box 5048, 2600 GA Delft, The Netherlands

▸ *what available:*
- A 3.5" disk with PROFILE.EXE and a KSVALUES.TXT file (together some 112 kB); version = 1.0, dated July 1990;
- User's Manual Profile, written by H. Hebermann & W. Schuurmans, dated February 1991, 13 pages.

▸ *what required:*
No data on requirements are given. Program will presumably run on IBM PC XT, AT, 386 or compatibles with a minimum of 256 kB memory.

▸ *written in:* not stated.

▸ *remarks:*
- Program starts after typing PROFILE;
- The KSVALUES.TXT file is too short and not geared towards earthen channels in field irrigation (Ks values are high). It can easily be replaced, but better guidance is expected from a program like this;
- User manual is very explicit, which is generally good;
- The English in the manual and in the Help could be improved;
- Future versions could include suggestions for b/h choices to be made, tabulated permissible flow velocities for various soil materials, and other channel shapes.
- The program makes files on the diskette for future reference, if a SAVE instruction is given; there needs to be space for this on the disk;
- A simple, small program suitable for a simple, small task.

Program 28: RAINBOW

▸ *what it does:*
Frequency analysis and probability plotting of hydrologic data, test of homogeneity of hydrologic records; uses Gumbel and (transformed) normal distributions only.

▸ *made where:*
Center for Irrigation Engineering, Catholic University, Vital Decosterstraat 102, 3000 Leuven, Belgium.

▸ *what available:*
- A 3.5" disk with version 1.6, March 1990;
- The manual, treating version 1.5 (October 1989); 43 pp.

▸ *what required:*
- IBM PC/XT/AT or fully compatible with 640 kB RAM;
- PC/MS-DOS 2.xx or higher;
- Monochrome or colour screen;
- Size approx. 160 kB (excl. data & output files).

▸ *written in:*
Borland's Turbo Pascal 4.0 with SUSI keyboard screen interactions.

▸ *remarks:*
- Start from disk, type RAINBOW;
- Disk works without problems and according to manual;
- LOGO does not come; first screen confusing, initially;
- Action bar at the bottom of the screen might be useful;
- The English in the manual should be edited;
- Can be quickly learnt in e.g. a few hours;
- A nice tool for a relatively simple job.

Program 29: **REHAB**

▸ *what it does:*
The program can be used by an individual or by one or more teams, who formulate a plan to rehabilitate a secondary canal command area within given budget and time constraints. Requirements of the plan are specified in socio-technical terms of e.g. improved water distribution and better farmer participation. Important stages are System introduction, Information Acquisition, Preliminary design, Final design, and Evaluation. The wider purpose is to create an interdisciplinary, problem-oriented learning experience for participants. An Asian and an African version are available.

▸ *made where:*
T.S. Steenhuis, Dept. of Agricultural & Biological Engineering, Cornell University, Riley-Robb Hall, Ithaca NY 14853-5701, USA

▸ *what available:*
- A 3.5" disk with the 1986 versions and the slide sets;
- Oaks, R.L., E.J. vander Velde & T.S. Steenhuis, 1986. Irrigation REHAB, User's manual. WMS Rep. 46, Ithaca
- Sikkens, R., R. Johnson, R.L. Oaks & T.S. Steenhuis, 1987. Irrigation REHAB - Africa version - User's manual. WMS Rep. 64, Ithaca

▸ *what required:*
- An IBM-compatible microcomputer with 256 kB RAM, running under MS-DOS 2.0 to 3.1, with or without a math co-processor;
- CGA or EGA or equivalent with colour monitor;
- Relay Adapter Card for automatic access to slides.

▸ *written in:* Not stated.

▸ *remarks:*
- The installation procedures are simple and work correctly;
- There is a clear root menu, leading to three sub-menu's (Environment, Information, Farmer), with several options; the Information Module is the most elaborate one;
- We had start-up difficulties on the Compaq, probably due to the monochrome VGA screen; there were no problems on the Portadesk;
- The manuals are clear on starting and running procedures, and give sufficient guidance for trying out individually;
- The graphics for the maps have a somewhat rudimentary appearance nowadays;
- The quality of many slides is not consistent with the rest of the game;
- As with most irrigation games, the group experience seems to be more important than any factual instruction.

Program 30: REUSE

▸ *what it does:*
The model simulates water and salt balances in a series of consecutive schemes in a river basin under different climatic (precipitation and evapotranspiration) and water management conditions. The latter can vary with respect to irrigation efficiencies, reuse of drainage water, quantity and salinity of water supply to the basin, etc. It is a simple mass balance, parametric model. Three types of variables need to be specified: general, river and scheme variables. Output is per sub-period or per period and relates to scheme or basin.

▸ *made where:*
Euroconsult, P.O. Box 441, 6800 AK Arnhem; Delft University of Technology, P.O. Box 5048, 2600 GA Delft; ILRI, P.O. Box 45, 6700 AA Wageningen. Limited availability.

▸ *what available:*
- A 3.5" diskette with REUSE.EXE, INPUT.DAT and OUTPUT.LIS;
- Hoogenboom, P.J., L.K. Smedema & W. Wolters, s.a. Manual of 'REUSE', Arnhem/ Delft/ Wageningen;
- Smedema, L.K., W. Wolters & P.J. Hoogenboom, 1992. Reuse simulation in irrigated river basin. J. Irr. Dr. Eng. 118(6): 841-851

▸ *what required:* not stated

▸ *written in:* Turbo-Pascal 4.0

▸ *remarks:*
- Input file lay-out needs to be exactly followed; no interactive data input; batch processing;
- Sample run with INPUT.DAT works OK and takes approximately 3 minutes on our test machine;
- Printing the output file would be best on a wide-carriage printer;
- An extra .TMP file, made during execution, is to be deleted manually afterwards;
- There is a counter during simulation (useful for the insecure or impatient user);
- Abbreviations used in the output file are in the manual;
- No iterations performed; possibly in a future version;
- Model is relatively simple, with a number of simplifying assumptions and with some slightly dated relationships;
- Testing is said to have been done in arid (Egypt: Fayoum) and semi-arid (Pakistan) conditions with satisfactory results;
- The model is clearly structured and the manual is concise and clear; it could be a useful educational program and a general planning tool, if tested and refined further;
- For wider application, the user-friendliness could be improved.

Program 31: RICEYLD

▸ *what it does:*
The program simulates yield performance of a number of plots under various irrigation schedules and policy alternatives. Its core is a simple water balance for a rice field, for which the various terms are estimated (evapotranspiration, seepage, irrigation, rainfall, drainage, etc.). A yield ratio for drought conditions actual/potential is calculated following a Wickham model as the main performance indicator. The program is a variant of SIMYIELD. It uses daily evapotranspiration and rainfall records so as to avoid effective rainfall estimates. Minimum and maximum water levels are specified.

▸ *made where:* The World Bank, New Delhi, India

▸ *what available:*
- A 3.5" disk with the SIMYIELD and RICEYLD source codes and .EXE files, plus additional files;
- Narayanamurthy, S.G., 1987. SIMULNDO software package for simulating crop performance under irrigation - user's manual (apparently pre-cursor to SIMYIELD and RICEYLD);
- Narayanamurthy, S.G., 1988. RICEYLD program for simulating performance of rice crop under irrigation - user's manual. World Bank, New Delhi.

▸ *what required:*
IBM PC with MS-DOS and an Epson FX or LX printer.

▸ *written in:* Basic

▸ *remarks:*
- The program will runs faster in the .EXE version;
- A test run for one year with existing data files took about five minutes to complete, with half a page abbreviated printed results;
- The program relies heavily on a Wickham yield relation for dry and wet season yields, and on I&D Paper 24 (Crop water requirements);
- The special flooded rice situation makes the program simpler than SIMYIELD (no unsaturated zone);
- No yield reductions due to high water levels (submergence) are calculated due to lack of existing relationships;
- There is no staggered sowing, only slightly staggered land preparation;
- The screen messages and questions are relatively simply laid out; there are no menus and no graphics and no choices to point to, merely questions to answer with letters or figures (Y, N, 1, 2, 3, etc.);
- File handling is neatly organised with choices appearing on screen, making backups, etc.;
- Data input is old-fashioned but proceeds OK using a special module GENRFILE.

Program 32: SALTMOD

▸ *what it does:*
Predicts soil salinity and the salt contents of groundwater and drainage effluent in irrigated agricultural land, based on seasonal data. It also calculates the depth of the groundwater table and the drain discharge. Calculations are based on water balances, and the salinity of each element is considered to arrive at salt balances. Various hydrologic conditions, water management options and cropping schedules can be simulated. An input data table is converted by the program to an output data table.

▸ *made where:*
R.J. Oosterbaan, International Institute for Land Reclamation and Improvement, P.O. Box 45, 6700 AA Wageningen, The Netherlands. Limited availability.

▸ *what available:*
- A 3.5" disk with the .EXE and the .FOR program files, and additional support files; revised version Jan. 92 (updated from 1986; Oosterbaan/Pedroso de Lima);
- A draft manual SALTMOD, by R.J. Oosterbaan, ILRI, revision January 1992; incomplete; 43 pp.
- Oosterbaan, R.J. & M. Abu Senna, 1989. Using SALTMOD to predict drainage and salinity in the Nile Delta. In: ILRI Annual report 1989: 63-74
- Rao, K.V.G.K., G. Ramesh, H.S. Chauhan & R.J. Oosterbaan, 1992. Salt and water balance studies to evaluate remedial measures for waterlogged saline irrigated soils. Proc. 5th Int. Dr. Workshop, ICID-IWASRI, Lahore: 2.67-2.77

▸ *what required:* IBM-PC or compatible; MS-DOS; ≥ 360 kB RAM

▸ *written in:* Fortran 77

▸ *remarks:*
- Running the program with a sample input data file is quick and without problems;
- For testing the influence of certain variables, a number of consecutive runs can easily be made (see e.g. Oosterbaan & Abu Senna, 1989);
- A thorough study of the manual is required to understand how the program operates and what it can do for the user;
- The many 3-letter abbreviations for input, for output and for temporary variables are explained in a separate file, but do not ease a quick understanding;
- Preparation of the input data table is typical for older Fortran programs, as is the batch processing;
- Output gives seasonal values for a specified number of years in a tabulated form;
- The program is still under development; scientific finalising (promised in the manual), thorough brushing up of the user interface, and providing an adequate manual are underway;
- Combination with program SGMP into a regional salinity model is attempted.

Program 33: SATEM

▸ *what it does:*
This package contains Selected Aquifer Test Evaluation Methods, which help in determining the hydraulic characteristics of water-bearing layers from pumping tests, a common phenomenon in studies of regional groundwater resources. There are four sub-programs, i.e. JACOB, HANTUSH, PARTIAL and RESIDUAL, corresponding with fully or partially penetrating wells, and confined, leaky or unconfined aquifers, and whether or not residual drawdown data are to be analyzed. Diagnostic plots are shown on screen and the user can select a satisfactory match between data and theoretical model.

▸ *made where:*
Dr. J. Boonstra, ILRI, P.O. Box 45, 6700 AA Wageningen, The Netherlands (Price NLG 34.00 for publ. 48 + floppy)

▸ *what available:*
- A 3.5" floppy with SATEM version 1.3 (Aug. 1991);
- Boonstra, J., 1989. SATEM: Selected Aquifer Test Evaluation Methods - a microcomputer program. Publ. 48, ILRI, Wageningen, The Netherlands
- Boonstra, J., 1992. Aquifer tests with partially penetrating wells: theory and practice. J. Hydrol. 137: 165-179

▸ *what required:*
IBM compatible microcomputer with Hercules card, CGA or higher and a corresponding monitor. A math co-processor would speed up the calculations.

▸ *written in:* QuickBasic

▸ *remarks:*
- The screens work OK in all four sub-programs and the test data lead to fast results, even without a co-processor;
- There are two additional small programs for assistance: INPUT helps to make input files, and with SCAL theoretical single-well and aquifer test data can be made;
- Manual is suitable mix of theoretical background and program user notes; limitations are clearly stated;
- The program is a nice, relatively small tool for a clearly defined job, and leaves sufficient room for personal interpretation and judgement;
- Program should be judged in combination with Kruseman & De Ridder's Analysis and Evaluation of Pumping Test Data (ILRI publ. 47);
- Relevance for irrigation or drainage limited to research for tubewells or boreholes (groundwater pumping or vertical drainage);
- A useful and modern enough tool.

Program 34: SGMP

▸ *what it does:*
The model can be used to predict the effect of new irrigation schemes, new patterns and rates of groundwater abstraction, and artificial recharge of the groundwater basin, for any desired length of time. It can be applied to a confined, semi-confined and an unconfined aquifer, but not to multi-aquifer systems. The model is devised for saturated laminar flow. It applies mainly the Gauss-Seidel iterative method to solve the finite difference equations, but the Gauss-Jordan elimination method can also be chosen. Plots of water table elevations can be made on screen. SGMP1 applies to single aquifers, SGMP2 to two-layered systems.

▸ *made where:*
J. Boonstra & N.A. de Ridder, ILRI, Wageningen (price for each of the programs on disk NLG 20.00; publ. 29 = NLG 40.00)

▸ *what available:*
- A 3.5" floppy disk with SGMP1 and SGMP2 programs, source codes, and sample input data files;
- Boonstra, J. & N.A. de Ridder, 1990. Numerical modelling of groundwater basins. ILRI publ. 29 (2nd ed.), Wageningen
- A short SGMP2 manual, stipulating the differences with Publ. 29 ("Description of the two-layered model").

▸ *what required:* IBM compatible microcomputer under MS-DOS

▸ *written in:* Fortran IV (SGMP1) and Fortran 77 (SGMP2)

▸ *remarks:*
- In SGMP1 there are four parts (-1, -2, -3a, -3b), to be run consecutively; results come fast in four corresponding .OUT files and two .TRF files;
- The structure of the SGMP2 package is the same, with four parts (-21, -22, -23, and -24), and there is a .DOC file, which is the text of the short SGMP2 manual, mentioned above; test input results come fast;
- Printed and graphical results must be printed on a wide carriage printer (130 char.);
- The input and output is standard older (inflexible) Fortran, dating from the punched card time (as is Publ. 29); no menu's, no interaction, no graphics (except a plotted results file for a wide printer); the program appearance looks outdated in 1992;
- The program requires a thorough understanding of the subject and the validity of the input data via Publ. 29 before the input routines can be used and before results can be interpreted;
- Attempts are made to integrate this model with SALTMOD into a regional salinity model (RSM), at the same time updating the user interface.

Program 35: SIMYIELD

▸ *what it does:*
The program simulates yield performance of a number of plots under various irrigation schedules and policy alternatives. Its core is a simple water balance for a layered top soil, for which the various terms are estimated (infiltration, runoff, evapotranspiration, seepage, rooting depth, soil moisture flow, etc.). A yield ratio actual/potential is calculated as the main performance indicator. The program draws heavily on FAO I&D papers 24 and 33. Daily data are calculated using historical rainfall records so as to avoid effective rainfall estimates.

▸ *made where:*
The World Bank, New Delhi, India

▸ *what available:*
- A 3.5" disk with the SIMYIELD and RICEYLD source codes and .EXE files, plus additional files;
- Narayanamurthy, S.G., 1987. SIMULNDO software package for simulating crop performance under irrigation - user's manual (apparently pre-cursor to SIMYIELD and RICEYLD);
- (do), 1988. SIMYIELD software package for simulating crop performance under irrigation - user's manual. World Bank, New Delhi.

▸ *what required:*
IBM PC with MS-DOS and an Epson FX or LX printer.

▸ *written in:* Basic

▸ *remarks:*
- The program will run faster in the .EXE version;
- A test run with existing *01 files took about ten minutes to complete, with 2 pages abbreviated printed results;
- The program relies heavily on I&D papers 24 and 33;
- The use of the Curve Number method for infiltration & runoff determination seems rather crude;
- Using a linear unsaturated conductivity function (K-theta) is also a gross simplification;
- There is some doubt about the multiplication of reduced yield ratios for different crop stages;
- The screen messages and questions are relatively simply laid out; there are no menus and no graphics and no choices to point to, merely questions to answer with letters or figures (Y, N, 1, 2, 3, etc.);
- File handling is rather neat and data input is old-fashioned but proceeds in a guided way in special organised modules (GENFARMF, GENRFILE and CRPSOLDT).

Program 36: SRFR

▸ *what it does:*
The program is meant to analyze a particular surface irrigation event by calculating the longitudinal distribution of infiltrated depth and the volume of runoff. The irrigation event is characterized by entering values for the relevant input parameters, which can vary widely: infiltration, bottom slope and roughness may be varied over the field length, inflow can be constant, as surges, or as a hydrograph, etc. For small-medium sloped the zero-inertia approach is used; for higher slopes the kinematic-wave approach is the default.

▸ *made where:*
Theodor Strelkoff, USDA-ARS US Water Conservation Laboratory, 4331 East Broadway, Phoenix, Arizona 85040, USA

▸ *what available:*
- A 3.5" diskette containing 16 files (651 kB), which is version 20 of January 1991; source code not available;
- The manual, called: SRFR - a computer program for simulating flow in surface irrigation -furrows-basins-borders; WCL report # 17, US Water Cons. Lab., Phoenix, by Theodor Strelkoff (69 pp.)

▸ *what required:*
IBM AT or 386 with a minimum of 540 kB free memory, CGA monochrome or EGA colour screen; a math co-processor is strongly recommended as it cuts calculation times to about 1/10th. Disk space is required for the files the program makes during execution.

▸ *written in:* Fortran 77

▸ *remarks:*
- Several settings are required before a run can start; this is mainly achieved by going through a SRFRPREP program, the entries from which are explained in quite some detail in the manual;
- The sample input (in SRFR.DAT) takes about 18 minutes on the Compaq 386N (without co-processor) to complete; 14 extra files are made, some empty;
- The SRFRPLOT aborts because QPHERC encounters an illegal function call in line 541 (in the CGA version); CGA or EGA have to be copied by the user into WS2.INI and LABELW.TEM; a new version is said to avoid this problem;
- No runs with own data (e.g. comparison with BASCAD) made;
- The program shows the pre-occupation of the researcher with the physical and mathematical theory, and the typical lack of user-friendliness nowadays standard in computer packages. The use of Fortran, the cumbersome input, and the long list of output figures are indicators. Work on a comfortable interface is in progress.

Program 37: SUBDRAIN

▸ *what it does:*
The program uses colour graphics to assist the user in designing and evaluating a simple subsurface drainage system, consisting of one collector and evenly spaced lateral pipe drains on one or on two sides, at any angle. The program is especially meant for teaching and demonstrations. Based on topographic features of an area it calculates the mainline configuration, the spacing, the depth and the diameters of the drains, as well as water table heights and the total cost of the system.

▸ *made where:*
Department of Agricultural Engineering, Riley Robb Hall, Cornell University, Ithaca, NY 14853, USA. Available via the Northeast Regional Agricultural Engineering Service at USD 30.00.

▸ *what available:*
- A 3.5" disk with the program version 2.5, copied from the original 5.25" disk;
- The manual: Bottcher, R.S., T.S. Steenhuis & M.F. Walter, 1984. SUBDRAIN - User's manual. NRAES, Ithaca, NY, USA

▸ *what required:*
IBM XT with 64 kB RAM, a colour monitor and board, PC-DOS 1.1 or 2.0

▸ *written in:* Basic

▸ *remarks:*
- The program was written (in 1984) to run with basica, but will also operate under gwbasic (but changes in the batch files are then required; the qbasic coming with MS-DOS 5.0 does not accept most basic programs as they are; conversions via gwbasic are then required;
- Program runs properly after starting gwbasic and loading and running SUBDRAIN.BAS;
- The program clearly dates from the early days of the microcomputer (see also hardware and software requirements), judging by the graphics;
- The water table depth calculations take considerable time, depending on the accuracy required (12-90 minutes);
- A relatively simple and rather dated program, which may have some application in elementary training or demonstration.

Program 38: SUKdemo

▸ *what it does:*
Demonstrates three small computer programs, i.e. Indus Allocations Program (IAP), Sukkur Barrage Game (SBG), and Pump Test Program (PTP). IAP is an interactive training model, which allocates river flows to the 14 canals fed at the 3 barrages on the Lower Indus, Pakistan. SBG simulates the operation of the largest Barrage, Sukkur Barrage, of the same river, using barrage gate openings and canal headwork settings. PTP should plot groundwater drawdowns, but the demo program on our disk aborts prematurely.

▸ *made where:*
Sir M. MacDonald & Partners, Demeter House, Cambridge, UK. IAP and SBG were made for the Government of Sind Province, Karachi (for Overseas Development Administration) and PTP by Groundwater Development Consultants, Cambridge, UK. Year of manufacture 1986.

▸ *what available:*
- A 3.5" disk with the demonstration programs for EGA and for HERCULES card (copied from two original 5.25" disks);
- 4 pages text/screens on Lower Indus Allocations (from P.D.S. Gunn in 1986);
- Ede, P.F. and P.D.S. Gunn, 1987. Computer aided management of Sukkur Barrage, Pakistan. Proceedings BHS, National symposium, Hull Univ., 33.1-33.5;
- Dempster, J.I.M., S.L. Marsden & I.K. Smout, 1989. Computer simulations in games for training irrigation management. Irr. & Drainage Systems 3: 265-280;
- Stoner, R.F., J.I.M. Dempster & S.L. Marsden, 1989. The use of simulation models in the management of irrigation systems.In: Rydzewski & Ward: Irrigation theory and practice. Pentech Press, London, UK: 901-910.

▸ *what required:*
PC/XT/AT with Hercules or EGA card; demo size 316 kB for each resolution.

▸ *written in:*
Prospero Fortran-77; graphics by Cambridge Graphics Ltd.

▸ *remarks:*
- To start: after choosing EGA or HERC directory on 3.5" disk, type DEMO;
- Rather simple demonstration set-up (leaving DEMO.BAT, starting 1.BAT, etc.);
- Not special demo's, but introductions copied from original programs;
- Pump Test Programs regrettably abort on defaults;
- Screens are moving rather quickly on the Compaq Deskpro 386N;
- Insufficient information as to what else the programs can be used for, except as a demo for Govt. of Sind officials.

Program 39: SUKKUR

▸ *what it does:*
Simulates incoming flows, head pond levels, canal indent levels and release volumes for the 3 left bank and 4 right bank canals, for scour/sedimentation requirements and for downstream releases at Sukkur Barrage on the Lower Indus river, Pakistan. The aim is to keep head pond levels steady at given upstream flows by setting barrage gate heights and canal headwork regulator openings. It operates for different seasons (setting irrigation requirements) and at various levels of complexity. Maximum 20 daily steps are made. It writes the performance of the player to the disk.

▸ *made where:*
Sir M. MacDonald & Partners, Demeter House, Cambridge, UK for the Government of Sind, Karachi, under assignment of the Overseas Development Administration. Year of release is 1987. Price at the end of 1987 GBP 100.

▸ *what available:*
- A 3.5" disk with the EGA version;
- A manual: MacDonald, 1987. The Sukkur barrage game. MacDonald Software, Sir M. MacDonald & Partners, Cambridge, UK. 10 pp.;
- Ede, P.F. & P.D.S. Gunn, 1987. Computer aided management of Sukkur Barrage, Pakistan. Proceedings BHS, National symposium, Hull Univ., 33.1-33.5;
- Dempster, J.I.M., S.L. Marsden & I.K. Smout, 1989. Computer simulations in games for training irrigation management. Irr. & Drain. Systems 3: 265-280;
- Stoner, R.F., J.I.M. Dempster & S.L. Marsden, 1989. The use of simulation models in the management of irrigation systems. In: Rydzewski & Ward: Irrigation theory and practice. Pentech Press, London, UK: 901-910.

▸ *what required:*
PC/AT, but will also run on XT with longer pauses; 384 kB RAM and MS-DOS 2.0 or higher; will fit on one 360 kB floppy (size is 350 kB).

▸ *written in:*
Prospero Fortran-77; Cambridge Computer Graphics Ltd.

▸ *remarks:*
- Start by typing AUTOEXEC after logging to drive;
- Objectives of the game are not immediately clear; what do I do ?;
- Graphics are nice (nicer still in colour);
- Switch between Introduction and Game is cumbersome;
- Abbreviations on the screen are not properly explained (KFE = ?);
- Question is what the game teaches you, if you do not operate Sukkur Barrage;
- The brief manual could have contained more explanations, so as to make it more widely usable.

Program 40: SURFACE

▸ *what it does:*
The program assists in the design of surface irrigation systems (borders, furrows, basins) and is based on the volume balance field design (cf. Walker & Skogerboe, 1987). Three flow regimes for furrows are possible, i.e. normal, cut-back and re-use of tailwater. Extensive input data have to be supplied, facilitated by input data screens.

▸ *made where:*
For FAO, Rome, by Prof. W.R. Walker, Dept. of Agric. & Irrig. Engineering, Utah State Univ., Logan, Utah 84322-4105, USA. Available free from FAO, from Utah State Univ. at USD 100.00 + 15.00.

▸ *what available:*
- A 3.5" disk with 10 user files in 307 kB, of which SURFACE.EXE dated 2.10.89 takes 176 kB, and Fortran source codes the remainder (received from FAO);
- W.R. Walker, 1989. Guidelines for designing and evaluating surface irrigation systems. Irrigation & Drainage Paper 45, FAO, Rome, Italy, 137 pp. (mentioning the availability of the disk in Appendix 1 on p. 137); especially chapter 5 (Surface irrigation design) seems applicable.

▸ *what required:* 256 kB RAM

▸ *written in:* Fortran 77

▸ *remarks:*
- There is no example or case study data file on the disk; the program only allows to fill an empty data input format and save it;
- A first trial run with basin data provoked an error and the program had to be aborted; upon changing the input data as best as possible according to chapter 5.6.1 of FAO#45 (file: BAS561.DAT), there was a run of output over the screen, ending in tabulated data of basin width, unit flow, advance and cutoff time and application efficiency;
- The above shows the lack of a manual (although this should not be needed): it is not clear which design parameters the program calculates, as most of them (basin width, basin length, etc. have to be entered; NB: zero slope is apparently not acceptable for basins);
- There is a reference to SURMOD (as in FISDEV) by the same author: available from USU at USD 150.00 + 15.00;
- The three flow regimes for furrows (Normal/ Cutback/ Reuse) are the same as in FISDEV;
- Sample printed output was not tested.

Program 41: SWACROP

▸ *what it does:*
The program simulates the water balance of a cropped soil under different boundary conditions, including the possibility of irrigation and drainage and the calculation of crop yield of potato (in this version of March 1989). From one general and 4 specific input data files, five output files are generated which contain tabulated figures for the water balance components and yield data. The program is based on solving the Richards equation for unsaturated soil moisture flow and additional terms (as in SWATRER) and on a crop production model (CROPR).

▸ *made where:*
J.G. Wesseling, P. Kabat, B.J. van den Broek & R.A. Feddes, The Winand Staring Centre for Integrated Land, Soil and Water Research, P.O. Box 125, 6700 AA Wageningen

▸ *what available:*
- A 3.5" disk with SWACROP.EXE and SWACROP7.EXE files (the latter for use with a co-processor) dated July 1991; one SWADAT.INP file and four .DAT files;
- P. Kabat, 1991. Agrohydrological simulation model SWACROP. Lecture notes 30th Int. Course on Land Drainage, ILRI;
- References (e.g.): Feddes, R.A., P.J. Kowalik & H. Zaradny, 1978. Simulation of field water use and crop yield. Simulation monographs, PUDOC, Wageningen; and Feddes, R.A., 1987. Simulating water management and crop production with the SWACRO model. 3rd Int. workshop on Land Drainage, Ohio State University

▸ *what required:* An IBM PC AT running under DOS. A math co-processor is recommended. Software package BALANCE would be useful.

▸ *written in:* Standard Fortran 77

▸ *remarks:*
- SWADAT.INP is the general data input file, which also allows the user to specify the names of 3 output files (e.g. OUTPUT.OUT, PROFIL.OUT and CROP.OUT); BALANCE.WB and BALANCE.SOL will be made automatically;
- Typing swacrop at the DOS prompt first results is nothing for a while, but then a time bar appears to show the simulation progress; the test run lasted about 15 minutes without a math co-processor;
- The input file is typical for the inflexible Fortran format used at the time of punched cards; there is no interactive input screen;
- The output consists of (long) lists of figures, which must be plotted, viewed and interpreted by hand or with other (graphical) packages; the BALANCE package is available for that purpose;
- Only potatoes appear as a crop in our version; this hampers the wider applicability.

Program 42: SWATRER

▸ *what it does:*
Simulates the actual water use of a field crop through calculating the various terms of the soil water balance, the main feature being the solution of the (unsaturated) soil moisture flow equation using an implicit finite difference technique with an explicit linearization. The original program SWATR (Soil Water and Actual Transpiration Rate) by Feddes et al. (1978) was extended (E) to SWATRE by Belmans et al. (1983) and in now revised (R) to SWATRER (1986). The program uses daily climatological values. An input table must be filled prior to running and tabulated output is given in four files.

▸ *made where:*
Laboratory of Soil and Water Engineering, Faculty of Agricultural Sciences, K.U. Leuven, Kardinaal Mercierlaan 92, b-3030 Leuven, Belgium. Cost USD 45.

▸ *what available:*
- Information brochure (2 pages);
- A 3.5" diskette (720 kB) with an .EXE version;
- A copy of the manual: Dierckx, J., C. Belmans & P. Pauwels, 1986. SWATRER a computer package for modelling the field water balance. Lab. of S&W Engineering, Leuven, Belgium; 114 pp. Contains program listings.

▸ *what required:* IBM PC/XT/AT or fully compatible

▸ *written in:* Fortran 77

▸ *remarks:*
- Filling in the input data is quite laborious and requires a thorough knowledge of soil, climatic, simulation and i/o parameters; program as presented appears a specific research tool;
- Having filled in the input file the program starts by typing SWATRER and then silently works on;
- Using the sample input file the program runs without any messages for almost 3 minutes on the Compaq Deskpro 386N (on HDD) and fills the four empty output files provided;
- Difficult to judge without further reading how "dated" the program is at the moment, seeing that it uses Ernst 1962 groundwater flow, a Ritchie's 1972 evaporation model, the SCS 1972 curve number method for run-off, a Hoogland 1981 root uptake model, etc.;
- It is not a program for quick learning and application, partly because the validity of the assumptions cannot be readily assessed by others than mathematical soil physicists.

Program 43: UNDP

▸ *what it does:*
This is a set of 10 small programs made for a water supply and sanitation project. The programs include BRANCH (for calculating the cheapest branched pipe network), LOOP (for calculating velocities and head losses in a looped network), SEWER (for calculating the best gravity sewer network), FLOW (for simulating flows in large looping networks), SCREEN (for financial screening of water supply projects), REGRESS (for doing multiple linear regressions), LINPROG (for carrying out linear optimizations), NELDER (for non-linear programming), HEADLOSS (for calculating head losses with the Hazen-Williams equation) and MINTREE (for finding the shortest path connecting the nodes in a primary (branched network of a looped system).

▸ *made where:*
Mostly at the Department of Environmental Sciences and Engineering, University of North Carolina, Chapel Hill, Raleigh, NC, USA

▸ *what available:*
- Three 5.25" diskettes with 8 programs (REGRESS and SEWER are missing); 8 programs in executable version have been copied onto one 3.5" disk;
- The manuals for all ten small programs, which include a listing of the source code.

▸ *what required:*
- IBM PC or compatible machines; 256 kB RAM; minimum one floppy disk drive;
- A monochrome or colour monitor and a parallel printer;
- PC-DOS 1.0 and above;
- Resident Basic (for HEADLOSS, MINTREE, LINPROG, NELDER); Fortran compiler if you want to change FLOW.

▸ *written in:* Basic (9 programs) and Fortran (only FLOW).

▸ *remarks:*
- The five most interesting for irrigation are: BRANCH, LOOP, FLOW, MINTREE and HEADLOSS;
- BRANCH and LOOP operate under the same PROGRAMS.EXE file, which should be used to start either; they run correctly;
- FLOW does seem to have problems with the input and output directories; the .EXE version cannot be changed;
- MINTREE and HEADLOSS do a very small job correctly under the Basic version of the Compaq test machine;
- BRANCH apparently does the same as OPTIPIPE, but better.

Program 44: WASAM

▸ *what it does:*
This Water Allocation, Scheduling And Monitoring program is used in the day-to-day water management of large-scale irrigation schemes. It is based on an intensive daily data collection at selected points in the system through a structured organisation for main system, laterals and canal sections and ditches. It allows comparison of canal flows and other items with expected values, so that adjustments can be made subsequently. It is thus clearly made to be an operational tool.

▸ *made where:*
ILACO/Euroconsult, P.O. Box 441, 6800 AK Arnhem, The Netherlands

▸ *what available:*
- A 3.5" diskette with 38 program files and 13 data files;
- Some information about the Kinda Irrigation Scheme in Burma, where WASAM was apparently developed/applied, but no specific info on WASAM itself;
- Van Vilsteren, A., 1987. Users oriented irrigation development in Thailand. In: Hydraulics Research, 1987: Irrigation design for management Asian regional symposium Kandy, Sri Lanka 16-18 Feb. 1987: 70-96.

▸ *what required:* not specified.

▸ *written in:* Basic.

▸ *remarks:*
- The AUTOEXEC on the program disk does not work because of the Basic version (HBasic); using the "normal" Compaq Basic of the test machine is OK;
- The collection of 51 files are lacking an overall structure, like a main menu is missing;
- The Basic programs refer to data files on disk B: which is slightly problematic on a one-FDD machine;
- Even though the individual Basic programs can be listed and read, it is not easy to evaluate the whole array of files due to the missing main menu;
- Although two locations are apparently using the package (Kinda Irrigation Scheme, Burma and Mae Klong Irrigation Projects, Thailand) it is difficult to judge how flexible the program is for other projects;
- What could be inferred from the listings is that rudimentary graphics have been incorporated, and that a workable program was created in several projects at the time (1987), but that a modernization (database oriented, menu-driven, a better graphics interface) would be required before it could be issued for general use; work on this is said to be in progress at Euroconsult, Arnhem.

Program 45: WYEGAME

▸ *what it does:*
The program is a training exercise in irrigation management in the form of a role-playing game. Participants are asked to play a farmer or an irrigation manager under the supervision of a game controller. They must make decisions based on limited inputs, which are then fed to the computer, which calculates consequences. Objectives are: showing basic irrigation principles, demonstrating interactions, and promoting group discussion.

▸ *made where:*
The Department of Agricultural Economics, Wye College, Univ. of London, Wye, Ashford, Kent TN25 5AH, England. Manual from Publications Department (GBP 6.50).

▸ *what available:*
- A 3.5" disk with version 1.0, dated 25.07.88, with the Basic source code; a short startup routine (CONSOL.BAT) was added; program has its own Basic version;
- The manual: Smith, L.E.D. & Youngman, J.P., 1988. The Wye College Irrigation Game, version 1.0, 25 July 1988. ADU Occasional paper 10, Dept. Agric. Economics, Wye College. 68 pp. 11 refs;
- Smith, L.E.D., 1989. The Wye College irrigation game "Stop the breach". Irr. & Drain. Systems 3: 255-264.

▸ *what required:*
An IBM PC XT computer with >= 128 kB RAM, running under MS-DOS. A wide carriage (Epson) printer. Sufficient copies of forms and information for participants.

▸ *written in:* Basic (basic86).

▸ *remarks:*
- The PC program is a not the game itself. Participants discuss and decide; the computer processes decisions (data) and produces summaries;
- The manual suggests that the *.BAS programs may be changed to fit local conditions. This would be hard work: program structure and logic are not clear at all (no headings, no spacing, no self-explanatory variable names, etc.);
- There are three modes of play, increasingly difficult;
- It takes quite some time for a trainer to get acquainted with the particulars of the game in such a way that he can answer all sorts of questions of participants;
- As an introductory exercise (for participants to do something together and get to know each other) it may not be a bad game, but it will take at least a few weeks to get it properly shaped and tested;
- The input sequence is not very clear; the produced output was not clear/consistent in our test run. Needs thorough checking before the program can be utilized;
- No graphics are used and there is no interaction.

ANNEX 2: ADDRESSES

Addresses included in this Annex comprise:

Serial number	Organization
1.	AEI, Canterbury, New Zealand
2.	CADI, Fort Collins, USA
3.	CEMAGREF, Montpellier, France
4.	CIE, Leuven, Belgium
5.	Delft Hydraulics, Delft, The Netherlands
6.	Euroconsult, Arnhem, The Netherlands
7.	ICIM, Rijswijk, The Netherlands
8.	IAHL, Velp, The Netherlands
9.	IGWMC, Delft, The Netherlands
10.	IHE, Delft, The Netherlands
11.	IIS, Southampton, UK
12.	ILRI, Wageningen, The Netherlands
13.	Lisboa University, Portugal
14.	LBII/WAPCOS, New Delhi, India
15.	LWDD, FAO, Rome, Italy
16.	LUW/TCT, Wageningen, The Netherlands
17.	Melbourne University, Australia
18.	Mott MacDonald, Cambridge, UK
19.	NCSU, Raleigh, USA
20.	NRAES, Ithaca, NY, USA
21.	ODU, HR Wallingford, UK
22.	Silsoe College, Silsoe, UK
23.	Staring Centre, Wageningen, The Netherlands
24.	USU, Logan, Utah, USA
25.	USWCL, Phoenix, USA
26.	World Bank, Washington, USA
27.	Wye College, Ashford, UK

Note:

The program names mentioned under a certain address may include programs not mentioned in this publication; such names are printed in italics. Programs appearing in Annex 1 are in bold type.

01
Agricultural Engineering Institute,
Lincoln University,
(Dr. P. John),
P.O. Box 84, Canterbury,
New Zealand

Producers of: IRRICAD, *SPRINKPAC*, *TURFCAD*

02
Computer Assisted Development Inc.,
(Dr. T. Sheng),
1635 Blue Spruce Drive, Suite 101,
Fort Collins, Colo 80524,
USA

Producers of: MIS

03
CEMAGREF,
Groupement de Montpellier,
(Contact Mr P.O. Malaterre),
B.P. 5095,
34033 Montpellier Cedex 1,
France

Producers of: *BAHIA*, *BEL*, BILANREG, *CANAL9*, *CERES*, *DACCORD*, *DEVER*, ICARE, MECENE, PB2DIAM, RAIEOPT, SIC, *SIDRA*, *STAB*, *TALWEG-FLUVIA*, *VERITAS*, XERXES-RENFORS

04
Center for Irrigation Engineering,
(Prof. J. Feyen),
Catholic University,
Vital Decosterstraat 102,
3000 Leuven,
Belgium

Producers of: CANALCAD, **DEFICIT**, DRAINCAD, **ETREF**, **ETCROP**, **ETSPLIT**, **FISDEV**, **IRSIS**, *PISCAD*, **RAINBOW**, *SUCROS*, **SWATRER**, TOPOCAD

05
Delft Hydraulics,
Division Water Resources and Environment,
(Dr. W. Schuurmans),
P.O. Box 177,
2600 MH Delft,
The Netherlands

Producers of: **OMIS**, **PROFILE**

06
Euroconsult,
(Ir. M. Schellekens),
P.O. Box 441,
6800 AK Arnhem,
The Netherlands

Producers of: **WASAM**, and internal programs: AUGER, PENMAN, TIDE, CANALDES, HAZEN-W, LACEY, CROPF, CROPW, REHAB, IRSCHED, TKB, *SALBAL*

07
Informatica Centrum voor Infrastructuur en Milieu bv,
ICIM,
P.O. Box 5809,
2280 HV Rijswijk,
The Netherlands

Producers of: **DUFLOW**

08
International Agricultural College Larenstein,
(Ir. J. Schoenmakers),
P.O. Box 9001,
6880 GB Velp,
The Netherlands

Producers of: **CID**, and internal programs: *ERNST*, *FTW*, *GWS1D*, *GWS2DV*, *HOOGHOUD*, *NAMOD*, NESTOR, *PPG*, *RONDO*, *SEMSPARE*

09
International Ground Water Modeling Center,
TNO Institute of Applied Geoscience,
P.O. Box 6012,
2600 JA Delft,
The Netherlands

Distributors of 72 low-priced quality groundwater modeling software

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10
International Institute for Infrastructural,
Hydraulic and Environmental Engineering,
(Ir. E.R. Dahmen),
P.O. Box 3015,
2601 DA Delft,
The Netherlands

Producers of: COBRA, Benelux agent for MIKE 11, *MUST*

11
Institute of Irrigation Studies,
(Mr. M. Burton),
The University,
Southampton SO9 5NH,
United Kingdom

Producers of: CAMSIS, **CRWTABLE**, **DRAINCAN**, **MAINSYST**, *SCIGRAF*

12
International Institute for
Land Reclamation and Improvement,
(Dr. J. Boonstra),
P.O. Box 45,
6700 AA Wageningen,
The Netherlands

Producers of: **BASCAD**, **CRIWAR**, *DATSCR*, RSM, **SALTMOD**, **SATEM**, **SGMP**

13
Department of Agricultural Engineering,
Institute of Agriculture,
Technical University of Lisbon,
(Prof. L.S. Pereira),
Tapada da Ajuda,
1399 Lisboa, Codex,
Portugal

Producers of: ISAREG

14
Louis Berger International Inc.,
Water and Power Consultancy Services (India) Ltd.,
213, Ansal Chambers-II,
Bhikaiji Cama Place,
R.K. Puram,
New Delhi 110066,
India

Producers of: **BCWEIR** (and irrigation & drainage courses overview)

15
Water Resources, Development and Management Service,
Land and Water Development Division,
(Mr. J. Sagardoy),
Via delle Terme di Carracalla,
00100 Rome,
Italy

Producers of: CIMIS, CLIMWAT, **CROPWAT**, **OPTIPIPE**, **SURFACE**

16
Department of Irrigation and Soil Conservation,
(Ir. T. Meijer),
Agricultural University,
Nieuwe Kanaal 11,
6709 PA Wageningen,
The Netherlands

Producers of: CANAL

17
Department of Civil and Agricultural Engineering,
University of Melbourne,
(Dr. B.L. Maheshwari),
Parkville, Vic 3502,
Australia

Producers of: **BICAD**, BICADAM

18
Mott MacDonald Software,
Demeter House,
Station Road,
Cambridge CB1 2RS,
United Kingdom

Producers of: IRRIGATION MANAGEMENT GAME, MAHAKALI, NILE, SAIDIYA, **SUKKUR**

19
Department of Biological and Agricultural Engineering,
North Carolina State University,
(Prof. W.R. Skaggs),
P.O. Box 7265,
Raleigh, NC 27695,
USA

Producers of: **DRAINMOD**

20
Northeast Regional Agricultural Engineering Service,
Cornell University,
152 Riley-Robb Hall,
Cooperative Extension,
Ithaca, NY 14853,
USA

Producers of: *BURBS*, *MOUSE*, **REHAB**, *RIVER BALANCE*, *SOIL WATER BUDGETING*, **SUBDRAIN**

21
Overseas Development Unit,
Hydraulics Research Ltd.,
(Mr. J. Skutsch)
Wallingford, Oxon OX10 8BA,
United Kingdom

Producers of: *CALSITE*, DACSE, **DORC**, HADES, **INCA**, MIDAS, *SWIMM*, *PARADIGM*

22
Silsoe College,
Department of Agricultural Water Management,
(Mr. R. Carter),
Silsoe, Bedford MK45 4DT,
United Kingdom

Producers of: JUBA SUGAR ESTATE GAME

23
The Winand Staring Centre,
(Dr. P. Kabat),
P.O. Box 35,
6700 AA Wageningen,
The Netherlands

Producers of: BALANCE, *FLOWEX*, SIWARE, SWATRE, **SWACROP**

24
Software Engineering Division,
Department of Biological and Irrigation Engineering,
(Prof. W. R. Walker),
Utah State University,
Logan, Utah 84322-4105,
USA

Producers of: **BCW/RBC**, *CANDI*, **CANAL**, **CATCH3D**, CROPWAT, *CRPSM*, *GATEDPIP*, *HYSYM*, **IRRIGAME**, *ICSS*, IRRiSKED, IRRITALK, IRRITURNS, LANDLEV, LEVLGRAM, *MULTILAP*, NETDES, PCET, *REF-ET*, *SPRNKSIM*, *STEADY*, **SURFACE**, SURMOD, UCA, *UTAHET*, *WATROP*

25
US Water Conservation Laboratory,
(Dr. A. J. Clemmens),
4331 E. Broadway Rd.,
Phoenix, AZ 85040,
USA

Producers of: **BASIN**, **BRDRFLW**, **SRFR**

26
The World Bank,
Water Supply and Urban Development Department,
1818 H Street, N.W.,
Washington DC 20433,
USA

Producers of: **UNDP** programs BRANCH, FLOW, HEADLOSSLOOP, LINPROG, MINTREE, NELDER, REGRESS, SEWER, SCREEN
In New Delhi: **RICEYLD**, **SIMYIELD**, SIMULNDO

27
Wye College,
(Mr. L.E.D. Smith)
University of London,
Ashford, Kent TN25 5AH,
United Kingdom

Producers of: **WYE** COLLEGE IRRIGATION GAME

INDEX OF PROGRAM NAMES