THE DISA HYDROSALINITY MODEL

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REPORT TO THE WATER RESEARCH COMMISSION ON THE PROJECT
"COMPLETION OF RESEARCH RELATING TO THE DISA MODEL - A DAILY IRRIGATION AND SALINITY ANALYSIS SYSTEM MODEL"

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EXECUTIVE SUMMARY

INTRODUCTION

The Breede River is one of South Africa's primary vine and deciduous fruit growing areas. Although irrigation occurs throughout the catchment, the greater portion of the irrigated lands, comprising some 45 000 ha, is situated between Worcester and Bonnievale. This irrigation occurs along the main stem of the Breede River, as well as along its tributaries. The majority of these lands are supplied with water from the Greater Brandvlei Dam as part of the Greater Brandvlei Dam Government Water Scheme (GBDGWS). Relatively small volumes of water are supplied from groundwater and small dams on tributary rivers. The bulk of the Brandvlei Dam water is either released into the Breede River channel from where it is diverted into canals or pumped, or released directly into the Le Chasseur canal for downstream distribution. The main channel of the Breede River, however, also acts as a drain for saline irrigation return flows, the effect of which requires amelioration in the form of freshening releases from Brandvlei Dam.

During the 1980s irrigated areas were expanding steadily, albeit at a relatively low rate. The political and constitutional reforms set in motion in the late 1980s created expectations of increased export opportunities for products from this area, leading to a distinct likelihood of increased irrigation expansion in the 1990s. Concerns arose that the concomitant increases in future saline return flows would render certain stretches of the Breede main channel unuseable as a supply conduit.

Against this background the then Department of Water Affairs (now known as the Department of Water Affairs and Forestry (DWAF)) appointed Ninham Shand in 1988 to develop and apply a computer model, capable of predicting the impact of irrigation development in the GBDGWS supply area on river flow and salinity.

During 1990, the DISA (Daily Irrigation and Salinity Analysis) model was completed and implemented to examine the potential impacts of a number of planning scenarios for the GBDGWS supply area. Aspects addressed included future salinity and flow patterns in the Breede River, as well as requirements for future freshening releases from Brandvlei Dam.

In 1987, an intensive five year hydro-salinity field research programme to support the development of the DISA model was initiated and conducted by the Hydrological Research Institute (HRI) in the Breede River Valley. This research was based on an intensive monitoring programme at measurement points in the main river, tributaries, canals, deep and shallow boreholes, piesometers in alluvial soils, tensiometer fields and rainfall stations. By 1990, Government spending cuts and subsequent Departmental budgetary constraints necessitated a curtailment of some longer term projects, which included a premature end to the HRI's Breede River Salination Research Programme. The time table for this termination required the conclusion of all

Breede River field studies, including intensive monitoring, by the end of the 1989/1990 irrigation season. This timetable meant that certain ongoing aspects related to the model development had to be regarded as provisional, as continued field research and monitoring was required for further model verification.

To ensure that the full potential of the Breede River Salination Research Programme be realised, an agreement was subsequently reached whereby the Water Research Commission would provide funding to ensure that certain actions relating to the original project specifications could be finalised. These included a further year of intensive monitoring, refinements to certain aspects of the DISA model, and effective technology transfer. This report describes the refined version of the DISA model, including model verification and sensitivity analyses. It also serves to upgrade the existing documentation, which is in the form of consulting reports to the DWAF, to a research oriented communication.

PROJECT AIMS

In January 1991, an agreement was reached whereby the Water Research Commission would fund a project to complete research related to the DISA model. The aims of this project, which culminates with the publishing of this report, were to :

(i) Implement refinements to the DISA model, comprising the following :

- Review of the representation of three important processes in DISA :
  - the fate of irrigation percolate from the higher-lying terrace soils and the influence on this of artificial drainage.
  - the fate of canal leakages.
  - bedrock contributions to river and alluvial aquifer salinities.
  - active soil volumes associated with different irrigation techniques and soil types.
- Incorporation of findings of various relevant field studies in the Breede River Valley funded by the Hydrological Research Institute (HRI) and the Water Research Commission (WRC).
- Further verification of DISA using the most recent hydro-meteorological and hydro-salinity observations in the Breede River system.

(ii) Achieve effective technology transfer of the software and the supporting research findings, including upgrading the existing model documentation and the user manual.

(iii) Complete the curtailed hydro-salinity monitoring programme with observations during the period 1 January - 30 April 1991.

DEVELOPMENT OF THE DISA MODEL

Model characteristics

The following comments summarize the modelling philosophy which governed the development of the DISA model :

- A non-calibration approach was adhered to – configuration of the system and all physical and salinity parameters were based on the best information available from field work, maps, Landsat data, surveys and relevant theory.
- DISA allows the catchment to be divided into a number of homogeneous physiographic units, each of which comprises a part of the catchment with relatively homogeneous agricultural and hydrolological features.
- Each of the physiographic units is further divided into areas termed "return flow cells", on the basis of soil type. A distinction is made between terrace and alluvial return flow cells. Terrace cells occur in the higher-lying areas of the physiographical units, while alluvial cells occur in the lower-lying areas, particularly in the vicinity of river channels.
- DISA configures the physical water distribution system accurately at any desired scale, including reservoir releases, irrigated physiographic units, river diversions, canals, pump schemes, farm dams and rejects.
- DISA is structured to preserve daily water and salt (as Total Dissolved Salts – TDS) balances in all irrigated soil profiles as well as in all canal and river channel components in the system during the irrigation season only.
- Soil moisture budgeting occurs via layer capacity limits, not via mechanistic soil moisture flow equations.
- DISA allows routing of seepage from canals and farm dams to appropriate receiving points.
- DISA distinguishes between irrigated alluvial soils and higher-lying irrigated (terrace) soils and models the groundwater levels in the former dynamically, with recognition of the capillary fringe as a redistributor of water and salts between saturated and unsaturated soil layers.
- DISA treats non-alluvial groundwater as a regional influence and requires empirical estimates of groundwater flows and salinities as inputs to the surface water flow system.
- DISA does not account for dynamic salinity-related soil processes such as weathering, sorption, dissolution or deposition, because suitable quantification of these processes can currently only be achieved by calibration of black-box equations, which is contrary to the approach aimed for in this study. (During the final stage of model development, an attempt was made towards the development

of a salt generation function for incorporation into the model. However, it was concluded that further research is still needed to successfully implement this concept.)

- DISA does not model rainfall-runoff processes in the catchment regions upland of the irrigated areas – the configuration is such that observed (or simulated by catchment modelling) flows and salt loads can be used to bring upland surface hydrosalinity influences to bear.
- DISA does not keep account of gypsum applications. In the Breede River system for example, data concerning this practice is almost non-existent, but it is surmised that the annual gypsum application is much less than 10 % of the total annual salt load applied in the form of irrigation water.

Model structure

The DISA model is imbedded in a user-friendly software environment, and was developed with the Turbo Pascal programming language. The software consists of four components :

- The Database Manager, which controls and manages the system database containing all the time series data that serve as external input to the catchment area being modelled.

- The System Configurator is used to configure the physical system in terms of modelling node types, node sequencing, process parameters and global parameters. It also controls the selection of nodes for producing graphical and numerical output.

- The System Model uses the time series database (in the Database Manager) and the system configuration file (in the System Configurator) to perform hydrosalinity simulations of all flow and salt transport through the conduits and soils of the irrigation system. Simulations are based on a daily time step.

- The Output Manager produces graphical output in the form of daily flow and salinity time series, and percentile (exceedance) curves, as well as numeric output files.

Data requirements

It can be appreciated that the modelling approach implemented by DISA, which is both physically based and highly organised in terms of the physical structure of the modelled area, is extremely data demanding. The data input to the model consists of two types, viz. time series data and physical data parameters.

Time series data serve as external input to the modelled catchment area. These include daily rainfall and evaporation records within the catchment, as well as daily flow (m^3/s) and salinity (mg/l) records in rivers and tributaries entering and leaving the catchment

Every return flow cell as well as every sub-model in the water distribution network has to be defined in the model in terms of parameters or physical process constants. To obtain these parameters, a detailed knowledge of the system is required in terms of layout, land-use, soil characteristics, river channel, canal and farm dam geometry and abstraction rules implemented by farmers.

MODEL VERIFICATION

The final stage of model development involved the verification of the model to demonstrate the applicability and accuracy thereof. The model was verified on the Breede River system as well as the Vaalharts Irrigation system.

The Breede River System

Model verification for the Breede River system was completed in two phases, namely an internal verification and an external verification. Three database years were used, viz. 1985/86, 1986/87 and 1987/88. Verification of the model was extended to cover two additional years, namely 1988/89 and 1989/90. Due to gaps in either inflowing datasets or downstream datasets, verification on these two years was only partially successful. The internal verification was done by evaluating alluvial aquifer behaviour, with the groundwater levels in the alluvial return flow cells used as an indicator of "acceptable" behaviour. Groundwater levels in the aquifers behaved as expected, with simulated water levels fluctuating between approximately 300 mm below the surface and 500 mm above the bottom of the lowest layer. Salinity concentrations in a few aquifers were not in equilibrium. In line with the "no calibration" approach, it was decided that overall model performance was not adversely affected by this and that no rectifying measures were required.

External verification was evaluated by comparison of observed and modelled river flow and salinity time series at two different flow gauging stations. It was found that seasonal trends and magnitudes of river flow were simulated satisfactorily.

The Vaalharts Irrigation System

During 1995 the DISA model was applied to the Vaalharts Irrigation system. This was done to evaluate the applicability of DISA to an irrigation system situated in a summer rainfall region, as well as to evaluate the performance of various additional processes incorporated into DISA, e.g. surface runoff, artificial drainage and deep percolation.

Only an external verification was completed. A period of five seasons between October 1988 and April 1991 was considered and included three summer and two winter seasons. Observed and modelled river flow and salinity time series at a weir situated at the downstream end of the system were compared.

Overall, the time series and percentile curves indicated that during certain months, DISA underestimated the salt concentrations, while simultaneously overestimating flow. This was attributed to the fact that the simulated volume of tailwater (water which is not abstracted from the canal system for irrigation) is too high. As this water is relatively fresh, it leads to low TDS concentrations and an accompanying overestimation of river flow. This was caused by incorrect monthly abstraction volumes for irrigation. The situation was remedied by modification of the monthly distribution of irrigation supply, which led to a much better fit between observed and simulated flows and especially salinities.

This application of the DISA model confirmed that about 80% of the TDS load in the incoming irrigation water is retained in deep groundwater bodies underneath the Vaalharts Scheme.

SENSITIVITY ANALYSES

The DISA model was subjected to two series of sensitivity analyses performed during different stages of the model development. Five model components for which inadequate or no field data existed, were identified during the verification phase of model development. The need for sensitivity testing of a further five model components came to the fore during model application for a planning study of the Breede River System. The full set of components which were tested are :

(i) The distribution of canal seepage between irrigated and non-irrigated alluvial soils.
(ii) The portion of groundwater outflow from terrace cells which is drained either by artificial means (surface ditches or pipes) or by natural collectors.
(iii) Capillary fringe depths associated with the various soil texture classes.
(iv) The Dry Evaporation Factor which expresses evaporation from bare soil as a fraction of A-Pan evaporation.
(v) Evaporation depths associated with the various soil texture classes.
(vi) The reduction of canal seepage due to riparian vegetation growing along the canal system.
(vii) The sensitivity of model response to a change in soil texture classes of return flow cells.
(viii) The rate of aquifer recharge to the main river channel.
(ix) The sensitivity of model response to a change in estimated soil profile depths.
(x) The performance of the model when model runs are extended over more than one irrigation season.

ACKNOWLEDGEMENTS

The research in this report emanated from a project funded by the Water Research Commission and entitled : "Completion of Research Relating to the DISA Model - A Daily Irrigation and Salinity Analysis System Model".

The Steering Committee responsible for this project, consisted of the following persons :

Mr H M du Plessis	Water Research Commission (Chairman)
Mr H Maaren	Water Research Commission
Mr F P Marais	Water Research Commission
Prof J H Moolman	University of the Free State
Prof J O G Kirchner	University of the Free State
Dr A J van der Merwe	Agricultural Research Council
Mr M van Veelen	Department of Water Affairs and Forestry
Mr L Bruwer	MBB Consulting Engineers

The financing of the project by the Water Research Commission and the contribution of the members of the Steering Committee is acknowledged gratefully.

At the present stage of modelling technology, no new model developments can take place without due cognisance of precursors in the specific field of modelling. In this vein we salute the progress made during the development of the following models that preceded the development of DISA :

FLOSAL	:	G Hall, NIWR, CSIR
NACL01/02	:	C Herold, HRU, Wits University
ACRU	:	R Schulze, University of Natal
IRRISS	:	S Forster, Department of Water Affairs

THE DISA HYDROSALINITY MODEL

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CHAPTER 1. INTRODUCTION

1.1 Background and motivation

The Breede River is one of South Africa's primary vine and deciduous fruit growing areas. Although irrigation occurs throughout the catchment, the greater portion of the irrigated lands, comprising some 45000 ha, is situated between Worcester and Bonnievale. This irrigation occurs along the main stem of the Breede River, as well as along its tributaries. The majority of these lands are supplied with water from the Greater Brandvlei Dam as part of the Greater Brandvlei Dam Government Water Scheme (GBDGWS). Relatively small volumes of water are supplied from groundwater and small dams on tributary rivers. The bulk of the Brandvlei Dam water is either released into the Breede River channel from where it is diverted into canals or pumped, or released directly into the Le Chasseur canal for downstream distribution. The main channel of the Breede River, however, also acts as a drain for saline irrigation return flows, the effect of which requires amelioration in the form of freshening releases from Brandvlei Dam.

During the 1980s irrigated areas were expanding steadily, albeit at a relatively low rate. The political and constitutional reforms set in motion in the late 1980s created expectations of increased export opportunities for products from this area, leading to a distinct likelihood of increased irrigation expansion in the 1990s. Concerns arose that the concomitant increases in future saline return flows would render certain stretches of the Breede main channel unuseable as a supply conduit.

Against this background the then Department of Water Affairs (now known as the Department of Water Affairs and Forestry (DWAF)) appointed Ninham Shand in 1988 to develop and apply a computer model, capable of predicting the impact of irrigation development in the GBDGWS supply area on river flow and salinity.

Reviews of existing models concluded that no software existed which was suitable for the conditions and characteristics of the Breede River system. There appeared to be a dearth of models with a daily resolution which combined, at a similar and appropriate level of complexity, irrigation scheme operation, root zone moisture and salt dynamics, alluvial water and salt dynamics, multi-crop and multi-supply point irrigation practices, catchment hydro-salinity processes and river flow regulation. In view of this, as well as the desire to apply simulation routines that are physically-based and user-friendly, it was decided that a new PC-based model should be developed to meet planning requirements for the Breede River system.

The DISA (Daily Irrigation and Salinity Analysis System) model was developed over a period of two years by Ninham Shand for DWAF. A report on the model development and its verification, by Beuster, Görgens and Greyling (1990a), was also released. A User's Guide by Beuster, Görgens and Greyling (1990b) was released with the DISA software. The model development benefited from significant inputs in terms of hydro-salinity field studies and local information provided by researchers of the Hydrological Research Institute (HRI) of DWAF and by officials in the Directorates of Geohydrology and of Project

Planning of DWAF. The DISA model was immediately employed by DWAF in a decision support role to examine the potential impacts of a number of planning scenarios for the GBDGWS region. Aspects addressed included the potential effect of new water distribution infrastructure, and irrigation development on future salinity and flow patterns in the Breede River, as well as requirements for future freshening releases from Brandvlei Dam. These investigations and their findings are described in detail in a report to DWAF by Beuster and Görgens (1992).

In 1987, an intensive five year hydro-salinity field research programme to support the development of the DISA model was initiated and conducted by the Hydrological Research Institute (HRI) in the Breede River Valley. This research was based on an intensive monitoring programme at measurement points in the main river, tributaries, canals, deep and shallow boreholes, piesometers in alluvial soils, tensiometer fields and rainfall stations. By 1990, Government spending cuts and subsequent Departmental budgetary constraints necessitated a curtailment of some longer term projects, which included a premature end to the HRI's Breede River Salination Research Programme. The time table for this termination required the conclusion of all Breede River field studies, including intensive monitoring, by the end of the 1989/1990 irrigation season. This timetable meant that certain ongoing aspects related to the model development had to be regarded as provisional, as continued field research and monitoring was required for further model verification.

To ensure that the full potential of the Breede River Salination Research Programme be realised, an agreement was subsequently reached whereby the Water Research Commission would provide funding to ensure that certain actions relating to the original project specifications could be finalised. These included a further year of intensive monitoring, refinements to certain aspects of the DISA model, and effective technology transfer. This report describes the refined version of the DISA model, including model verification and sensitivity analyses. It also serves to upgrade the existing documentation, which is in the form of consulting reports to the DWAF, to a research oriented communication.

A number of technology transfer actions occurred during the course of the project. These took the form of three conference papers, one workshop paper and the installation, with training, of the model at the DWAF office in Worcester and at the Institute for Water Research at Rhodes University.

As a separate project by the Department of Geography of the University of Stellenbosch, the WRC and DWAF also funded the development of a GIS-based interface to allow the spatial input data to be easily manipulated and verified (Wolff-Piggot, 1994). The work was carried out by the Institute for Geographical Analysis at the University of Stellenbosch and Ninham Shand, which led to further technology transfer on a number of fronts.

1.2 Aims

During January 1991, the project to complete research related to the DISA model commenced, with the following aims :

(i) Implement refinements to the DISA model, comprising the following :

- Review of the representation of three important processes in DISA :
  - the fate of irrigation percolate from the higher-lying terrace soils and the influence on this of artificial drainage.
  - the fate of canal leakages.
  - bedrock contributions to river and alluvial aquifer salinities.
  - active soil volumes associated with different irrigation techniques and soil types.
- Incorporation of findings of various relevant field studies in the Breede River Valley funded by the Hydrological Research Institute (HRI) and the Water Research Commission (WRC).
- Further verification of DISA using the most recent hydro-meteorological and hydro-salinity observations in the Breede River system.

(ii) Achieve effective technology transfer of the software and the supporting research findings, including upgrading the existing model documentation and the user manual.

(iii) Complete the curtailed hydro-salinity monitoring programme with observations during the period 1 January - 30 April 1991.

1.3 Methodology

Model characteristics were formulated based on inputs from an advisory group of civil engineers, geohydrologists, irrigation specialists and soil scientists. This culminated in a set of guidelines for further model development.

Model development progressed in the following stages :

(i) Development of a dedicated systems model representing the current and future water supply network using the appropriate sub-routines from the FLOSAL (Hall, 1981) daily model as a starting point.

(ii) Development of routines to simulate the delivery of water and salts to the irrigated lands.

(iii) Development (to the extent made possible by available information) of simplified routines to simulate root zone and delivery zone return flow processes.

(iv) Verification of the model to demonstrate applicability and accuracy.

(v) Implementation of refinements to, and further verification of the DISA model, based on the further research and completion of the monitoring programme funded by the Water Research Commission.

1.4 Report layout

Chapter 2 describes the context of model development, with emphasis on the modelling requirements and the modelling approach which was adopted. Chapter 3 provides a general overview of model characteristics, while Chapter 4 describes the various processes incorporated into the model. The results of model verification, for both the Breede and Vaalharts Irrigation systems, are discussed in Chapter 5. Chapter 6 provides the results of sensitivity analyses which were conducted. The report concludes with a discussion of the key conclusions in Chapter 7, and recommendations for further research (Chapter 8).

CHAPTER 2. CONTEXT OF MODEL DEVELOPMENT

2.1 Problem statement

The model characteristics were formulated by applying the "brainstorming" technique with an advisory group of civil engineers, geohydrologists, irrigation specialists and soil scientists. This was seen as a useful method of generating new and original ideas towards a solution of a complex problem. The problem statement presented to the participants was :

"How to model the flow and salinity of the Breede River between the Greater Brandvlei Dam and the Zanddrift Canal offtake so as to include the water supply system, crop irrigation, all significant salt sources, long term development and the spatial variability of conditions."

2.2 Modelling requirements

The outcome of the above exercise was a set of consensus decisions on the model characteristics, which were formulated as guidelines for further model development. The most important of these guidelines were :

- Only the man-influenced and not the pristine areas should be modelled.
- The man-influenced areas should be divided into two general categories, viz. the river alluvium and the old river terraces.
- The areas of river alluvium should be divided on the basis of specific locations in the adjacent river channels, e.g. weirs, canal off-takes or tributary inflows.
- The model should cater for spatially different groundwater bodies with a range of interaction.
- Groundwater movement from the pristine areas to the man-influenced areas should occur along the boundary of the two areas.
- Assume a homogeneous movement of water and salts into the alluvium from groundwater at a higher level.
- Time lags in the groundwater response should be related to aquifer head, distance and permeability.
- There should be different time lags for the response of salts and water. These should be based on field observations.
- The groundwater in the alluvium should be divided into two separate bodies ; the water in the alluvium and the water in the bedrock below the alluvium. Only one groundwater body is necessary in the terrace areas.
- The model should cater for the recharge of groundwater bodies from canal and farm dam leakage.
- Establish a salt reservoir in the groundwater, which is replenished during periods of leaching (i.e. during winter rains), and which introduces salt to the soil profile (through capillaric rise) during dry periods.

- Use observed data for starting conditions such as soil salinity, soil moisture and groundwater levels.
- Feedback mechanisms in the model should be accomplished by simulating the entire system for one step prior to proceeding to the next time step. The time step should be daily.
- Implementation of the operating "rule base" should be made optionally interactive in order to simulate, as near as possible, the real day-to day operation of the scheme.

In order to achieve the project aims, and in line with the guidelines formulated during the brainstorming session, it became clear that the software should be structured to consist of the following units :

(i) The Database Manager to control and manage the system database, which contains all the time series data required for simulation.
(ii) The System Configurator, which should control, on a menu-driven basis, all aspects of system configuration and produce a system description for use by the model at runtime. Aspects to be controlled by this unit includes process parameters, modelling node type, node sequencing, selection of nodes for producing graphical and numeric output and system layout.
(iii) The System Model, which will use the time series database and the system description to perform model runs. It will encompass a number of process sub-models.
(iv) The Output Manager, which will present graphical output in the form of flow- and salinity time series, percentile curves and longitudinal salinity profiles.

2.3 Modelling approach

The specific application of the DISA model as a decision-making tool to aid the future planning and management of irrigation systems, limited the choice of model structures and approaches. The ability to simulate the net effect of sub-processes, such as root zone, delivery zone and river channel behaviour, had to be maintained without making data demands prohibitive. It was therefore decided to allow for the discretisation of the catchment into homogeneous units in terms of agricultural and hydrological features. A fundamental principle adopted in the modelling approach, was the avoidance of calibration. Configuration of the system and all physical and salinity parameters were therefore based on the best information available from field work, maps, Landsat data, surveys and relevant theory.

CHAPTER 3 . GENERAL OVERVIEW

3.1 Characteristics of the DISA Model

3.1.1 Discretisation of the catchment

DISA allows the catchment to be divided into a number of homogeneous physiographic units, each of which comprises a part of the catchment with relatively homogeneous agricultural and hydrological features.

Sub-division of the catchment into physiographic units proceeds in a top-down fashion. Points of interest such as possible future canal and pumping scheme offtakes, existing offtakes and tributary confluences are used as node points. Topographical boundaries connecting these points with the catchment boundary defines the primary cells. In the case of the Breede River, this division resulted in cells that deliver point inflows to the Breede River, as well as cells that are traversed by the Breede River. The latter were subdivided along the river.

Each of the physiographic units is further divided into areas termed "return flow cells", on the basis of soil type. A distinction is made between terrace and alluvial return flow cells. Terrace cells occur in the higher-lying areas of the physiographical units, while alluvial cells occur in the lower-lying areas in the vicinity of river channels.

3.1.2 The water distribution network

The water supply distribution system acts as the main driving force in the model and is described in terms of five sub-models :

(i) Abstraction nodes

River and canal abstractions are governed by abstraction nodes. Provision is made for multiple operating rules such as :

- compensation flow checks
- monthly demand patterns
- weekday on/off rules
- checks on water quality

(ii) Inflow nodes

Inflow nodes manage time series from areas outside the model boundary. They are also used to accept outflows from one or more neighbouring model elements.

(iii) Farm dam nodes

These nodes combine the distributed farm dam storage on individual return flow cells. Provision is made for seepage to groundwater, pumping from boreholes, evaporation, and multiple operating rules. Inflows from up to three model elements are catered for.

(iv) Canal nodes

Canal reaches are modelled by canal nodes which perform a daily mass balance calculation. Evaporation and seepage to groundwater is calculated according to canal width and the wetted perimeter to flow ratio respectively. Provision is also made for water use by riparian vegetation along the canal routes.

(v) River routing nodes

A routing node links any model element to upstream neighbours, calculates longitudinal dispersion of flow and salts and simulates river channel processes.

3.2 Model Structure

The DISA model is imbedded in a user-friendly software environment and was developed with the Turbo Pascal programming language. A comprehensive User's Guide (Appendix 1) accompanies the software. The broad structure of the software environment is shown in Figure 3.1. The software suites consist of four components :

3.2.1 The Database Manager

The Database Manager combines and stores daily input records in a binary format. It controls and manages the system database, which contains all the time series data that serve as external input to the modelled catchment area. The time series include rainfall, evaporation, flow and salinity data. The rainfall and evaporation time series are in dimensionless form (% of mean annual values), while the daily flow and salinity (TDS) records are expressed in m^3/s and mg/l, respectively.

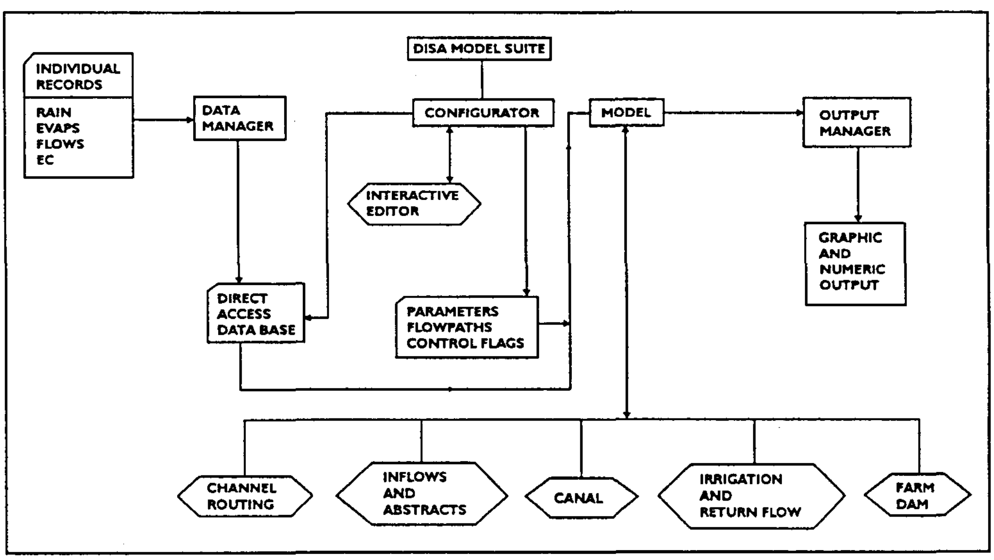


Fig 3.1 : Components of the DISA modelling suite

3.2.2 The System Configurator

The System Configurator is used to configure the physical system in terms of modelling node types, node sequencing, process parameters and global parameters. It also controls the selection of nodes for producing graphical and numerical output. A system description is thus produced and saved as a configuration file for use by the model at runtime. This configuration file consists of a system network describing the characteristics of the areas of land under irrigation and the water distribution network overlying the whole system. Figure 3.2 shows the menu hierarchy of the system configurator.

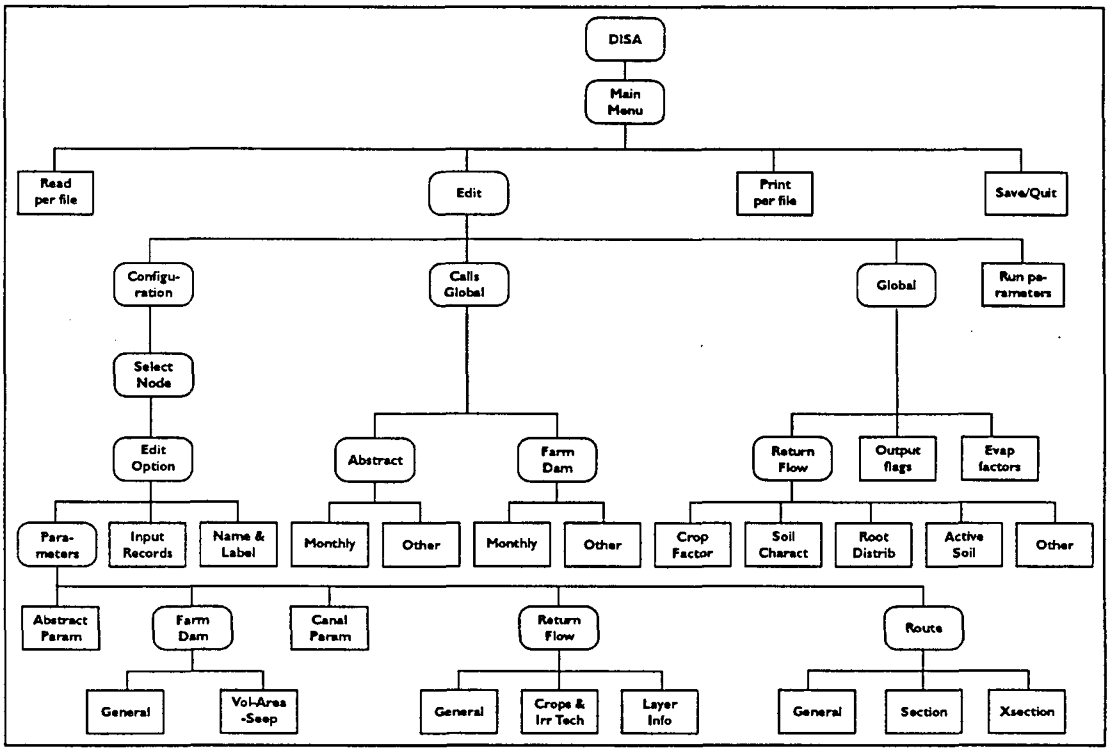


Fig 3.2 : Decision paths in DISA system configurator

3.2.3 The System Model

The System Model uses the time series database (in the Database Manager) and the system configuration file (in the System Configurator) to perform hydrosalinity simulations of all flow and salt transport through the conduits and soils of the irrigation system. Simulations are based on a daily time step. The entire system is simulated for one time step before proceeding to the next time step.

3.2.4 The Output Manager

The output manager produces three kinds of output :

- Graphical output in the form of daily flow and salinity time series
- Graphical output in the form of daily flow and salinity percentile (exceedance) curves
- Numeric output files

3.3 Data Requirements

It can be appreciated that the modelling approach implemented by DISA, which is both physically based and highly organised in terms of the physical structure modelled area, is extremely data demanding. The data input to the model consists of two types, viz. time series data and physical data parameters.

3.3.1 Time series data

The DISA model requires a number of time series that serve as external input to the modelled catchment area. These include daily rainfall and evaporation records within the catchment, as well as daily flow (m^3/s) and salinity (mg/l) records in rivers and tributaries entering and leaving the catchment.

The rainfall and evaporation records should be distributed over the whole catchment area to reflect spatial variability. The data is utilised in a data-economical way, by allowing a number of return flow cells to make use of the same time series. This is achieved by using non-dimensionalised time series as input to the model. During simulation, the time series are dimensionalised by multiplying the non-dimensional series with the mean annual rainfall or mean annual evaporation associated with the relevant return flow cell, routing node, canal or farm dam node.

3.3.2 Physical data parameters

Every return flow cell as well as every sub-model in the water distribution network has to be defined in the model in terms of parameters or physical process constants. To obtain these parameters, a detailed knowledge of the system is required in terms of layout, land-use, soil characteristics, river channel, canal and farm dam geometry and abstraction rules implemented by farmers. Appendix A provides more detailed information regarding the physical data requirements and gives examples of data input sheets.

3.4 Model Output

As mentioned in paragraph 3.2.4 above, DISA produces graphical output in the form of flow and salinity time series and duration curves.

An example of a time series plot for a specific reach of a river is shown in Figure 3.3, while Figure 3.4 displays a typical duration curve.

Numerical output of any selected results or inputs is also possible.

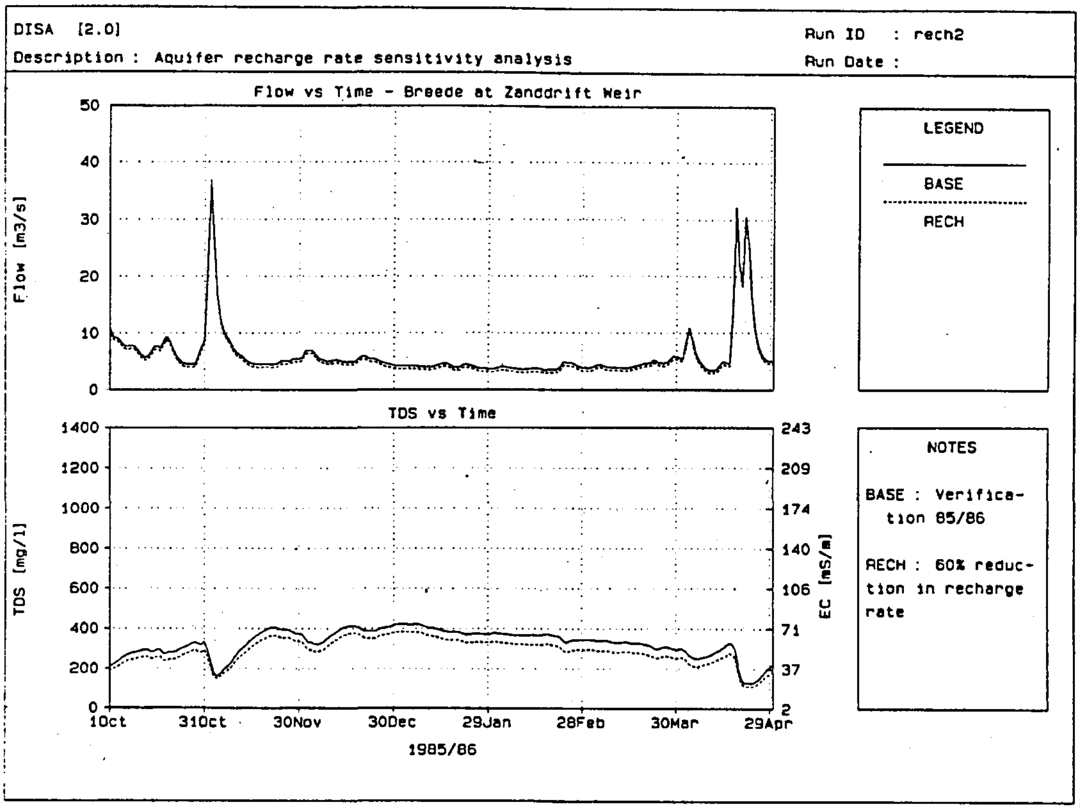


Figure 3.3 : A time series plot of flow and TDS for a river reach

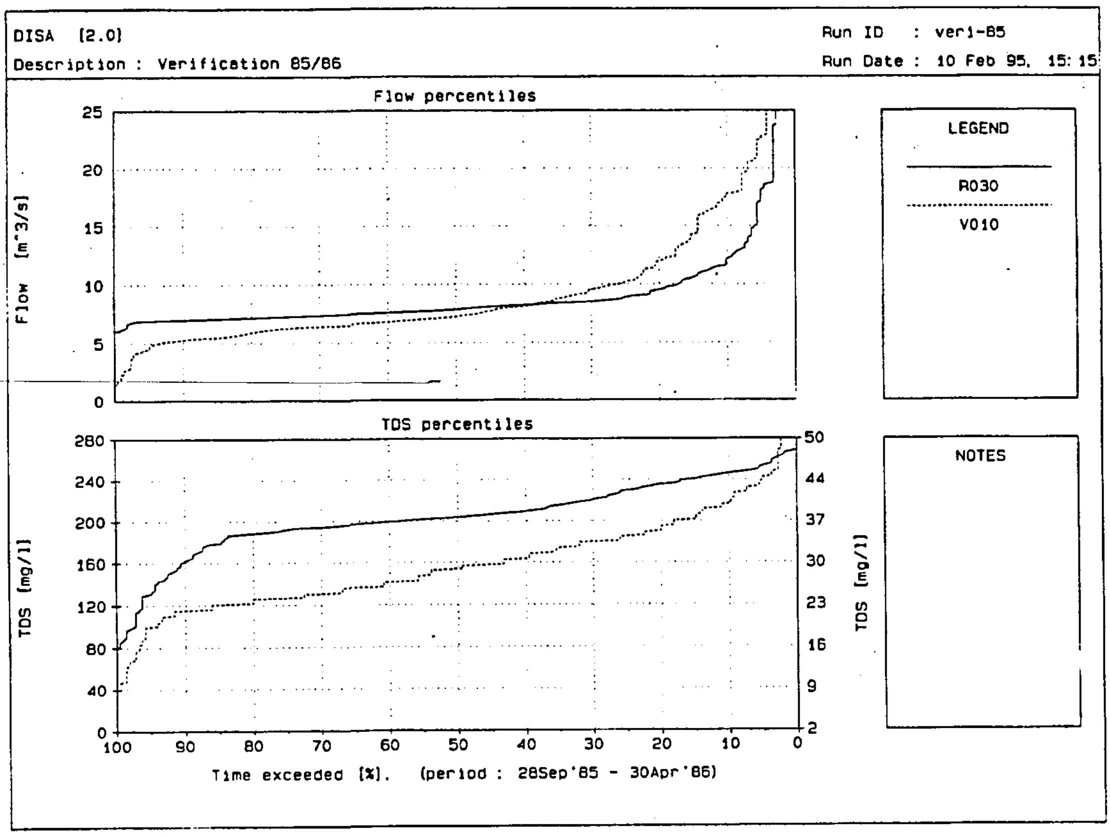


Figure 3.4 : Typical duration curve

Numeric output consist of daily and monthly mass balances of flow volumes and salt loads for each of the modelling nodes.

CHAPTER 4. PROCESS DESCRIPTION

4.1 Introduction

The physical processes governing water and salt movement through the system were determined primarily from field studies undertaken by DWAF's Hydrological Research Institute and Directorate of Geohydrology. Where necessary, the knowledge base was supplemented by extensive literature reviews and discussions with experts in particular fields. Preference was given to proven process routines, as opposed to purely theoretical concepts.

The main physical processes involve the movement of water and salt through the soil profile and the distribution network, supported by related processes such as surface runoff, artificial drainage, deep percolation and seepage from canals and farm dams.

4.2 Movement of water and salt through the irrigated soil profile

4.2.1 Conceptual overview

The return flow sub-model simulates water and salt distribution inside an irrigated model element, as well as the root zone and delivery zone processes. Initially, the root zone moisture and salt balance processes were incorporated into the model on the basis of concepts used in the IRRISS model (Forster, 1987). The moisture balance component was subsequently upgraded to include concepts used in the ACRU model (Schulze, 1984), such as layering, moisture retention characteristics and layer drainage. The empirical treatment of canal and farm dam seepage losses was further developed from concepts used in the IRRSCHEME model (Ninham Shand, 1985).

During formulation of the sub-model structure, considerable emphasis was placed on the need to apply the correct volume of water of a certain quality, to the right surface area in order to produce reasonable estimates of root zone percolate. DISA therefore distinguishes between irrigated and non-irrigated areas in a return flow cell as defined by the user. In addition, it is possible to simulate an irrigated area with a number of different crop types, each of which may be irrigated from a separate water source, using any one of a range of irrigation methods. For each combination of crop type and irrigation method, an 'active soil factor' is defined, which represents the actual ('wetted') area to which the irrigation water is applied. Figure 4.1 illustrates the simulation of water and salt dynamics in the soil profile within the return flow sub-model.

Apart from the points mentioned above, the following processes and assumptions are incorporated into the irrigation sub-model:

- The irrigated soil profile consists of a layered soil structure, allowing for a root zone, unsaturated zone and a saturated zone.
- DISA simulates the movement of water between the different layers on a daily basis, starting at the top layer and progressing downwards.
- DISA caters for capillaric rise of water and salts into the unsaturated zone.
- Movement of water between layers occurs only when field capacity is exceeded and is controlled by a percolation factor as a function of soil moisture status.
- Groundwater movement in the saturated zone is modelled by a one-dimensional Dupuit approximation and aquifer outflow is dynamically controlled.
- Salt transport through the saturated zone is controlled by a Lagrangian layering approach, ensuring different time lags for water and salt responses.
- Seepage from canals and farm dams can be introduced into the sub-surface system at a pre-determined level.
- Terrace soils are not allowed to have saturated zones, on the grounds that most higher-lying irrigated soils are artificially drained.
- The regional groundwater is not mixed with the saturated zone, but provided as a diffuse input along routing reaches in the main river channel.
- Saturated zone outflows are provided as point or diffuse input to routing reaches.
- Although provision is made for the configuration of gypsum application, it was decided not to implement this feature in the sub-model due to a lack of reliable information.

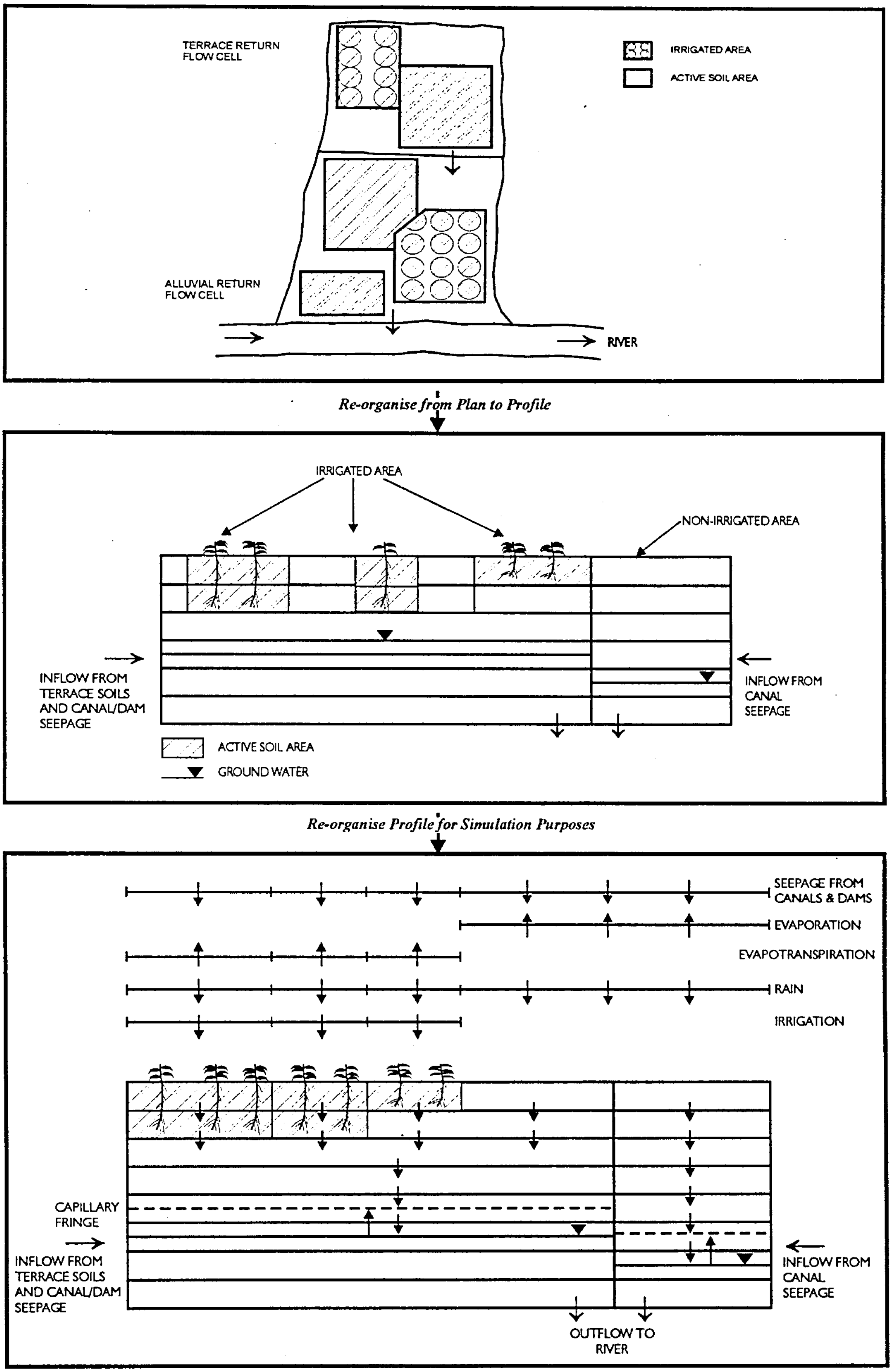


Figure 4.1: Simulation of water and salt in the soil profile

Figure 4.2 shows a typical cross section, together with a diagram illustrating aquifer-stream interaction.

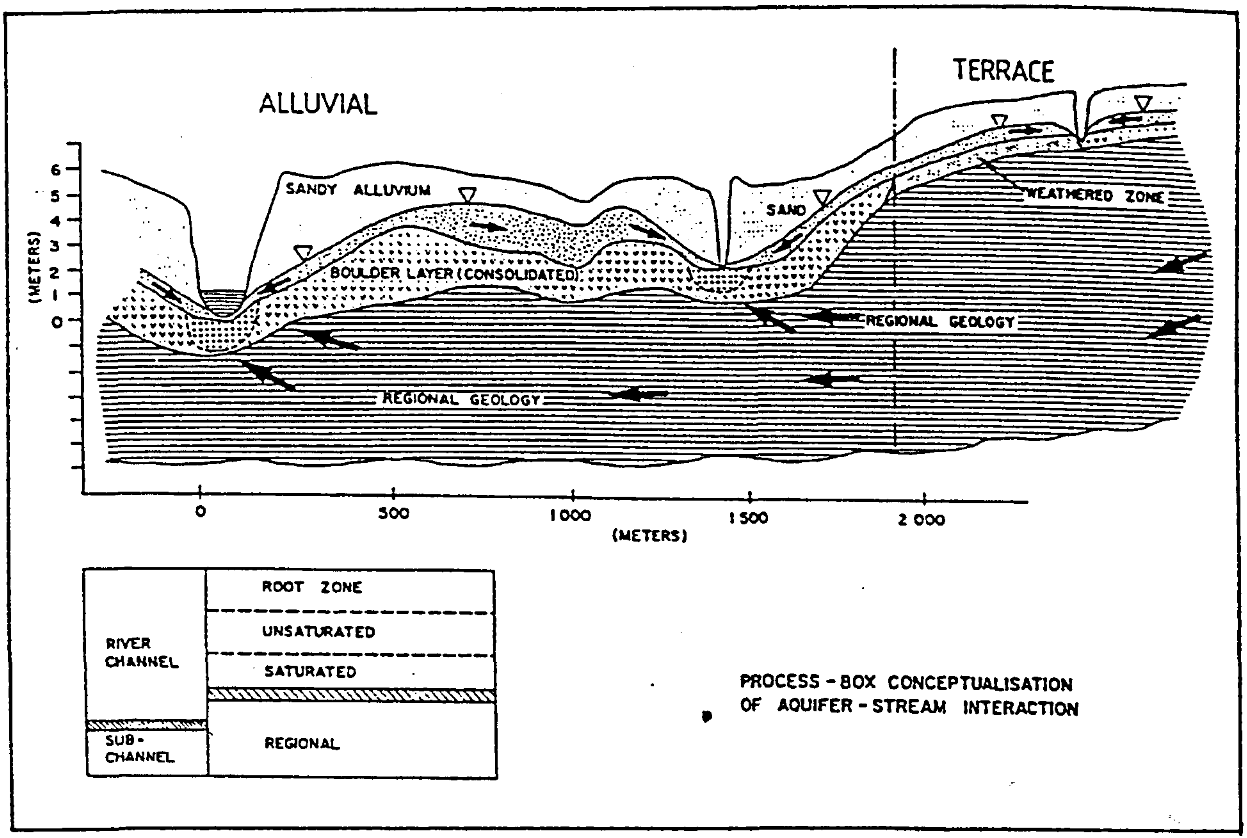


Figure 4.2 : Aquifer – stream interaction

4.2.2 Root zone moisture and salt balance

DISA distinguishes between a root zone, an unsaturated, and a saturated zone within the vertical irrigated soil profile. Different processes govern the movement of water and salt within each of these zones. During configuration, the soil profile is divided into a number of layers of equal thickness. The layers which constitute the root zone are defined as 'top layers'. Each top layer is broken down into smaller units in a horizontal plane. These units define the basic scale at which DISA models the movement of water and salt within the root zone, with each unit representing the wetted area associated with a unique combination of crop type, water source and irrigation method. The total non-wetted area within the irrigated area of the return flow cell is treated as a single unit, which receives no irrigation water, and from which water is lost through evaporation, rather than evapotranspiration.

(i) Net inflow to first layer

The topmost layer of the root zone receives rainfall and/or irrigation water. Rainfall is calculated based on daily time series of rainfall. The salt concentration of the rainwater is set to zero. Irrigation applied to a return flow cell may be abstracted from a farm dam, or directly from a river or canal. DISA calculates an 'irrigation distribution factor' for each unit within the return flow cell, based on the weighted average of the product of irrigated area and crop factor per unit. The daily volume of irrigation water from each source is then distributed amongst the units according to these factors. Finally, DISA also calculates the daily volume of surface runoff for each unit (paragraph 4.3).

The net daily inflow to each unit within the first layer of a return flow cell is calculated from equation 4.1.

$$Q_{TOPIN} = Q_{RAIN} + Q_{IRR} - Q_{RUNOFF} \qquad (4.1)$$

with Q_{TOPIN} : net daily inflow (mm)

Q_{RAIN} : daily rainfall (mm)

Q_{IRR} : daily irrigation supply (mm)

Q_{RUNOFF} : daily surface runoff (mm) (see Section 4.3)

The salt concentration of the net inflow (and surface runoff) is equal to

$$Q_{IRR}.S_{IRR}/(Q_{RAIN} + Q_{IRR}) \qquad (4.2)$$

with S_{IRR} : salt concentration of irrigation water (mg/l)

(ii) Evapotranspiration

Within the root zone, the daily volume of water lost as evapotranspiration from each unit, is calculated from equation 4.3.

$$Q_{EVT} = EVP_{REC} * CF * R_{\%} \qquad (4.3)$$

with Q_{EVT} : daily evapotranspiration loss (mm)

EVP_{REC} : recorded A-Pan evaporation (daily time series data) (mm)

CF : monthly crop factor (specified for each crop type)

$R_{\%}$: root distribution as a percentage per layer (specified for each crop type)

(iii) Evaporation

Evaporation is calculated from equation 4.4 for all soil layers within the non-wetted portion of the irrigated area of a return flow cell, and within a user defined evaporation depth.

$$Q_{EV} = EVP_{REC} * EF \qquad (4.4)$$

with Q_{EV} : daily evaporation loss (mm)

EVP_{REC} : recorded A-pan evaporation (daily time series data) (mm)

EF : dry evaporation factor which expresses evaporation from bare soil as a fraction of pan evaporation

Daily evaporation per soil layer is limited to the difference between the soil moisture content before evaporation and the wilting point.

(iv) Moisture and salt balance

Within the root zone, water moves to the next layer only when field capacity is exceeded. The movement is controlled by a percolation factor as a function of soil moisture status (equation 4.5).

$$Q_{PERC} = (SMC_S + Q_{IN} - Q_{EVT} - FC) * PF \qquad (4.5)$$

with
- Q_{PERC} : water percolating to next layer (mm)
- SMC_S : initial soil moisture content (mm)
- Q_{IN} : inflow ; = Q_{TOPIN} if first layer, otherwise = Q_{PERC} of layer above (mm)
- $Q_{EVT/EV}$: evapotranspiration / evaporation loss (mm)
- FC : field capacity (specified for each soil type) (mm)
- PF : percolation factor (specified for each soil type) (mm)

The final (end-of-day) soil moisture content in each unit (SMC_E)is then calculated from equation 4.6. (Note that SMC_E is limited to the soil porosity, with any excess added to Q_{PERC}.)

$$SMC_E = \min(SMC_S + Q_{IN} - Q_{PERC} - Q_{EVT} \quad ; PO) \qquad (4.6)$$

with
- SMC_E : soil moisture content at end of day (mm)
- PO : soil porosity (mm)

Once the final soil moisture content has been calculated, DISA calculates the corresponding final salt concentration within each unit from equation 4.7.

$$S_E = (SMC_S.S_S + Q_{IN}.S_{IN} - Q_{PERC}.S_{PERC})/SMC_E \qquad (4.7)$$

with
- S_E : final soil moisture salt concentration (mg/l)
- S_S : initial soil moisture salt concentration (mg/l)
- S_{IN} : inflow salt concentration (mg/l)
- S_{PERC} : outflow salt concentration (mg/l)

In order to ensure a realistic simulation of salt movement within the soil profile, a conceptual approach was adopted in DISA, which divides the total volume of water entering a unit into sub-volumes, each with a different salt concentration depending on the unit from which the water originated. Figure 4.3 is a diagrammatic representation of salt movement within the root zone. It shows that if the volume of water which enters a unit (Q_{IN}) is more than the initial soil moisture content of the unit immediately above $SMC_{S(i-1)}$ (with corresponding salt concentration $S_{S(i-1)}$), the excess water has a salt concentration equal to that of $S_{S(i-2)}$. If Q_{IN} is more than ($SMC_{S(i-1)}$ + $SMC_{S(i-2)}$), the process continues until the total volume which constitutes Q_{IN} has been accounted for.

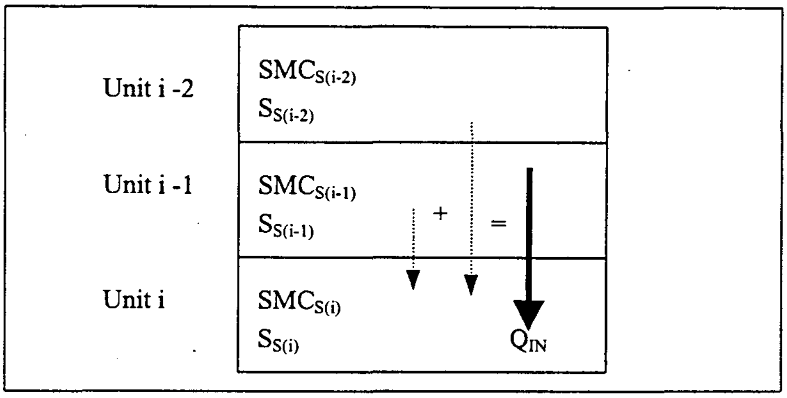


Figure 4.3 : Salt movement in the soil profile

4.2.3 Delivery zone processes

(i) Water movement

The main difference between the root zone and the layers below is that whereas root zone layers are divided into smaller units, each of which are modelled individually, layers in the unsaturated zone and the groundwater body in the saturated zone are modelled as single units for the whole return flow cell (see Figure 4.1). As different mechanisms govern the movement of water and salt in the saturated and unsaturated zones, the location of the groundwater table within the soil profile is very important. Based on the criterion that a layer is saturated when its soil moisture content equals or exceeds its porosity, the soil layer within which the groundwater table is situated, i.e. the location of the interface between the saturated and unsaturated zones, is determined. The movement of water in the unsaturated zone is also governed by equations 4.5 and 4.6. The water body in the saturated zone, however, is treated as a single unit for the whole return flow cell, with inflows and outflows depicted diagrammatically in Figure 4.4.

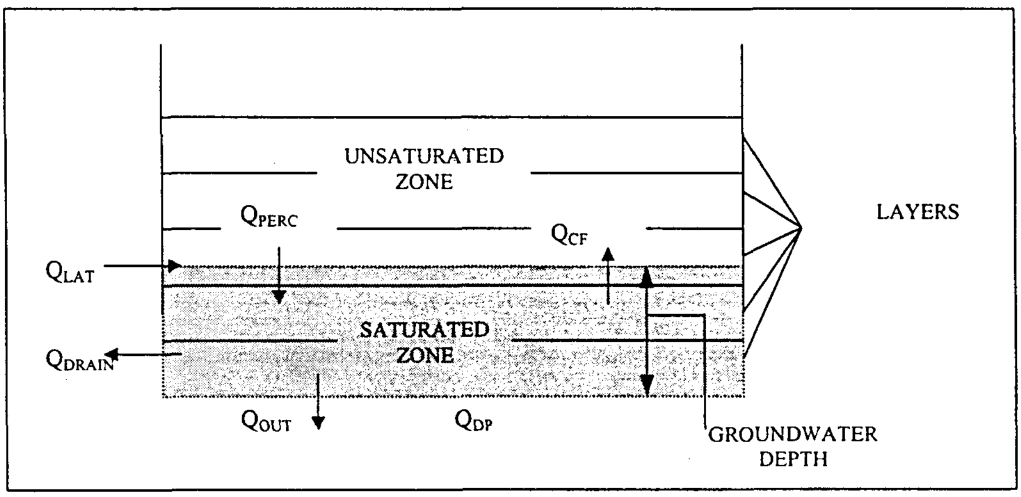


Figure 4.4 : Water movement in the saturated zone

- Q_{PERC} represents water percolating to the saturated zone from the unsaturated layer above.

- Q_{LAT} represents the sum of all lateral inflows, i.e. from a terrace cell and/or seepage from dams and canals. By default, Q_{LAT} is introduced into the top layer of the saturated zone. (In the non-irrigated area of the return flow cell, only a specified portion of canal seepage is allowed as lateral inflow.)

- Artificial drainage (Q_{DRAIN}) and deep percolation (Q_{DP}) are expressed as functions of the groundwater depth (refer to paragraphs 4.4.1 and 4.4.2).

- Q_{CF} represents water lost by evapotranspiration or evaporation from within the capillary fringe. A capillary fringe depth is specified for each soil type, representing the extent of the capillary fringe above the saturated zone. Whenever the root zone (in the wetted, irrigated area) or the evaporation depth (in the non-wetted, irrigated area) is situated within the capillary fringe, DISA deducts the evapotranspiration or evaporation losses in the relevant top layers from the groundwater in the saturated zone.

- The calculation of groundwater outflow from the saturated zone (Q_{OUT}) is based on a one-dimensional Dupuit approximation (equation. 4.8).

$$Q_{OUT} = (GW_{DEPTH})^2 . K_{SAT} . \frac{\pi^2}{4w^2} \qquad (4.8)$$

with

Q_{OUT}	: aquifer outflow (mm)
GW_{DEPTH}	: groundwater depth (m)
K_{SAT}	: saturated hydraulic conductivity (specified per soil type) (mm/day)
w	: aquifer width (specified per return flow cell) (m)

Once DISA has calculated daily inflows to, and outflows from the saturated zone, the net change in groundwater storage (d_{SAT}) is calculated from equation 4.9.

$$d_{SAT} = Q_{PERC} + Q_{LAT} - Q_{OUT} - Q_{DP} - Q_{CF} \qquad (4.9)$$

In the case of an increase of groundwater in storage, d_{SAT} is distributed amongst the layers above the groundwater table, starting at the layer in which the groundwater table is situated, and progressing upwards. A portion of d_{SAT} , equal to the difference between the porosity and soil moisture content, is allocated to each layer until d_{SAT} has been completely accounted for. Similarly, if the net change in groundwater is negative, the soil moisture content of layers below the water table is decreased (up to their field capacity) until the total change in soil moisture content is equal to d_{SAT}. The new position of the groundwater table is then determined as described above.

It is important to note that the above description of water movement within the saturated zone is only applicable to alluvial return flow cells, as terrace cells are not allowed to have a saturated zone. In the case of terrace cells a daily volume of direct outflow (Q_{TOUT}) is calculated from equation 4.10, which may be provided as lateral inflow to an alluvial cell.

$$Q_{TOUT} = Q_{PERC} + Q_{LAT} \tag{4.10}$$

with Q_{TOUT} : outflow from terrace cell (mm)

Q_{PERC} : water percolating from bottom layer (equation 4.5) (mm)

Q_{LAT} : dam/canal seepage (mm)

(ii) Salt movement

As salt movement in the irrigated soil profile is controlled by the movement of water, DISA simulates the movement of salt within the layered soil profile based on the net movement of soil moisture between the soil layers.

Within the unsaturated zone, salt movement is based on the water mass balance as described in Section 4.22 (iv) above. Provision is made for the total volume of water entering a layer to be divided into sub-volumes of different salt concentrations, depending on the layer of origin.

The movement of salt in the saturated zone is achieved by means of a salt-stacking algorithm. Salt concentrations are allowed to vary within each saturated soil layer. With consideration of the inflows and outflows as depicted in Figure 4.4, as well as the net change in groundwater movement, the net movement of soil moisture between the saturated soil layers is calculated. The salt concentration of water entering each layer is again related to the layers from which the water originated. By following this approach, DISA ensures different time lags for the respective responses of water and salt within the groundwater body.

4.2.4 Salt generation

The DISA model does not account for dynamic salinity related soil processes such as weathering, sorption, dissolution or deposition. This simplification does not significantly affect the results, when DISA is used for single season simulations.

However, when simulations are performed over multiple seasons, the simulated salinities in the system experience a steady decline from the second season onwards (Figure 4.5). An attempt was therefore made to develop a salt generation function so that a realistic representation of salinity in the irrigation scheme can be obtained for simulation periods of more than one season.

The development of the salt generation function was governed by various principles of which the following are the most important :

- The mass of salt generated in the soil profile must increase with the volume of water infiltrating the soil profile, asymptotically up to a limit above which more water does not generate more salt.
- The mass of salt generated must be dependent on the salt concentration of the water entering the soil.
- The function accommodates net salt dissolution rather than the precipitation of salts.
- Salt generation and leaching is accommodated in a single function, assuming an unlimited source of salt in the salt profile.

The salt generation function which was developed, allowed for two types of salt generation, viz. salt generated by water, and salt generated by chemical weathering. The daily water-related salt generation in each layer was modelled with a negative exponential function, while the daily salt mass generated from chemical weathering was assumed to remain constant over time.

A detailed description of the approach that was followed during the development and evaluation of the function is available (Jonker, 1995). Within the context of this report, suffice it to say that the very simple, purely empirical function did not succeed in a realistic simulation of salt generation within the soil profile and would need further refinement.

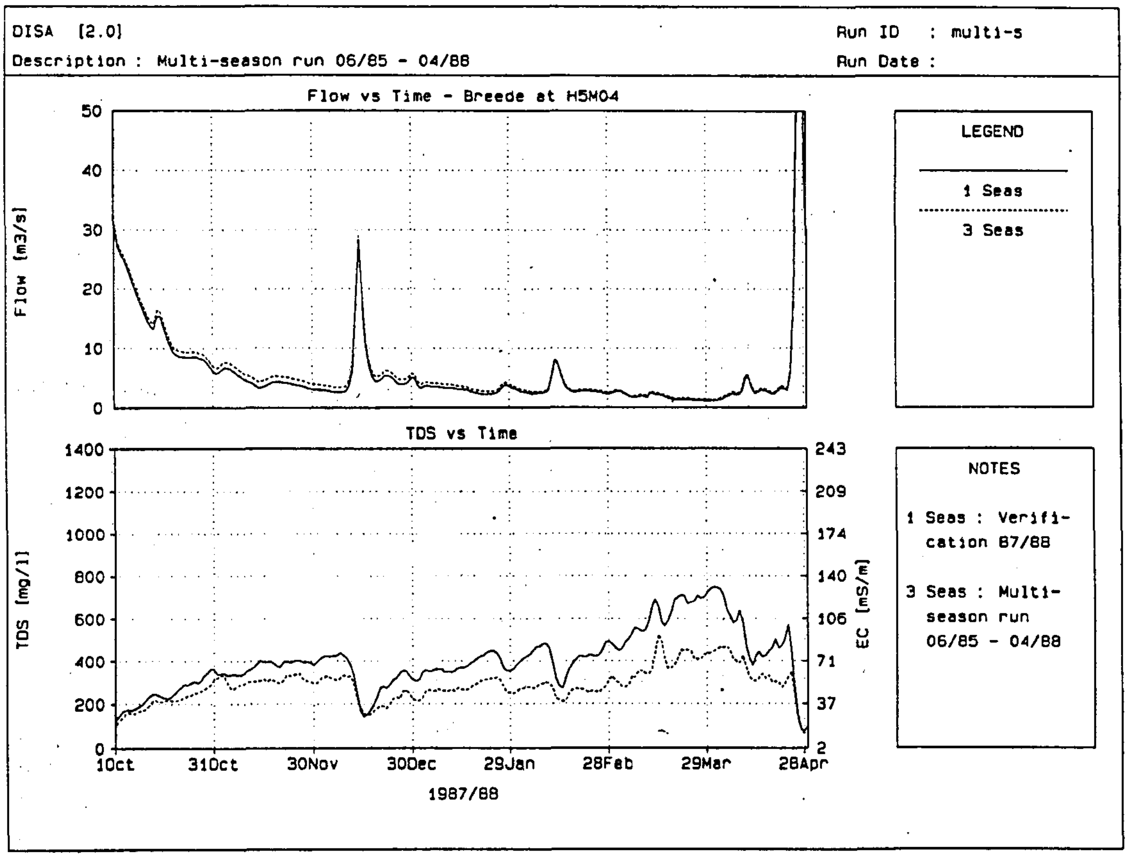


Figure 4.5 : The effect of no salt generation on groundwater salinity during a multi-season simulation

4.3 Surface Runoff

Originally, the DISA model did not include surface runoff generation processes, as it was intended for irrigation (summer-) season modelling in the Western Cape, during which period rainfall is minimal. In order to accommodate multi-season irrigation in summer rainfall regions, the simulation of surface runoff was incorporated into the model.

Surface runoff is calculated by means of the SCS equation, developed by the Soil Conservation Services of the United States Department of Agriculture. The equation has previously been adapted for use in Southern Africa by Schulze (1984), and Schmidt and Schulze (1987). The fundamental concept of the equation is that the runoff potential is an inverse function of the relative wetness of a soil, as can be seen in equation 4.11.

$$q = \frac{(p - cs)^2}{p + (1 - c)s} \qquad (4.11)$$

with q = surface runoff (mm)
p = daily rainfall and applied irrigation (mm)
c = coefficient of initial abstraction
s = soil water deficit (mm)

Equation 4.11 is applied on a daily time step basis for each return flow cell within the DISA model. The value of p is calculated from rainfall time series data and irrigation applications. Initial values for the coefficient of initial abstraction and the soil water deficit are specified in the model, after which they are re-calculated daily. The daily surface runoff in mm, from each return flow cell, is converted to a volume by multiplying it with the total area of the return flow cell.

4.3.1 Coefficient of initial abstraction

The coefficient of initial abstraction (c) can range between 0,0 and 0,3 and is a representation of the amount of water that goes into surface retention before surface runoff can commence. The magnitude of the coefficient depends on the type of vegetation, as well as on site and management characteristics. For example, immediately after ploughing when surface roughness is high, the coefficient can increase to 0,3, while it can be as low as 0,05 under conditions of soil compaction.

4.3.2 Soil water deficit

The soil water deficit (s) is defined as the water retention at saturation minus the actual soil water content prior to water application (rainfall or irrigation). In each return flow cell, the soil water deficit is calculated for a critical soil depth. Values for the critical soil depth, as suggested for use in the ACRU model, are shown in Table 4.1 below. The DISA model sets the critical soil depth equal to the soil layer depth specified during configuration, i.e. the soil water deficit in the topmost layer is considered for calculation of surface runoff.

SPARSE VEGETATION		DENSE VEGETATION	
0,10 m	0,15 m	0,20 m	THIN SOILS EUTROPHIC LOW ORGANIC CARBON
0,20 m	0,25 m	0,30 m	
0,25 m	0,30 m	0,40 m	HIGH ORGANIC CARBON DYSTROPHIC DEEP SOILS
ARID CLIMATE INTENSIVE RAINFALL		HUMID CLIMATE LIGHT RAINFALL	

Table 4.1 : Critical soil depth values (ACRU Manual, 1989)

4.4 Groundwater Body Interaction

4.4.1 Artificial drainage

Originally, DISA allowed for a percentage of drained outflow to be specified, which represents the portion of ground water which drains directly to a surface collector or drain. This approach was only applied to terrace return flow cells. As large areas of many irrigation schemes, such as the Vaalharts are artificially drained, it was considered essential for the accuracy of the model to include a drainage sub-routine in DISA.

A Dupuit-Furcheimer type equation (equation 4.12), where the hydraulic head above a sub-surface drain determines the volume of water that enters the drain, is used to calculate the daily drainage volume from each return flow cell. Linear flow of the groundwater towards each drain is assumed.

$$q = \frac{K_{SAT}\ L\,(H^2 - h^2)}{R} \qquad (4.12)$$

with q = flow rate per drain of length L (m^3/day)

K_{SAT} = saturated hydraulic conductivity

H = water table height midway between drains relative to reference level (m)

h = height of drain above reference level (m)

R = parallel drain spacing / 2 (m)

The value of K_{SAT} in equation 4.12 is related to the soil textures of the soil layers above the drain. At the end of each daily time step the value of H is determined from the height of the water table above a reference level. The user specifies the soil layer in which the drains are situated. With known layer depths, the value of h is calculated by assuming that a drain is situated at the bottom of a layer. The total daily artificial drainage per return flow cell is calculated by multiplying q with the total number of drains in the return flow cell. Figure 4.6 provides a diagrammatic representation of artificial drainage and defines the parameters in equation 4.12 .

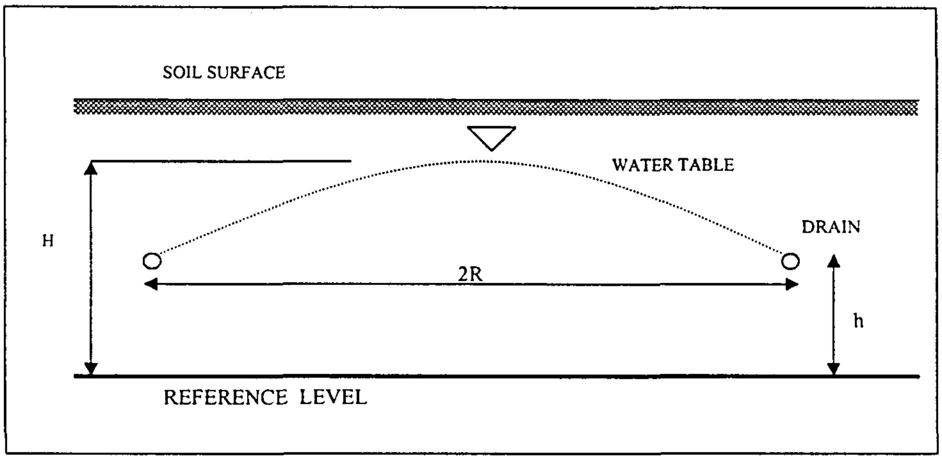


Figure 4.6 : Definition sketch – artificial drainage

4.4.2 Deep percolation

In order to simulate a scenario where groundwater percolates from a perched water table through a layer with relatively low permeability to a deeper water reservoir, DISA employs a "Deep Percolation Factor". This factor is specified for each return flow cell as a daily percentage of the groundwater in the perched water table, which will drain to a deeper water reservoir.

Deep percolation is simulated prior to seepage and artificial drainage, as it is assumed that the water will percolate relatively quickly through macro-openings such as fissures and cracks in the geological layer which separates the perched and deep groundwater. The specification of deep percolation as a percentage of the groundwater in the perched water table allows for an approximation of the relationship between the hydraulic head of perched water, and percolation to the deep water reservoir. This rather simplistic approach thus assumes a non-Darcian flow of groundwater to the deep water reservoir. Figure 4.7 is a diagrammatic representation of deep percolation.

The volume and TDS concentration of the water percolating to the deep water table is written to an output file, where the volume and time series data of deep percolation water can be independently manipulated during the model verification stage. This enables the extent and rate of deep percolation and the associated accumulation of salts within the deep water reservoir to be examined.

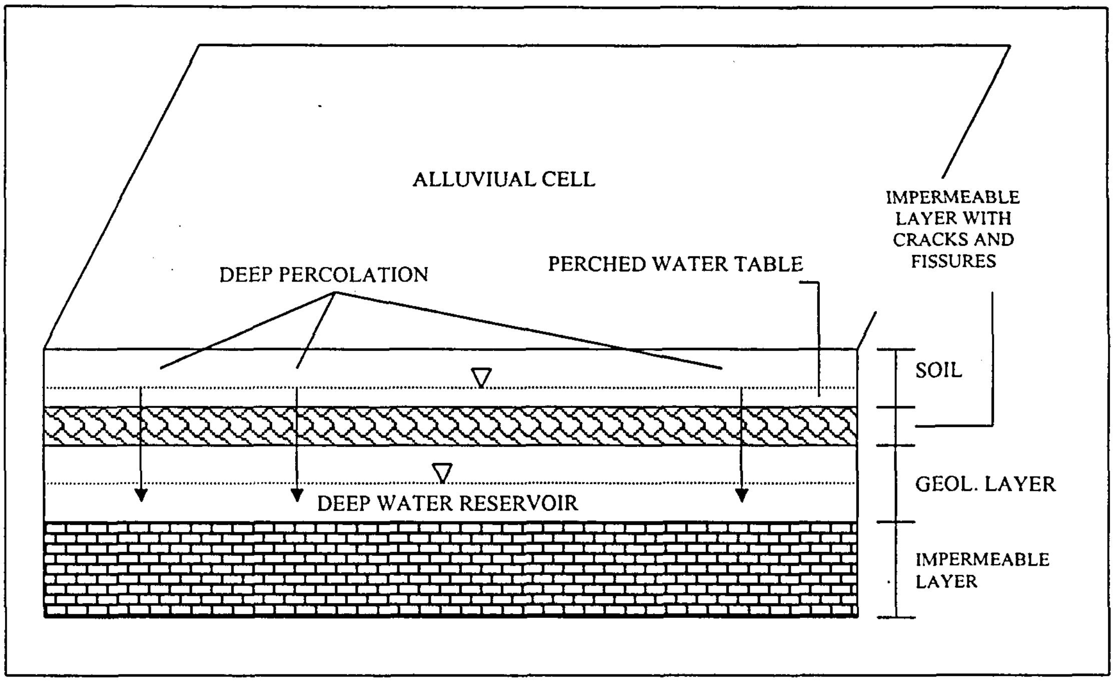


Figure 4.7 : Deep percolation

4.4.3 Seepage from canals and farm dams

DISA caters for the recharge of groundwater bodies from canal and farm dam seepage. The seepage water is introduced into the sub-surface system at a pre-determined level.

(i) Seepage from canals

Seepage from canals is expressed as a relationship between the flow rate and the wetted perimeter for each canal node. The daily volume of seepage water is then calculated, based on a user-defined ratio of seepage rate per thousand m^2 of wetted perimeter and on the simulated flow rate in the canal. Salt concentration of seepage water is set equal to the salt concentration of water entering the canal. Daily volumes of seepage water from canals are allocated to return flow cells and proportionally distributed between irrigated and non-irrigated areas.

A portion of the canal seepage water is lost as evapotranspiration through the riparian vegetation. The evapotranspiration is assumed to be equivalent to open water evaporation, and is based on a riparian width specified by the user.

(ii) Seepage from farm dams

For each farm dam node, the user is allowed to specify a seepage rate/volume ratio for up to twelve different storage levels within the dam. These ratios are then used to calculate the daily amount of water lost to seepage, based on the volume of water in storage at the start of the day. The farm dam seepage enters the groundwater body in the irrigated portion of a return flow cell.

4.5 Movement of water and salt through the distribution network

4.5.1 Dams and canals

DISA performs a daily mass balance calculation for each farm dam and canal node within the system.

(i) Farm Dams

A daily water- and salt balance for each farm dam node is performed by DISA. The water balance is governed by the following equation:

$$Vol_E = Vol_I + Vol_{(R\text{-}EVAP)} + Vol_{IN} - Vol_{SEEP} - Vol_{ABS} \qquad (4.13)$$

with Vol_E : final water volume (10^3 m^3)

Vol_I : initial water volume (10^3 m^3)

$Vol_{(R\text{-}EVAP)}$: daily volume of rainfall – daily volume of evaporation (10^3 m^3)

Vol_{IN} : total volume of water inflow (diverted/pumped from canals/rivers/boreholes) (10^3 m^3)

Vol_{SEEP} : daily seepage volume (10^3 m^3)

Vol_{ABS} : daily water volume abstracted for irrigation (10^3 m^3)

Since the functions for calculating rainfall, evaporation and seepage volumes in the above equation are dependent on the water volume in the dam, an iterative procedure is employed for calculation of the end of day water volume. During the first iteration, Vol_{I1} is set equal to the water volume at the end of the previous day. Rainfall, evaporation and seepage are calculated based on this water volume and a final volume (Vol_{E1}) is calculated from equation 4.13. For the next iteration, the average of Vol_{I1} and Vol_{E1} is used as the initial volume (Vol_{I2}). Rainfall, evaporation and seepage are recalculated based on Vol_{I2} and the final, end of day volume (Vol_{E2}) is re-calculated from equation 4.13.

The salt balance equation is as follows:

$$Load_E = (Vol_S.S_S) + (Vol_{IN}.S_{IN}) \tag{4.14}$$

with $Load_E$: total salt mass at end of day (t)

Vol_S : water volume at start of day (= water volume at end of previous day) (10^3 m^3)

S_S : salt concentration at start of day (= salt concentration at end of previous day) (mg/l)

S_{IN} : weighted average of total inflow's salt concentration (mg/l)

The corresponding final salt concentration in the farm dam node at the end of the day is then calculated from equation 4.15 :

$$S_E = Load_E / (Vol_S + Vol_R + Vol_{IN}) \tag{4.15}$$

(ii) Canals

Equation 4.16 represents the daily water balance which DISA performs for each canal node.

$$Vol_{OUT} = Vol_{IN} + Vol_R - Vol_{SEEP} - Vol_{EVAP} \tag{4.16}$$

with Vol_{OUT} : volume of water leaving canal at end of day (10^3 m^3)

Vol_{IN} : volume of water entering canal at start of day (10^3 m^3)

Vol_R : daily volume of rainfall (10^3 m^3)

Vol_{SEEP} : daily seepage volume (10^3 m^3)

Vol_{EVAP} : daily evaporation volume (10^3 m^3)

The salt balance is governed by equation 4.17 :

$$S_{OUT}.Vol_{OUT} = Vol_{IN}.S_{IN} - Vol_{SEEP}.S_{SEEP} \tag{4.17}$$

with S_{OUT} : salt concentration of water leaving canal at end of day (mg/l)

S_{IN} : salt concentration of water entering canal at start of day (mg/l)

S_{SEEP} : salt concentration of seepage water (= $Salt_{IN}$) (mg/l)

4.5.2 River channel processes

(i) Introduction

River channel processes in DISA are simulated by the routing sub-model. The routing reach serves as a link between neighbouring model elements and is therefore designed to accept outflows from return flow cells, inflow nodes and upstream routing nodes in the form of point or diffuse water and salt inputs.

Within the Breede River system, the nature of the Brandvlei Dam operation necessitated the development of a relatively sophisticated routing sub-model as travel times in the individual routing reaches are of the order of a few hours. Sensitive model response to releases from an upstream storage is ensured by allowing the routing sub-model to operate on a user defined sub-daily timestep.

Typically, a routing sub-model can accept up to four lateral inflows in the form of point or diffuse inflows at user defined chainages along its length. Point and diffuse lateral inflows are assumed to have a constant sub-daily distribution.

Net evaporation is calculated and subtracted for each sub-daily time interval Δt and distance interval Δx. The evaporation calculation is based on the surface area determined for the previous Δt.

Two output sets are generated from each routing reach, viz.

- Average daily flow- and TDS values.
- A sub-daily outflow distribution which is expressed as percentages of the total daily outflow volume.

A routing reach further downstream uses the outflow distribution from the upstream reach to distribute incoming flows, which are composed of outflow from the upstream reach as well as point inflows between the two reaches (see Figure 4.8).

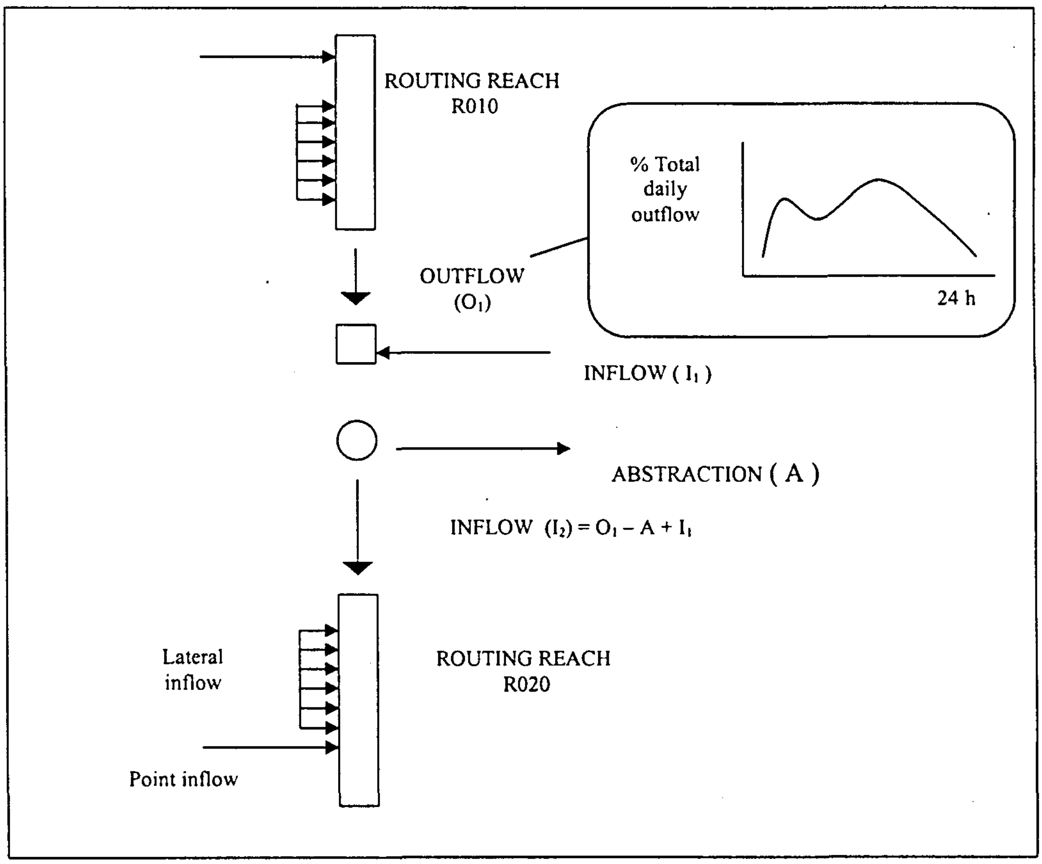


Figure 4.8 : Routing reach inflow determination

(ii) Flow routing

Flow routing is achieved by the application of a Muskingum-Cunge kinematic approximation of the St Venant's equations with variable kinematic parameters as derived by Ponce and Yevjevich (1978).

Cunge (1969) proposed an explicit finite difference scheme which is formulated as follows :

$$Q_4 = C_1Q_1 + C_2Q_2 + C_3Q_3 + C_0Q_0 \quad (4.18)$$

and :

$$C_0 = 2\Delta t/[\Delta t + 2K(1 - \Theta)] \quad (4.18a)$$

$$C_1 = [\Delta t + 2K\Theta]/[\Delta t + 2K(1 - \Theta)] \quad (4.18b)$$

$$C_2 = [\Delta t - 2K\Theta]/[\Delta t + 2K(1 - \Theta)] \quad (4.18c)$$

$$C_3 = [2K(1 - \Theta) - \Delta t]/[\Delta t + 2K(1 - \Theta)] \quad (4.18d)$$

$$C_1 + C_2 + C_3 = 1.0 \quad (4.18e)$$

$$K = \Delta x/c_{REP} \quad (4.19)$$

$$\Theta = 0.5(1 - Q_{REP})/(B_{REP} * S_{REP} * c_{REP} * \Delta x) \quad (4.20)$$

$Q_{1..4}$ are the flow rates at the grid corners of a computational cell with dimensions of Δt (time interval) and Δx (distance interval) as shown in Figure 4.9.

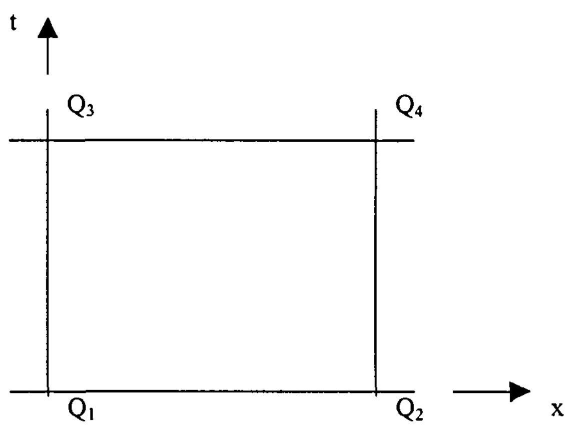


Figure 4.9 : A computational cell

Whereas Q_0 represents overland flow in the original Cunge formulation, the DISA model employs this term to introduce lateral inflows to the river channel. $C_{1..4}$ are ratios of flood wave celerities. Subscripts $_{REP}$ denote representative values for a computational cell. B is the water surface top width, and S is the bed slope.

The parameter K gives an indication of the travel time of a flood wave through a distance Δx. The parameter Θ is a weighting coefficient which varies between 0 and 0,5. Ponce and Yevjevich (1978) proposed a scheme whereby K and Θ are allowed to vary in time and space as the flow varies. Previously, the conventional approach in Muskingum routing was to define average values for K and Θ for an entire flood event.

The routing sub-model used in the DISA model implements variable K and Θ parameters. In order to do this, it is neccessary to calculate average Q (Q_{AVE}) and C (c_{AVE}) values for each computational cell at the four grid points of a computational cell. Flow conditions at the fourth grid point are unknown, which implies an iterative solution. Holden and Stephenson (1988) have shown that an explicit weighted average of the three known grid points show almost identical results to implicit routing. The weighted average values to compensate for the missing flow and celerity Q_4 and c_4 at the downstream end of the segment are found by :

$$Q_{AVE} = \tfrac{1}{4}(Q_1 + Q_2 + 2Q_3) \qquad (4.21)$$

$$c_{AVE} = \tfrac{1}{4}(c_1 + c_2 + 2c_3) \qquad (4.22)$$

Since the flood wave celerity c is defined as dQ/dA, differentiating equation (4.3) with respect to flow area results in :

$$c_{REP} = \alpha\, \beta\, A_{REP}^{\beta - 1} \qquad (4.23)$$

(iii) Initialisation

A routing reach is divided into one or more sections, each with a representative cross-section, average slope and user-defined number of finite difference steps (calculation intervals). The cross-section is defined in terms of x- and y-coordinates and Manning n-values. Figure 4.10 shows the convention used for cross section definition. Y-values can be defined relative to any reference level, and DISA can also accommodate irregular channels with more than one low-flow channel. As indicated in Figure 4.10, DISA provides for varying values of Manning's n over a cross-section.

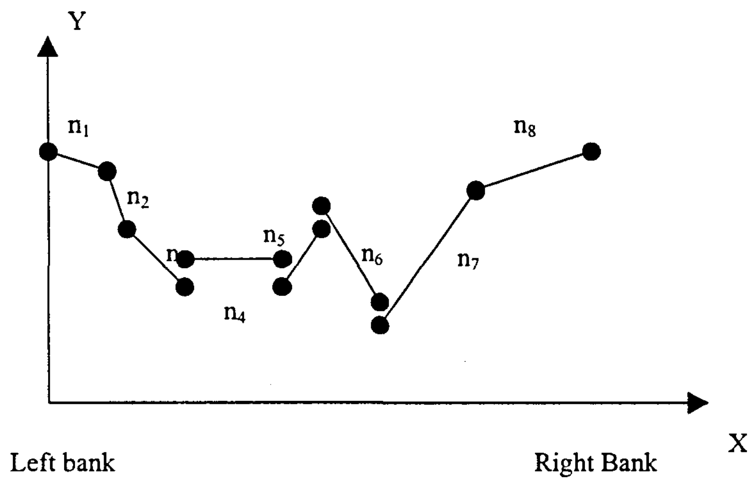


Figure 4.10 : Definition of cross section parameters

At the start of a run all return flow cells and routing nodes are "initialized", i.e. constants that remain the same for the duration of the run are calculated. In the case of routing sub-models, the following groundwork is done:

- In order to achieve a significant saving in computational time, the DISA routing sub-model makes use of Discharge-Flow Area relationships as proposed by Huang (1978). At the start of a simulation, these relationships are determined for every cross-section by computing representative flow areas, top widths and flow rates (Manning) for a range of water depths. Each cross-section within the routing reach is divided into twenty evenly spaced horizontal sub-areas from the lowest point on the bed to the lowest point on the bank. For each cross section, the following table (Table 4.2) is then generated. When compiling Discharge-Flow Area-Top Width tables, composite roughnesses are calculated for each of the flow areas. These tables remain available for each of the sections of the reach for the duration of a run and serve as "look-up" tables.

Sub-area No.	Total flow area	Top width	Total representative flow
1	✓	✓	✓
2	✓	✓	✓
:	✓	✓	✓
20	✓	✓	✓

Table 4.2 : Cross-section calculation table

- For each cross-section, three sets of straight lines are fitted to the logarithmic flow area (A) and discharge (Q) points (Figure 4.11). Points P_1 and P_2 are found by looking for the largest and second largest change in slope between succeeding (log Q, log A) coordinates. The three sets of α and β-values, together with their "cut-off" areas are stored for later use. The lines are defined by an equation of the form :

$$Q_{REP} = \alpha \, A_{REP}{}^{\beta} \quad (4.24)$$

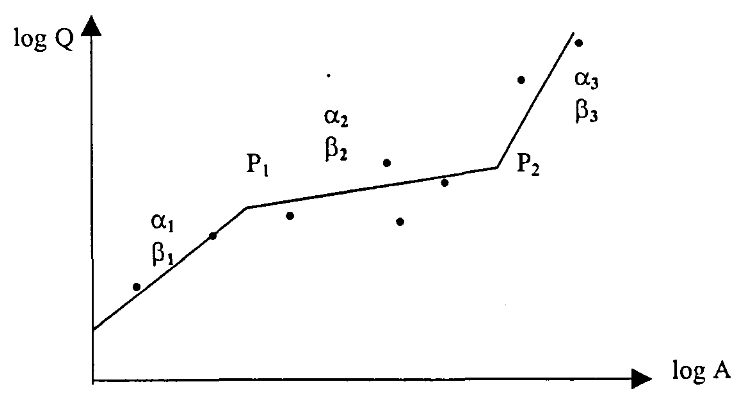


Figure 4.11 : Discharge – Flow Area relationship for a typical cross-section

- Uniformly distributed lateral inflows are discretized into point inflows at finite difference grid points along the reach length (Figure 4.12).

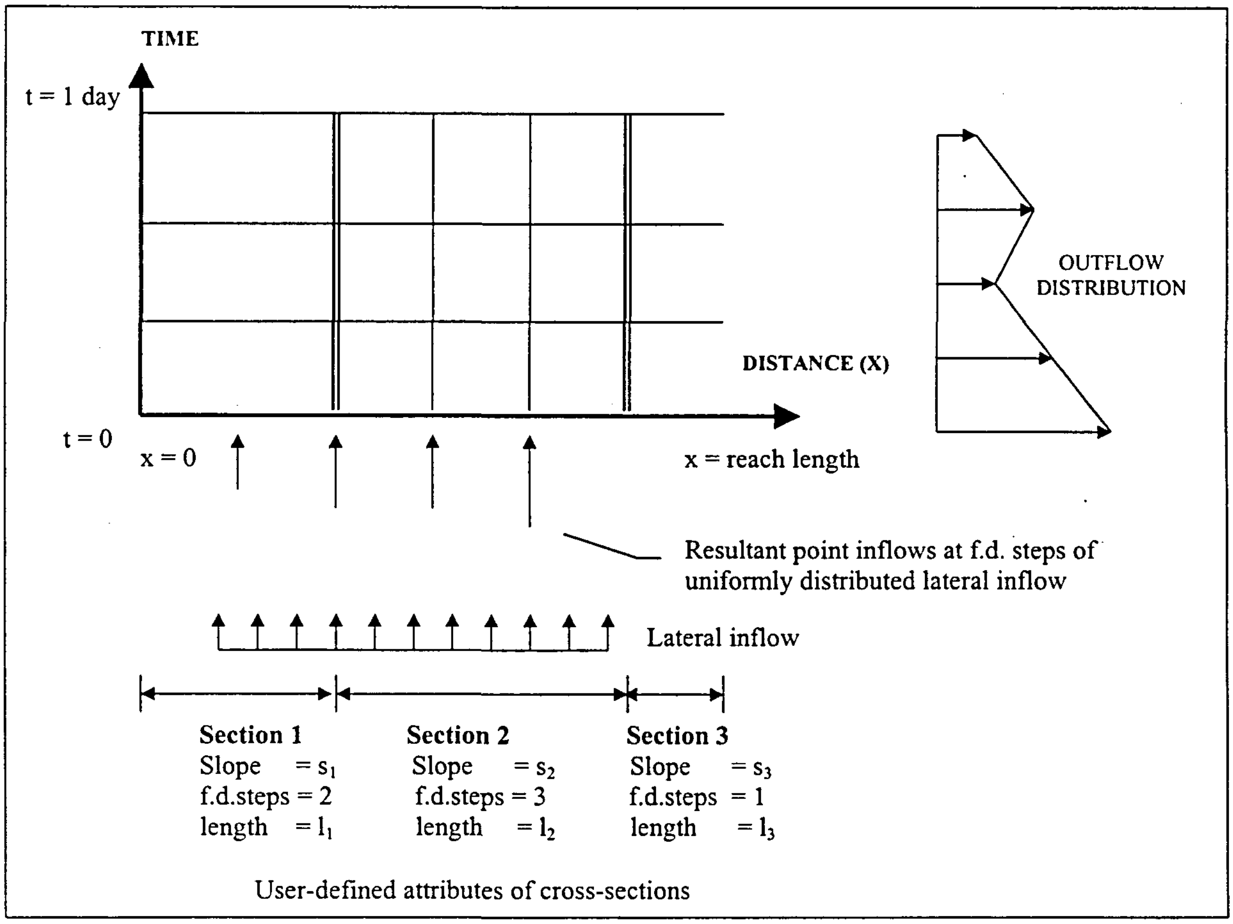


Figure 4.12 : Finite difference grid

- The initial flow for the routing reach (user-defined) is divided into a fixed number of "packets", each with a salt load equivalent to the (user-defined) initial TDS value, in order to set the starting conditions for "salt-stacking".

The upstream inflow to a particular routing reach is distributed according to the upstream routing reach's outflow distribution. If no outflow distribution is available, the inflow is distributed evenly. This sets the boundary conditions for distance (x = 0). The boundary conditions for time (t = 0) are set equal to the flows at the end of the previous day's simulation.

(iv) Calculation Sequence

Once the boundary conditions have been defined, flows at the grid points are calculated in the following sequence:

```
For t = 1 to NoIntervals

    For s = 1 to NoSections

        For v = 1 to NoFiniteDifferenceSteps

        End {v}
    End {s}
End {t}
```

In terms of the finite difference grid defined in Figure 4.12, the calculation sequence is as shown in Figure 4.13.

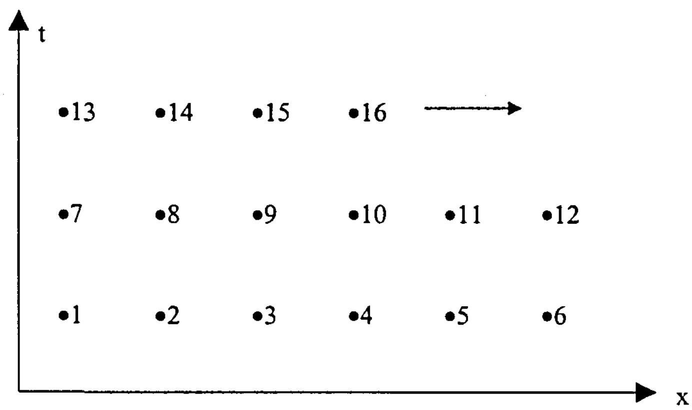


Figure 4.13 : Calculation sequence

The actual calculation is done in the following way:

1. Determine three sets of α and ß for each of the cross-sections in a routing reach.

2. *Begin loop t (time)*

3. *Begin loop s (sections)*
   - Calculate net evaporation by looking up top width corresponding to flow at this section for previous timestep.
   - Calculate "representative" celerity from equation 4.23, by looking up α and β values for the corresponding flow area at this section for the previous time step.
   - Calculate K and θ parameters for this section using representative Q, A and C values.

4. *Begin loop v (finite difference steps)*
   - Define flows from previous loops : Q_1, Q_2 and Q_3.

- Calculate c_{AVE} and Q_{AVE} from equations (4.22) and (4.21) ; Use these values to look up A_{REP} and B_{REP} from cross-section tables.
- Calculate K and Θ from equations (4.19) and (4.20).
- Calculate C_1, C_2, C_3 and C_0 for use in equation 4.18.
- Calculate Q_4 from equation (4.18)

5. *Next v*
6. *Next s*
7. *Next t*

Once all the grid point flows have been determined, the flows along the x-grid at time t = 1 day are stored in a state variable for setting the (x) boundary conditions for the next day's routing. An average daily outflow is calculated for output set no. 1. The outflow distribution is saved as output set no. 2

(v) Salt-stacking

Routing of salt loads through the system is achieved by using a plug-flow ("stacking") algorithm similar to the method used by Herold (1980) for simulating advection through a reservoir.

Only after flow routing for a particular routing reach has been completed for the day, do salt-stacking calculations commence. The salt-stacking calculations are based on the following data arrays, which are either determined at initialisation or during flow routing:

- The number of "packets" and their associated volumes and salt loads present in the reach at the start of the day (state variables).
- An array of sub-daily inflow volumes.
- An array of sub-daily outflow volumes (determined by flow routing).
- An array of sub-daily lateral inflows and net evaporations.
- The daily inflow TDS.

The salt-stacking calculations are done within a time loop at sub-daily time intervals. The following sequence is followed:

1. *begin loop t*

- Calculate volume and salt load of incoming packet, incrementing the number of packets currently in the reach.

- Check if number of packets now in reach exceeds hardwired maximum. If this is the case, packets are combined and mixed, starting from the downstream end of the reach.
- Distribute lateral inflow amongst all of the packets currently in the reach pro-rated to packet volumes.
- Subtract net evaporation volume from packets currently in the reach, again according to individual packet volumes.
- Remove packets from downstream end of the reach with their combined volume equal to the total outflow for this time interval. If necessary, a portion of the last packet to be removed may be used.

2. next t

The average daily outflow TDS is calculated by dividing the total salt load, removed from the reach during the day, by the total daily outflow volume. The number of packets in the reach at the end of the day, as well as the salt loads and volumes of the individual packets are stored in state variables for setting starting conditions for the following day's simulation.

CHAPTER 5. MODEL VERIFICATION

The final stage of model development involved the testing and verification of the model. The following paragraphs address model verification which was carried out for the Breede River and Vaalharts Irrigation systems.

5.1 The Breede River System

5.1.1 Database used for verification

Model verification for the Breede River system was completed in two phases, namely an internal verification and an external verification. Three database years were used, viz. 1985/86, 1986/87 and 1987/88. Two further database years (1988/89 and 1989/90) were compiled for the whole system and implemented in the DISA Database Manager - leading to a five year database. Verification of the model was extended to cover all five years. Due to gaps in either inflowing datasets or downstream datasets the verification on the additional two years could only be partially successful. The extended monitoring programme, which was funded by the Water Research Commission, covered a further database year, namely 1990/91. The original dataset for 1990/91 contained a number of problems, the most notable of which was a downward drift in electrical conductivity (EC) readings, due to progressive under-registration of the reading instrument. Based on laboratory tests of the EC probes in the monitoring, executed by Prof H Moolman of the University of Stellenbosch, the original datasets were adjusted to compensate for the instrument error. This exercise was carried out with limited success, due to uncertainties regarding the exact starting date of under-registration. Due to the concerns about the quality of the data for the 1990/91 database year, model verification was not carried out for this year.

The internal verification was evaluated on the basis of alluvial aquifer behaviour, with the groundwater levels in the alluvial return flow cells used as an indicator of "acceptable" behaviour.

External verification was evaluated according to the following criteria :

- Correlation between observed and simulated flow and salinity time series at weir H4H017 which is situated 34 km downstream of Brandvlei Dam.
- Correlation between observed and calculated time series at weir H5H004, which is situated at the downstream end of the modelled area, 75 km downstream of Brandvlei Dam.

5.1.2 Internal verification

The final configuration of the Breede River system included a total of 35 alluvial return flow cells. The behaviour of each of these cells was investigated.

Groundwater levels in the aquifers behaved as expected, with simulated water levels fluctuating between approximately 300 mm below the surface, and 500 mm above the bottom of the lowest layer. During the final model configuration, it became clear that the apportioning of terrace cell drainage and canal seepage has a significant influence on salt concentrations in the alluvial aquifers. A sensitivity analysis confirmed this and led to the implementation of certain rules, after which the salinity concentrations of alluvial groundwater varied between about 1000 mg/l and 4000 mg/l. Salinity concentrations in a few aquifers were not in equilibrium. In line with the "no calibration" approach, it was decided that overall model performance was not adversely affected by this and that no rectifying measures were required.

5.1.3 External verification

(i) Modelled time series at weir H4H017

Observed and modelled river flow and salinity time series at weir H4H017 for the 1985/86 irrigation season are shown in Figure 5.1. Seasonal trends and magnitudes of river flow were simulated satisfactorily for all three irrigation seasons in the database. However, Figure 5.1 shows that the model over-predicted salinity during the middle part of the 1985/86 irrigation season.

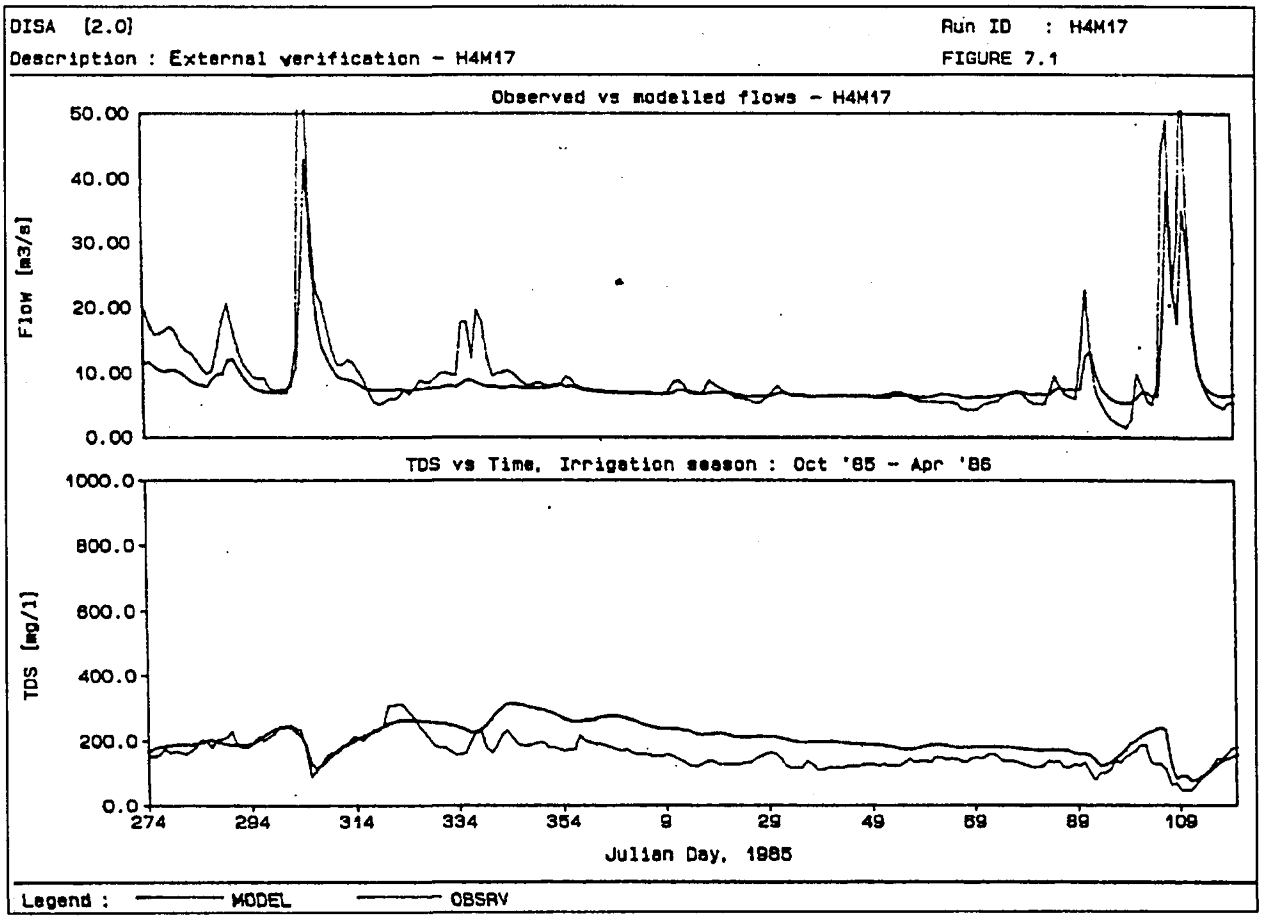


Figure 5.1 : Simulated and observed flow and salinity time series at weir H4H017

(ii) Modelled time series at weir H5H004

Observed and modelled river flow and salinity time series at weir H5H004 for the 1985/86 irrigation season are shown in Figure 5.2. Short duration peak flows caused by local runoff events were not reflected in the modelled time series. This is due to the fact that the return flow sub-model does not cater for overland runoff. Generally however, seasonal trends in river flows and salinities were predicted accurately for all three irrigation seasons in the database.

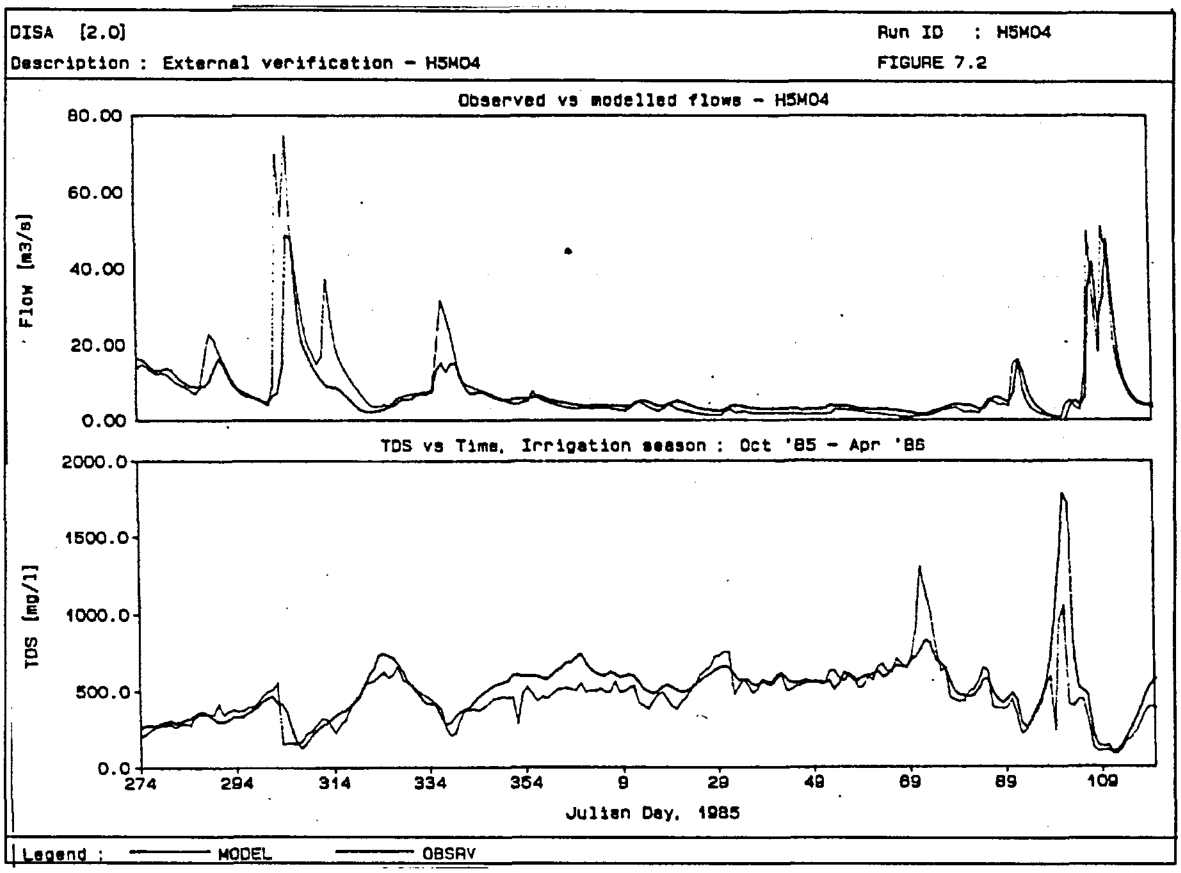


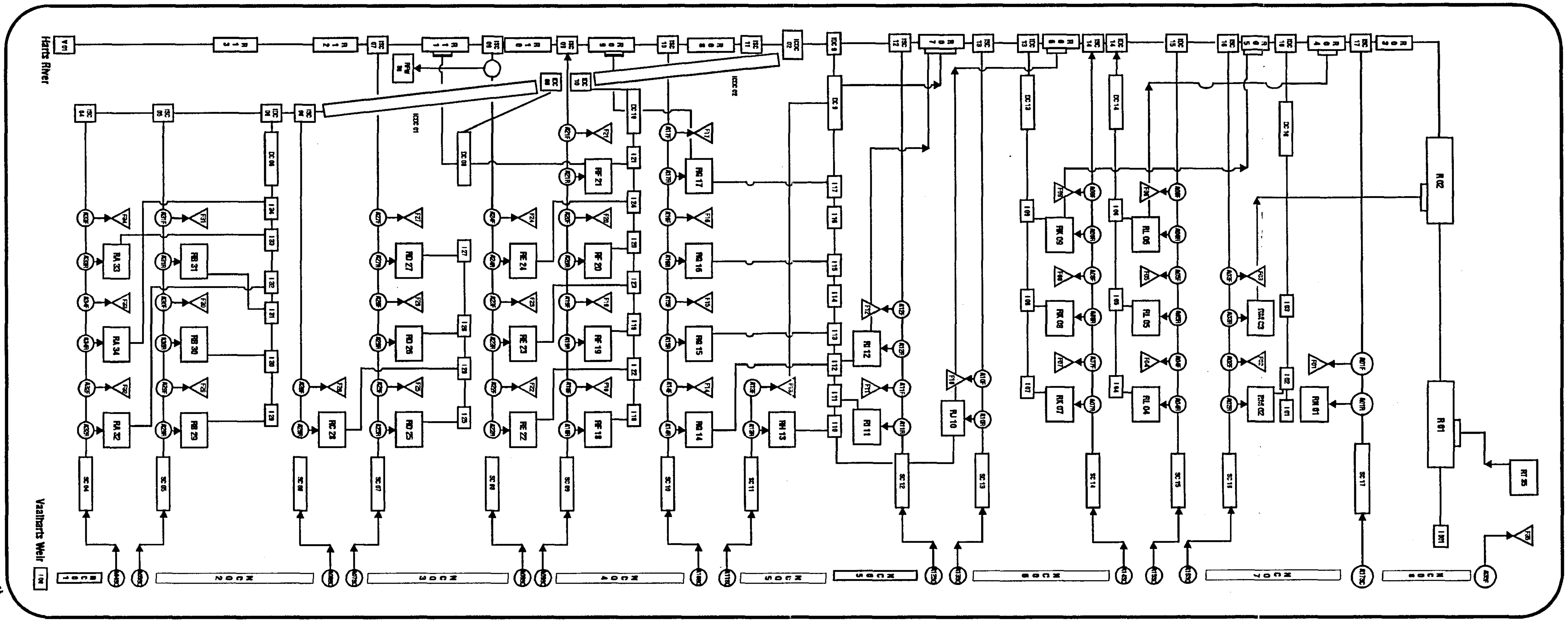
Figure 5.2 : Simulated and observed flow and salinity time series at weir H5M04

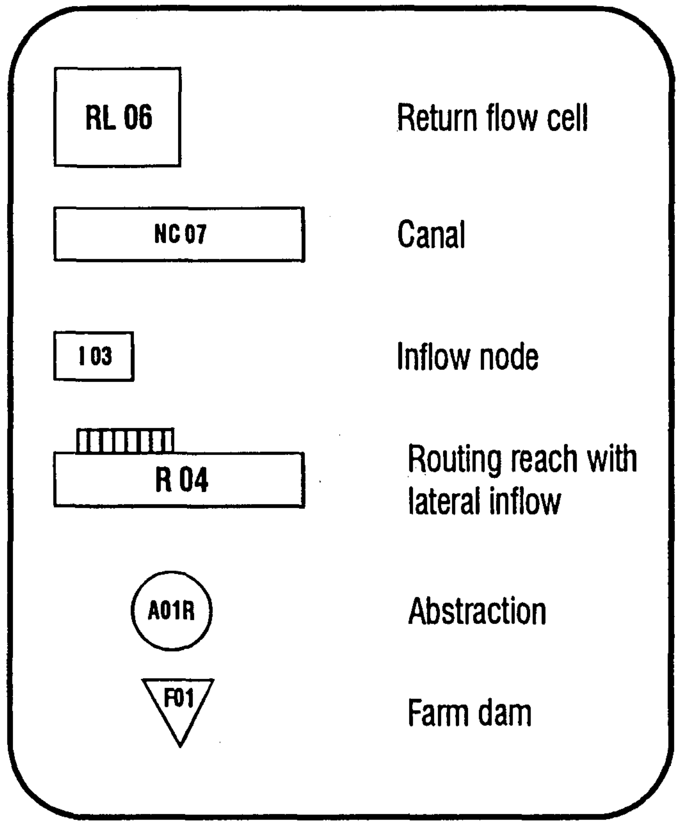
5.2 The Vaalharts Irrigation System

During 1995, as part of the refinement process, the DISA model was applied to the Vaalharts Irrigation system (Figure 5.3). This was done to evaluate the applicability of DISA to an irrigation system situated in a summer rainfall region, as well as to evaluate the performance of various additional processes incorporated into DISA, e.g. surface runoff, artificial drainage and deep percolation.

Only an external verification was completed. A period of five seasons was considered, ranging from October 1988 to April 1991. These included three summer and two winter seasons. Observed and modelled river flow and salinity time series for one of the irrigation seasons, at weir C3H007 at the downstream end of the system, are shown in Figure 5.4.

Overall, the time series and percentile curves indicated that during certain months, DISA underestimated the salt concentrations, while simultaneously overestimating flow. Various possibilities were subsequently considered to explain this phenomenon, including an incorrect Deep Percolation Factor or the incorrect simulation of artificial drainage. However, it was finally concluded that the phenomenon may be attributed to the fact that the simulated volume of tailwater (water which is not abstracted from the canal system for irrigation), which enters the Harts River, is too high. As this water is relatively fresh, it leads to low TDS concentrations and the accompanying over-estimation in river flow. This was caused by incorrect monthly abstraction volumes for irrigation. The situation was remedied by modification of the monthly distribution of irrigation supply. This led to a much better fit between observed and simulated flows and especially salinities.





System Diagram of DISA Configuration of Vaalharts Irrigation Scheme

Figure 5.3 : Configuration diagram for the Vaalharts System

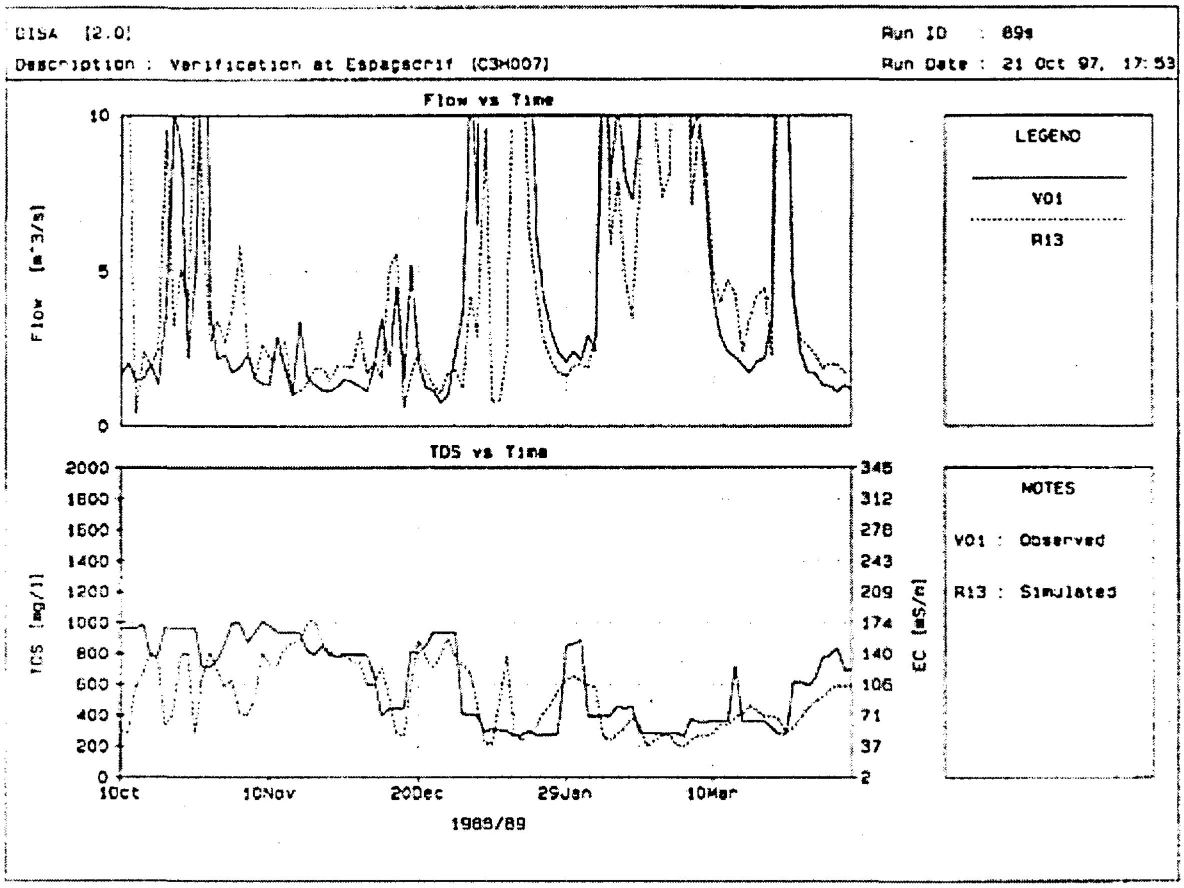


Figure 5.4 : Simulated and observed flow and salinity time series at weir C3H007

CHAPTER 6. SENSITIVITY ANALYSES

6.1 Introduction

A modelling approach which is physically based and highly detailed in terms of model structure, is extremely data demanding. Where sound data is not available from field observations or theoretical knowledge, those model components which are affected should be subjected to well designed sensitivity tests.

The DISA model was subjected to two series of sensitivity analyses performed during different stages of the model development. Five model components for which inadequate or no field data existed, were identified during the verification phase of model development. The need for sensitivity testing of a further five model components came to the fore during model application to a planning study for the Breede River System. The full set of components which were tested are :

(i) The distribution of canal seepage between irrigated and non-irrigated alluvial soils.
(ii) The portion of groundwater outflow from terrace cells which is drained either by artificial means (surface ditches or pipes) or by natural collectors.
(iii) Capillary fringe depths associated with the various soil texture classes.
(iv) The Dry Evaporation Factor which expresses evaporation from bare soil as a fraction of A-Pan evaporation.
(v) Evaporation depths associated with the various soil texture classes.
(vi) The reduction of canal seepage due to riparian vegetation growing along the canal system.
(vii) The sensitivity of model response to a change in soil texture classes assumed for the return flow cells.
(viii) The rate of aquifer recharge to the main river channel.
(ix) The sensitivity of model response to a change in the estimated soil profile depths.
(x) The performance of the model when model runs are extended over more than one irrigation season.

6.2 Test Scenarios

Table 6.1 summarises the test scenarios designed to test model responses to variations in the model components listed above. The sensitivity analyses were conducted on the Breede River system.

	Component		Scenario
(1)	Canal seepage	(a) (b) (c)	100% seepage through irrigated soils 100% seepage through non-irrigated soils seepage "lost" from the system
(2)	Terrace cell drainage	(a) (b) (c)	100% drained to alluvial cells 100% drained directly to river Terrace cell outflow "lost" from system
(3)	Capillary fringe depth	(a) (b) (c)	"best estimate" (a) increased by 50% (a) increased by 100%
(4)	Evaporation depth	(a) (b) (c)	"best estimate" (a) increased by 50% (a) increased by 100%
(5)	Dry evaporation factor	(a) (b) (c)	0.2 times A-Pan evaporation 0.4 times A-Pan evaporation 0.6 times A-Pan evaporation
(6)	Canal riparian vegetation	(a) (b)	no riparian vegetation 10 m wide strip of riparian vegetation along canals
(7)	Soil texture class	(a) (b)	"best estimate" all soil texture classes set to one class coarser
(8)	Aquifer recharge rate	(a) (b)	"best estimate" (a) reduced by 60%
(9)	Soil profile depth	(a) (b)	"best estimate" (a) increased by 20%
(10)	Multi-season run	(a) (b)	single season run (1987/88) three season run (1985/86 - 1987/88)

Table 6.1 : Sensitivity test scenarios

In order to assess model response to the scenarios outlined in Table 6.1, the return flow sub-model behaviour (internal) and model response at the downstream end of the modelled area (external) were monitored.

Internal model response was evaluated by monitoring changes in the groundwater levels of four representative alluvial return flow cells, namely :

- a large bank cell (delivering diffuse outflow to the river) ;
- a small bank cell ;
- a large tributary cell (delivering point outflow to the river) ;
- a small tributary cell.

External model behaviour was assessed according to changes in modelled outflows and associated salinities at Zanddrift Weir (72 km downstream of Brandvlei Dam).

The results of the sensitivity analyses are presented in the form of flow and salinity time series at Zanddrift Weir (external). Groundwater and salinity time series for return flow cells (internal), are shown only when a point needs to be illustrated.

6.3 Results and Conclusions

Terrace cell drainage to alluvial cells was eliminated completely during the analysis of scenarios (1) (a) to (c); likewise, canal seepage to alluvial cells was eliminated for scenarios (2) (a) to (c). Scenarios (1)(c) and (2)(c) therefore represented the same situation and could be used as "reference" configurations.

6.3.1 Canal seepage

Figure 6.1 shows the modelled time series at Zanddrift Weir for scenarios (1) (a) to (c). It can be seen that an increase in salinity (20 mg/l TDS on average) occurs when all canal seepage is routed through the irrigated areas as opposed to the non-irrigated areas. This can be ascribed to the fact that groundwater flow through the non-irrigated areas is not subject to capillaric rise and crop water usage. Consequently, retention time is short and the concentrating effect of evaporation minimal.

The small and large bank cells were completely saturated for most of the irrigation season when all canal seepage was routed through the irrigated areas. Tributary cells were relatively insensitive to an increase in canal seepage through the irrigated soil profile. Possible reasons for the difference in response between bank and tributary cells are :

- During the model configuration process, it was found that aquifer widths for tributary cells (alluvial return flow cells delivering point inflows to the river), could be determined with reasonable accuracy from 1:50 000 maps. This was possible due to the fact that artificial drainage lengths in tributary catchments are short in comparison to natural collector lengths. The opposite is true for bank cells and it was suspected that aquifer widths determined for these cells could be too long.
- As a rule, the ratio of canal length/irrigated area is larger for bank cells than for tributary cells.
- The ratio of aquifer width/irrigated area is larger for bank cells than for tributary cells. This results in a slower rate of outflow per unit area from bank cells.

Scenarios (1)(a) and (b) represent two extreme cases with reality to be found somewhere in between. It was decided to implement a simple "rule-of-thumb" for determining the distribution of canal seepage on the alluvial cells by apportioning the seepage according to the ratio between irrigated and non-irrigated areas.

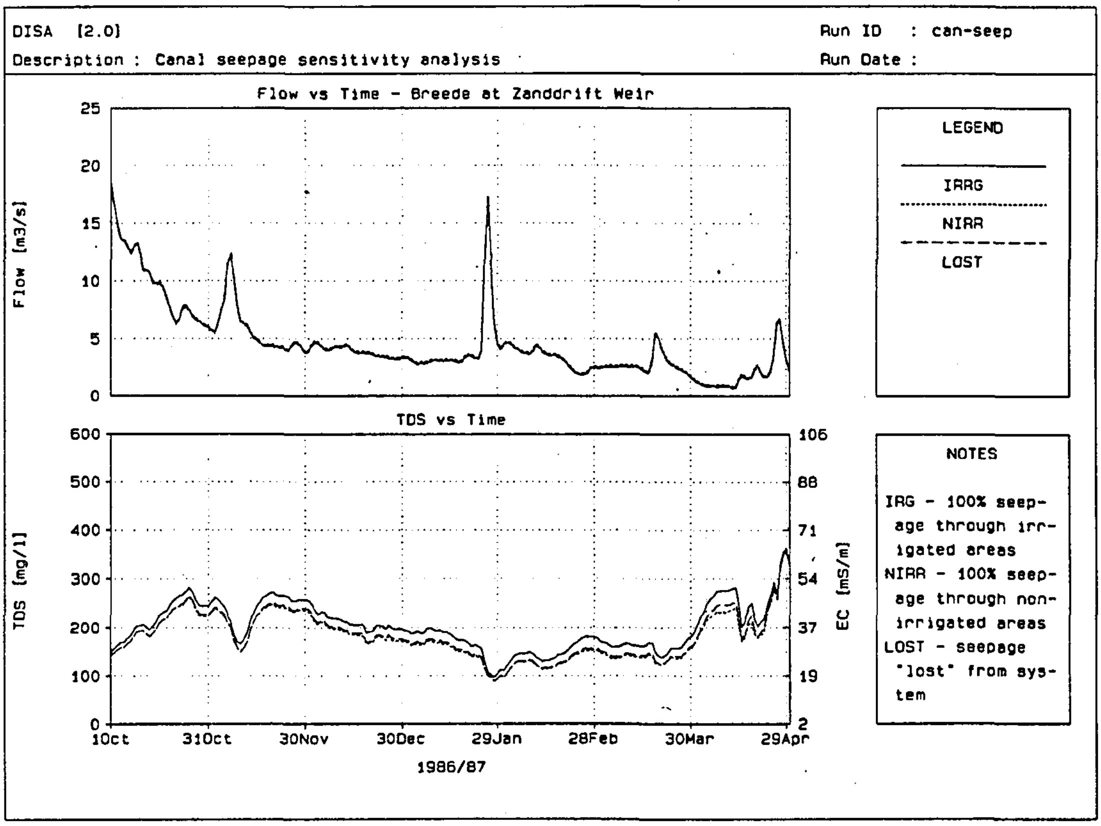


Figure 6.1 : Sensitivity analysis : canal seepage

6.3.2 Terrace cell drainage

Figure 6.2 shows the modelled percentile curves at Zanddrift Weir for scenarios (2)(a) to (c). As can be expected, a significant increase in salinity (42 mg/l TDS on average) occurs when terrace cell outflow is routed through the alluvial cells instead of delivering outflow to the river.

The groundwater levels in bank cells were more responsive to scenario (2)(a) than those of the tributary cells. Inspection of the representative cells indicated that the size of alluvial irrigated areas, relative to the terrace irrigated areas, determined whether saturation problems could be expected.

In order to quantify the apportionment of terrace cell outflows, surface drainage areas within a number of representative return flow cells were delineated on 1:50 000 soil maps. The portion of surface area draining directly to the river within a given terrace cell was found to be larger for bank cells (approximately 80%) than for tributary cells (approximately 60%). No distinction was made between irrigated and non-irrigated areas, accordingly the ratios were taken as upper limits associated with full irrigation development.

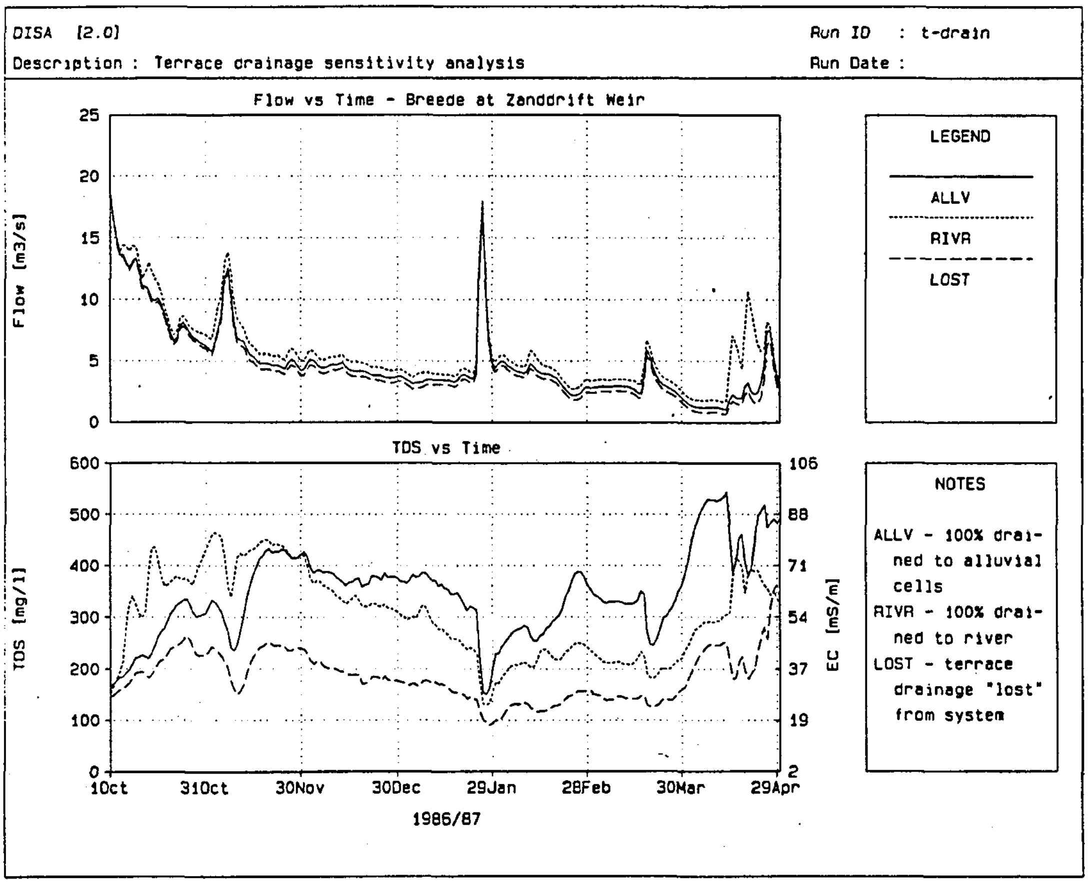


Figure 6.2 : Sensitivity analysis : terrace cell drainage

6.3.3 Capillary fringe depths

Figure 6.3 indicates a slight decrease in average salinity during the middle part of the irrigation season with an increase in capillary fringe depths for the various soil texture classes. (Scenarios (3)(a) to (c)). This is due to the fact that more groundwater is exposed to evaporation and crop water use, resulting in a higher salinity in the groundwater and lower groundwater levels. The resultant effect is a smaller saltload being delivered to the river.

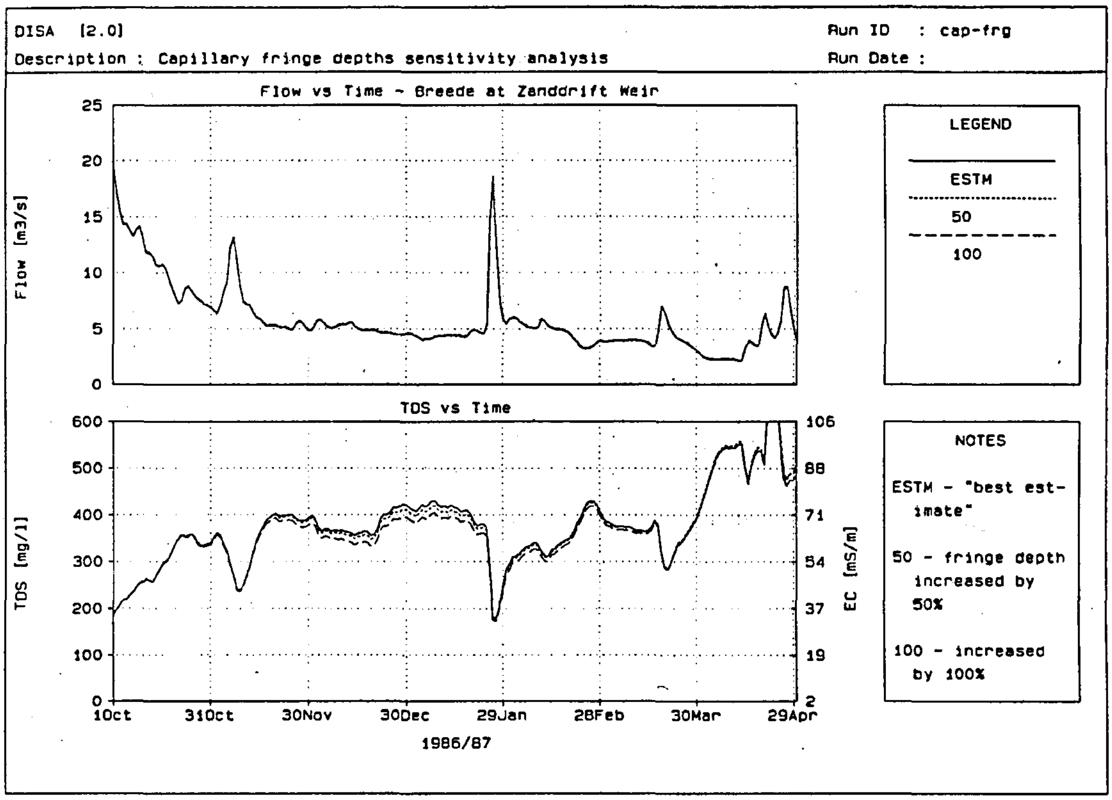


Figure 6.3 : Sensitivity analysis : capillary fringe depths

6.3.4 Evaporation depths

Figure 6.4 indicates that model response at Zanddrift Weir is relatively insensitive with regard to changes in evaporation depths for the various soil texture classes, (scenarios (4)(a) to (c)). Inspection of groundwater levels and associated salinities in the return flow cells confirmed this observation.

No justification was found for adjusting the evaporation depths.

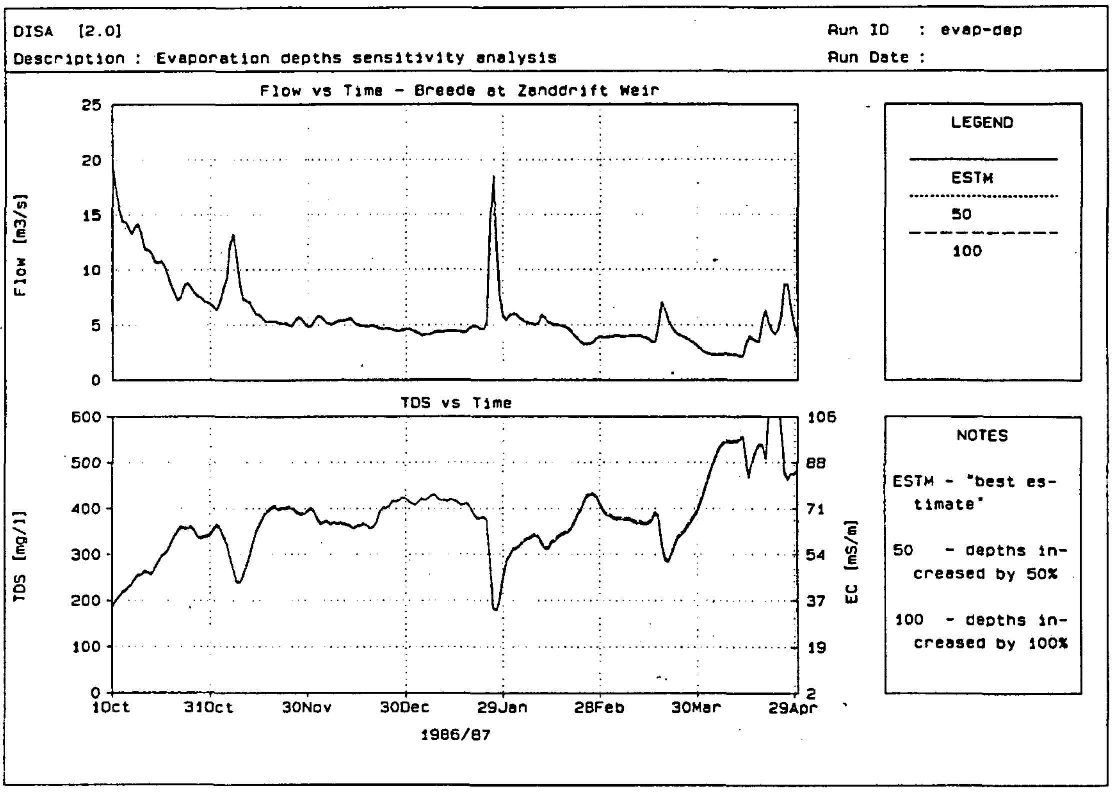


Figure 6.4 : Sensitivity analysis : evaporation depths

6.3.5 Dry evaporation factor

Figure 6.5 shows groundwater level and salinity time series for one of the four representative alluvial return flow cells, (scenarios (5)(a) to (c)).

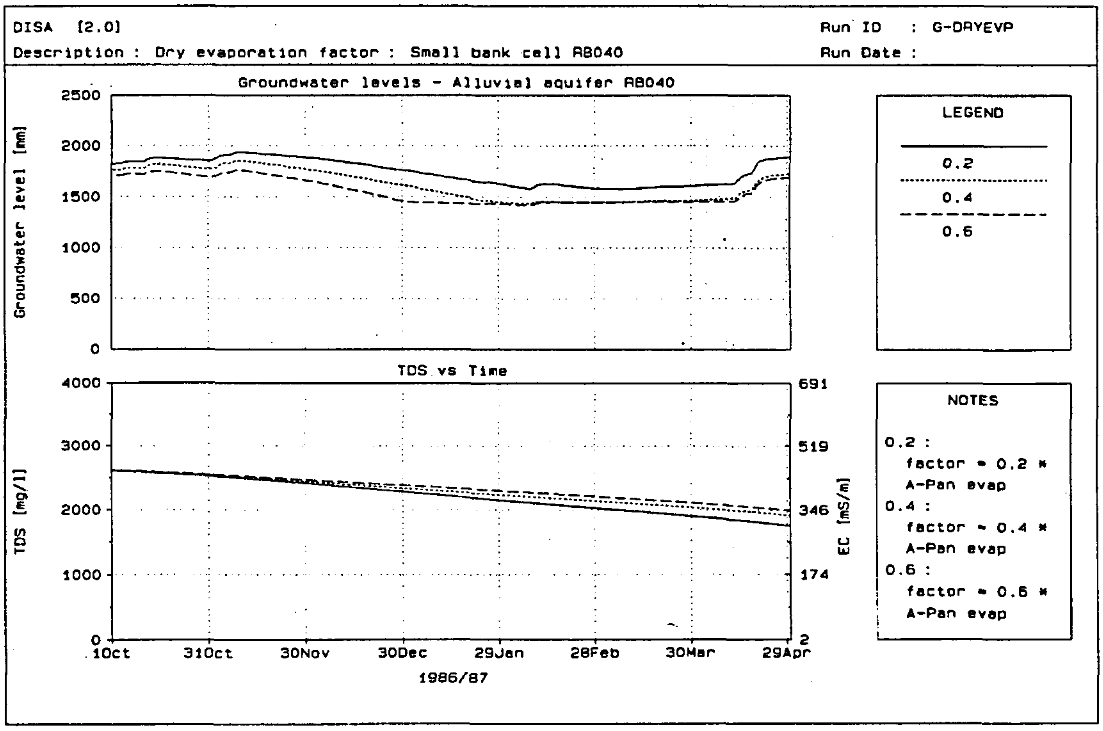


Figure 6.5 : Sensitivity analysis : dry evaporation factor (return flows)

As expected, using a higher dry evaporation factor resulted in increased groundwater salinities and lower groundwater levels. It can also be seen that for this alluvial aquifer (a small bank cell), salinity concentrations are not in equilibrium and the aquifers tends to leach during the course of an irrigation season. However, the situation as depicted in Figure 6.5, represents the interim configuration used for the first series of sensitivity tests.

Figure 6.6 shows that in spite of an increase in groundwater salinity, average river salinity decreases due to the reduction of saltload delivered from the alluvial aquifers.

A dry evaporation factor of 0.4 was used for final model configuration.

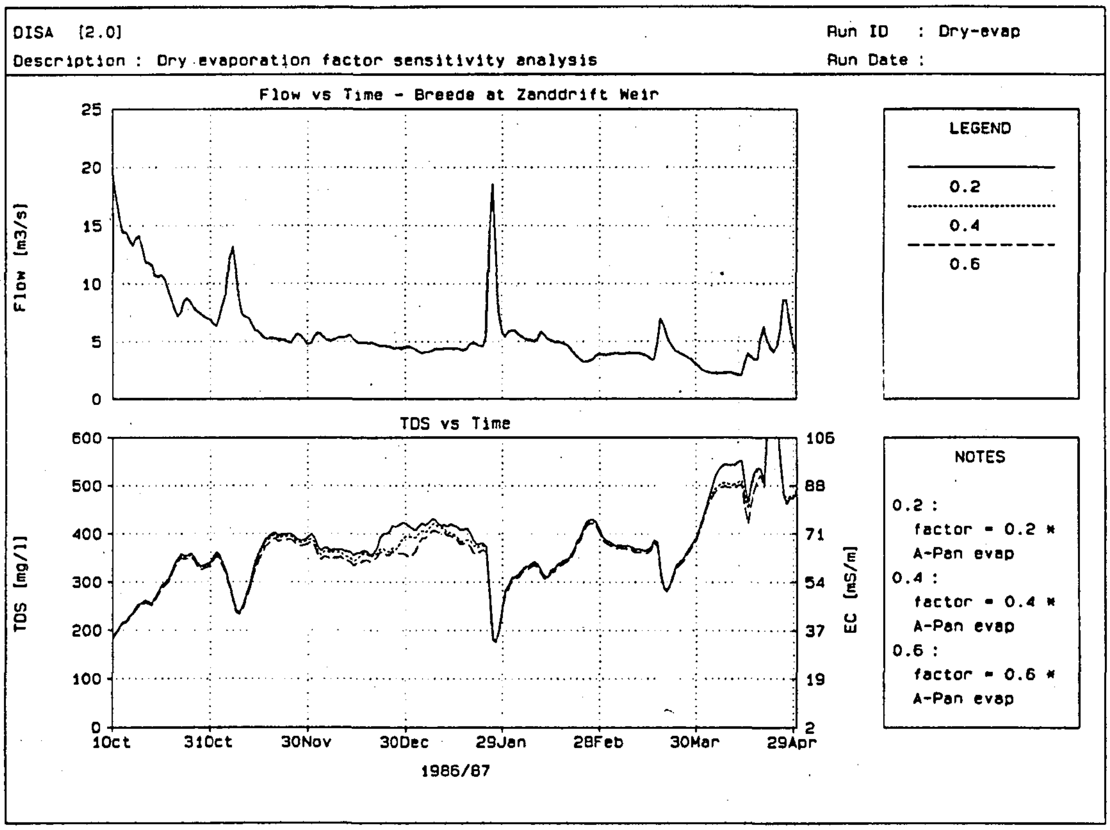


Figure 6.6 : Sensitivity analysis : dry evaporation factor (streamflow salinity)

6.3.6 Canal riparian vegetation

Evaluation of scenarios (6) (a) and (b) showed that model response at the downstream end of the modelled area is virtually insensitive to the relatively small reduction in canal seepage volumes affected by canal riparian vegetation water use. However, the canal sub-model was modified to provide for a user-defined riparian vegetation width along canals, as small changes in the groundwater behaviour of adjacent alluvial cells could conceivably be of interest if the DISA model is applied to a different study area.

6.3.7 Soil texture class

The "best estimate" configuration of soil texture classes of the return flow cells were based on soils investigations carried out by the Hydrological Research Institute between 1987 and 1989 (Flügel, Parsons, 1990). Soil moisture retention constants as defined for South African soil texture classes in the ACRU model (Schulze, 1984), were used for model runs. Table 6.2 summarizes scenarios (7) (a) and (b). Soil texture classes for scenario (b) are one class "coarser" than those for scenario (a) (the "best estimate" configuration).

Return flow cell	Layer	Soil texture class Scenario (a)	Scenario (b)
Alluvium	1 to 8	Loamy Sand	Sand
Terrace	1 to 3	Loam	Sandy Loam
	4 to 6	Sandy Clay	Clay Loam

Table 6.2 Soil texture class sensitivity analysis

Figure 6.7 shows marginally higher flows at Zanddrift weir during periods of low flows for Scenario (7)(b) than that simulated under scenario (a). This can be ascribed to the shorter water retention time (and consequently, less evaporation), associated with the more porous, coarser soil texture classes. The effect of a shorter retention time can also be seen in the salinity time series, where the unseasonal flood during October produces a marked increase in main river salinity, compared with the finer texture class scenario.

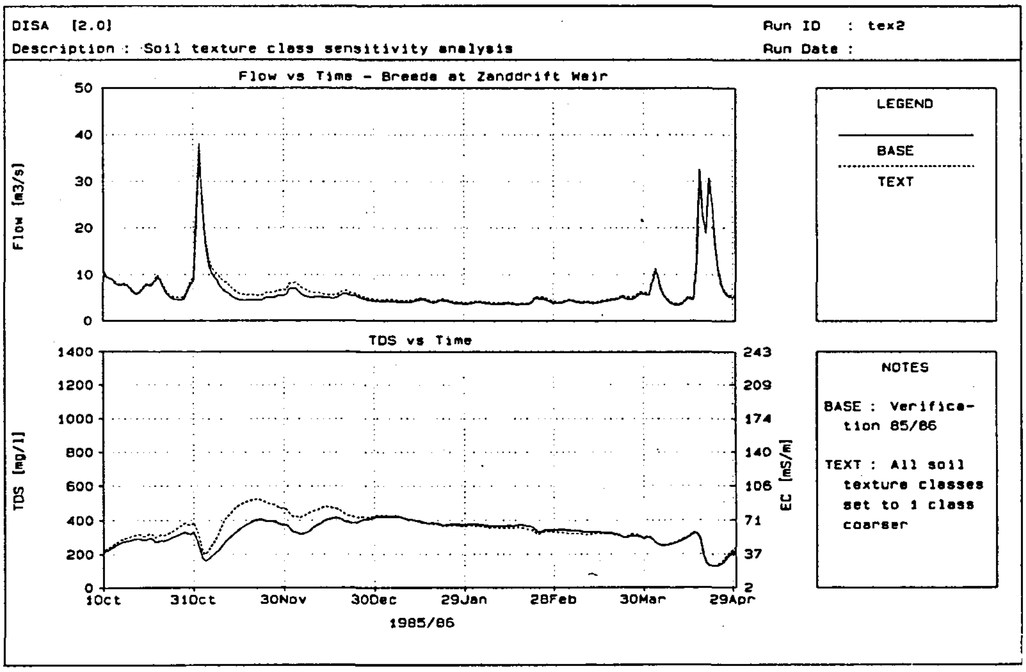


Figure 6.7 : Sensitivity analysis : soil texture class

6.3.8 Aquifer recharge rate

Saline groundwater seepage from the fractured bedrock aquifer is represented in the model by lateral inflows to the routing reaches in the main river channel.

During configuration of the model, the seepage from fractured bedrock underlying the modelled area to the main river channel was estimated at about 1120 m^3/km/day (Jolly, 1990). Subsequently, a second estimate, based on a mass balance of the portion of the system between H4M17 and H5M04, resulted in a figure of about 453 m^3/km/day, or 60% less than the first estimate (Kirchner, 1992). Scenarios (8)(a) and (b) were designed to test the relative effect of these two estimates. The salinity concentrations of the alluvial recharge were kept the same for both scenarios, as no second estimate was available. Figure 6.8 shows that, as can be expected, an average reduction of about 0.6 m^3/s in flow rate is simulated at Zanddrift weir for scenario (b). As the salinity of the aquifer recharge was the same in both cases, the salt load reaching the main river is reduced in the case of scenario (b), resulting in marginally lower TDS at Zanddrift Weir.

Due to the inherent uncertainties associated with both estimates, it was decided to retain the more conservative estimate simulated as scenario (a).

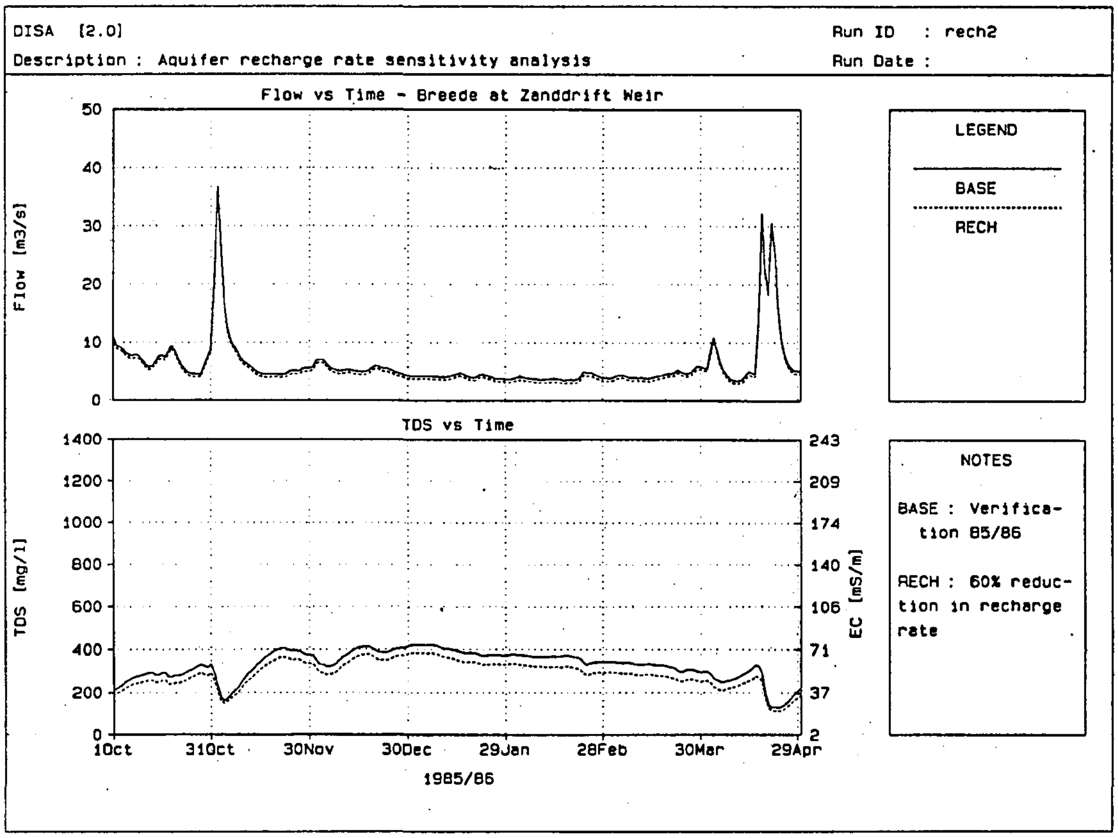


Figure 6.8 : Sensitivity analysis : aquifer recharge rate

6.3.9 Soil profile depths

During the model verification phase of model development, return flow cell soil depths were estimated at about 2.4 m and 1.8 m for alluvial and terrace cells, respectively. In order to test model sensitivity to this estimate, scenario (9) (b) was configured with all soil profile depths increased by an arbitrary 20%. Figure 6.9 shows that marginally higher salinities are simulated at Zanddrift weir during periods of low flow. This is possibly due to a combination of a larger available salt reservoir and relatively higher hydraulic heads in the groundwater bodies of the deeper soils. On the whole, external model behaviour seems to be relatively insensitive to a 20% increase in soil profile depth.

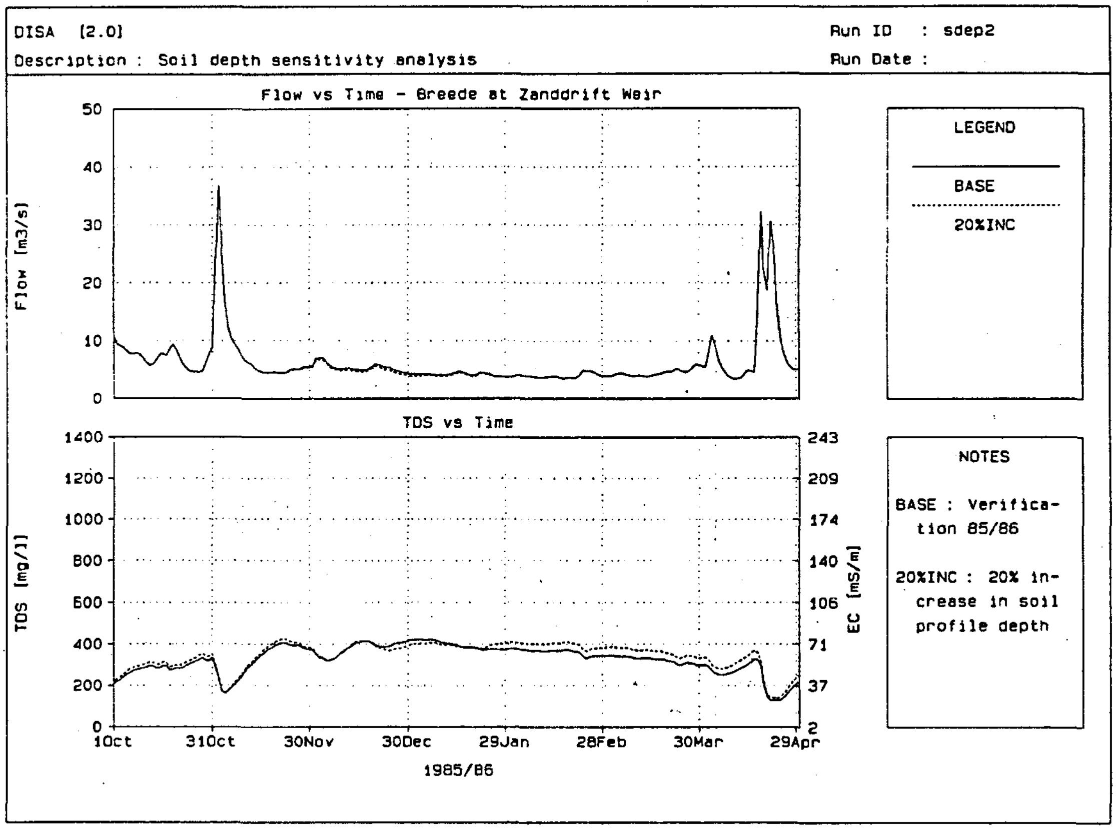


Figure 6.9 : Sensitivity analysis : soil profile depths

6.3.10 Multi-season simulation

The DISA model is intended for single irrigation season modelling. In order to determine the effect of multi-season simulations, a number of considerations needed to be addressed. In order to investigate these aspects, the results of a continuous multi-season run (1985/86 to 1987/88) were compared to those of a conventional single season run (1987/88).

From Figure 6.10, it can be seen that flows at Zanddrift weir for the two scenarios differ slightly during the first part of the irrigation season, probably due to a residual effect of the preceding winter. Salinities during the final irrigation season (1987/88) are markedly lower in the case of the multi-season run.

If the model were to be used for multi-season simulations, it is clear that the leaching effect of winter rains needs to be counter-balanced by a mechanism which replenishes the salt reservoir in the groundwater bodies prior to the start of an irrigation season. The sensitivity analysis was performed in the absence of a surface runoff component in the model. However, it did not unduly affect flow predictions during the irrigation season. (Note that a surface runoff sub-model has since been incorporated in DISA) (see Section 4.3).

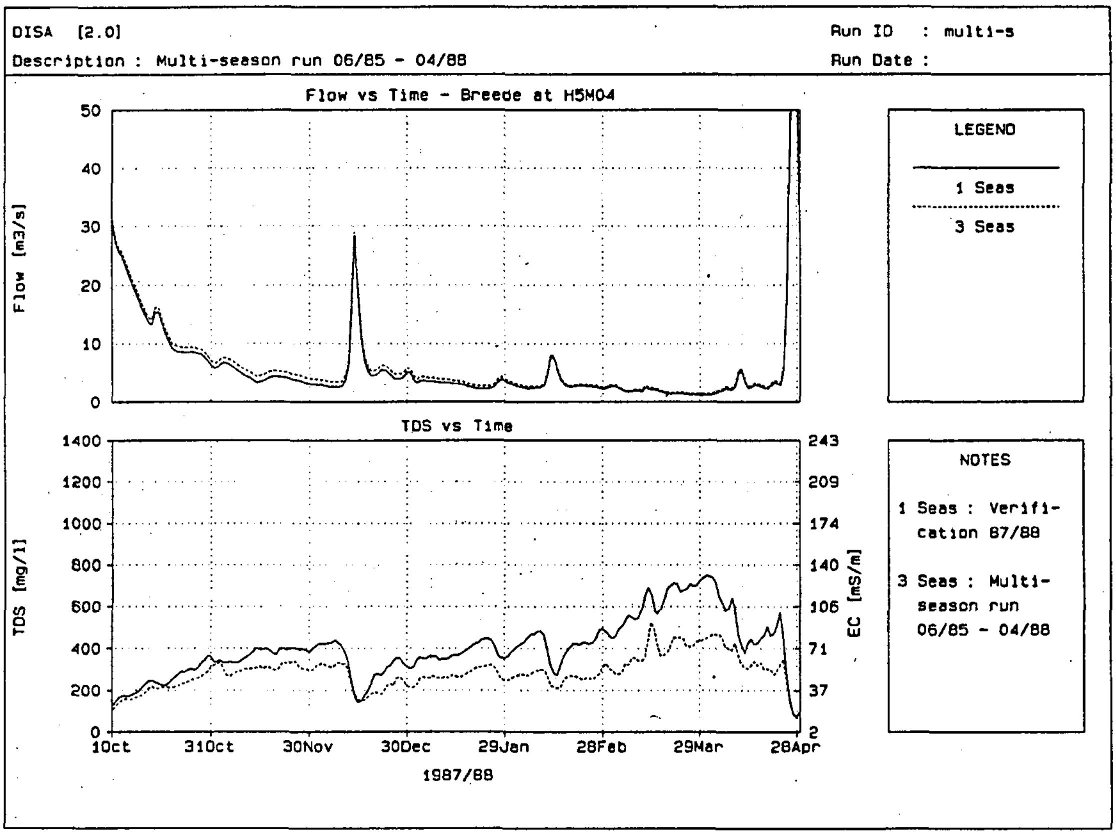


Figure 6.10 : Sensitivity analysis : multi-season simulation

CHAPTER 7. DISCUSSIONS AND CONCLUSIONS

The DISA model provides a useful tool for anticipating the effect of various irrigation and operational planning scenarios on river salinity because it allows a detailed representation of the irrigation scheme without excessive soil data requirements. This report describes the development of the DISA model in terms of model structure and characteristics as well as the main process routines incorporated into the model. The model was verified on both the Breede and Vaalharts Irrigation systems, while sensitivity analyses were performed to test model response to variations in several model components.

The principal conclusions that have been reached during model development and the subsequent verification thereof, are :

- The modelling approach, whereby the catchment is discretized into a number of homogeneous units and return flow cells, which is overlain by a water distribution network, allows a relatively flexible configuration of an irrigation system.
- The structure of the model, which consists of the database manager, system configurator, system model and the model output component, provides a structured framework for model application.
- Due to the no-calibration approach which was adhered to, the DISA model requires detailed and extensive data on irrigation applications and on unused abstracted water. During model verification it was evident that a lack of detailed data regarding certain aspects of system configuration, leads to inaccuracies in the model output. Further critical data requirements include crop type and irrigated area.
- The process routines which simulate the delivery of water and salts to the irrigated areas as well as root zone and delivery zone processes within the irrigated soil profile, provide a realistic representation of actual water and salt movement. This was confirmed during model verification for both the Breede and Vaalharts Irrigation systems, when seasonal trends in river flow and salinity were accurately predicted.
- Although a preliminary salt generation function was developed, it still requires further refinement to accurately predict dynamic salinity-related soil processes.

CHAPTER 8. RECOMMENDATION FOR FURTHER RESEARCH

During verification of the DISA model, it became clear that further improvements could be made to either facilitate its application or improve its accuracy. These improvements include :

- Changing the system configurator so that it will not be necessary to set up a different parameter file for each season when successive irrigation seasons are modelled and only the crop types and irrigation supply varies.
- Developing a salt generation function which will allow the accurate simulation of dynamic salinity-related soil processes such as weathering, dissolution or deposition and as such, replenish the salt reservoir in the groundwater body.
- Allowing for seepage in any direction between adjacent alluvial return flow cells, based on the difference in groundwater levels. (Presently, seepage is always in the direction of the river, irrespective of groundwater levels.)
- The development of a GIS-based interface for the model to allow the spatial input data to be easily manipulated and verified. (This aspect was addressed during a project by the Institute for Geographical Analysis at the University of Stellenbosch (Wolff-Piggot, 1994)).

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APPENDIX 1

DISA User's Guide

THE DISA USER'S GUIDE

1. INTRODUCTION

The DISA model consists of a fully interactive suite of programs designed to predict the impact of irrigation expansion on river flow and salinity.

This document comprises the User's Guide of the program suite. Further background information can be obtained by reading the Model Development Report (Department of Water Affairs, Report No. H 000/00/0790).

Sections included in the Guide are as follows :

General Overview of the model describes the model structure and defines program conventions.

Getting Started describes the procedure for installing and using the programs.

Important Concepts provides information required for effective program operation.

The **Database Manager, System Configurator, System Model** and **Output Manager** sections provide detailed instructions on the use of the four main components of the model suite. program operation is illustrated by making use of a series of example menus and input screens.

2. GENERAL OVERVIEW

2.1 MODEL COMPONENTS

Figure 2.1 shows a schematic representation of the model suite. The model consists of four main components :

(a) The **Database Manager** controls and manages the system database which contains all the time series data required for a model run.

(b) The **System Configurator** controls, on a menu-driven basis, all aspects of system configuration, including modelling node type, node sequencing, selection of nodes for producing graphical and numeric output, system layout, and process parameters. It produces a system description which is saved as a configuration file for use by the model at run-time.

(c) The **System Model** uses the time series database and the system description to perform model runs. Simulations are based on a daily time step. The whole system is simulated for one time step before proceeding to the next time step.

(d) The **Output Manager** presents graphical output in the form of flow and salinity time series and duration curves.

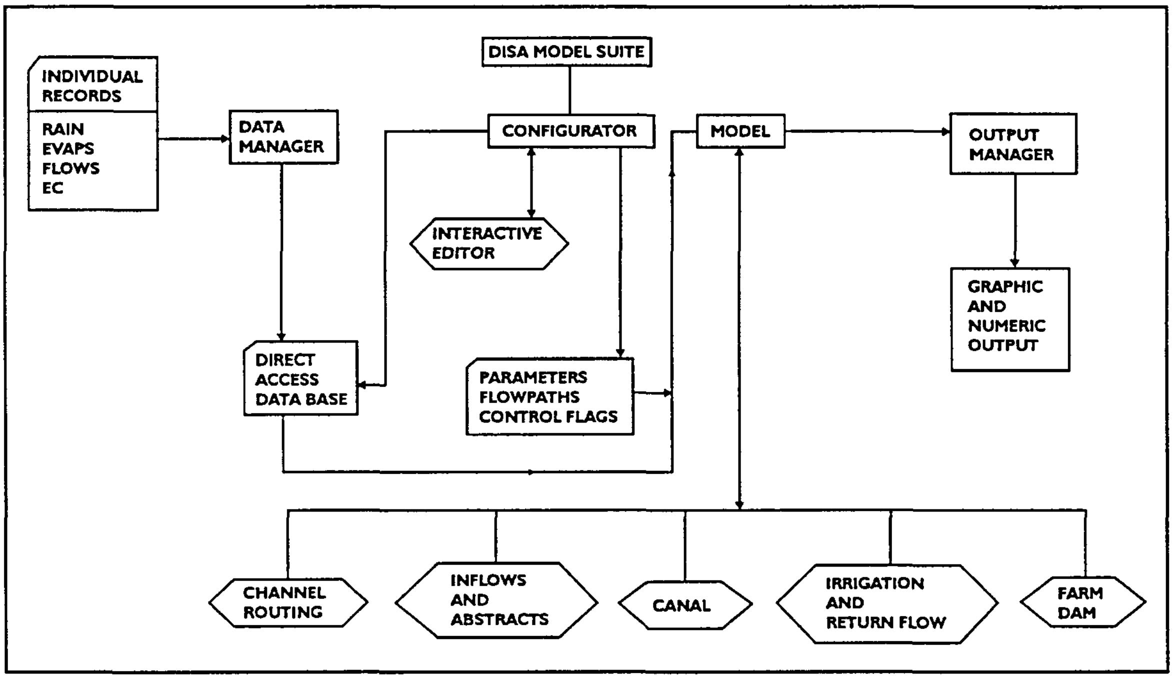


Figure 2.1 : Simplified schematic of the DISA model suite

2.2 MENU AND INPUT SCREEN OPERATION AND CONVENTIONS

The four model components are completely interactive and accept user input through structured menus and a number of input screens.

Program menus (such as the one shown in Figure 2.2), allow you to select the task which you wish the program to perform.

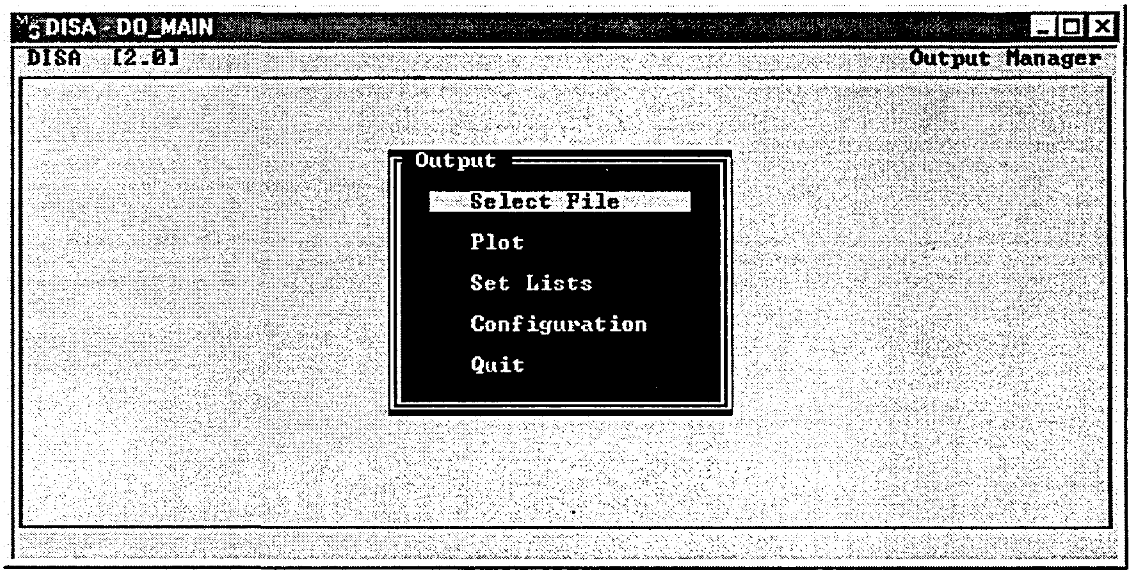


Figure 2.2 : Example menu

To select a task from a menu, use the cursor keys to highlight the option you wish to execute and press the <ENTER> key. Each of the items on the menu contains a highlighted letter. Typing this letter is an alternative way of selecting an option. After a menu task has been selected, an input screen or next level menu will appear on the screen.

Pressing <ESC> at any stage will cause the program to step back to the previous screen/ menu.

Data entry to an input screen is achieved by moving the highlighted block over the field you want to change, and entering the new value.

Editing is undertaken in a similar manner to many popular spreadsheet programs. Existing data entries can be edited by pressing **<F2>** while the appropriate entry is highlighted. The **<Del>**, **<Ins>** and **<Backspace>** keys can be used to assist editing. Pressing <ESC> leaves the entry unchanged. An example input screen is shown in Figure 2.3.

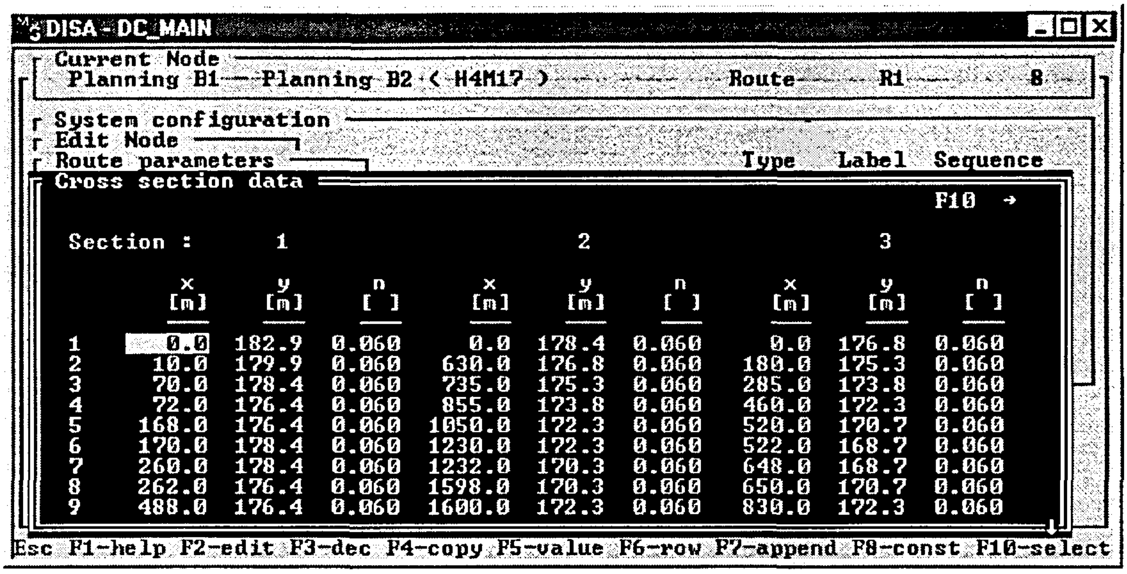


Figure 2.3 : Example input screen

2.3 LOADING INPUT FILES

The loading of input files is identical for each of the four model components. This is achieved by using the **Select File** input screens. The sequence of steps are as follows :

(a) You will first be prompted for a file search path. Enter the directory path where the required input file can be found.

(b) Enter the file name (with extension) in the file name entry field. Alternatively, you may specify a file"mask" by using DOS wildcards. This will enable you to select an input file from a list of files that match the specified mask. For example, if you specified the file name as "***.par**", a directory window containing all the file names with "**.par**" extensions will appear on the screen.

(c) Use the **<Up>**, **<Down>**, **<Left>** and **<Right>** cursor keys to move the highlighted block over the file name which you wish to select.

(d) Press **<ENTER>** to read the file into memory.

3. GETTING STARTED

In order to install and use DISA, you should be familiar with the basics of operating an IBM PC (or compatible) under MS-DOS. You will need to know how to create directories and navigate between them, how to copy and delete files and how to use other basic DOS commands.

3.1 HARDWARE REQUIREMENTS

DISA will run on any IBM PC compatible personal computer with a minimum of 640 kB RAM and a hard disk with MS-DOS 3.0 or later.

3.2 INSTALLATION PROCEDURE

3.2.1 File and Directory Organisation

Assuming that your hard disk is designated as drive C:, creating the following (or a similar) directory tree will ensure efficient input and output file organisation.

DIRECTORY	CONTENTS
C:\DISA	Program and configuration files
C:\DISA\DATA	Time series data
C:\DISA\DBASE	Database files
C:\DISA\OUT	Output files
C:\DISA\PAR	Parameter (System description) files

Table 1 : Directory organisation

All the files on distribution diskettes 1 and 2 are necessary for program operation and must be copied to the **C:\DISA** directory. Copy the example parameter files supplied on distribution diskette 3 to **C:\DISA\PAR** and the example time series input files on diskette 4 to **C:\DISA\DATA.**

3.2.2 Starting the Program

Once you have copied the program files on to the hard disk, the model can be started as follows :

(a) Change directory to the sub-directory where you have installed the program.

(b) Type **DISA <ENTER>**. The program will automatically detect whether it has been configured for your system. If this has not yet been done, the **Hardware Configuration** menu (Figure 3.1) will be displayed.

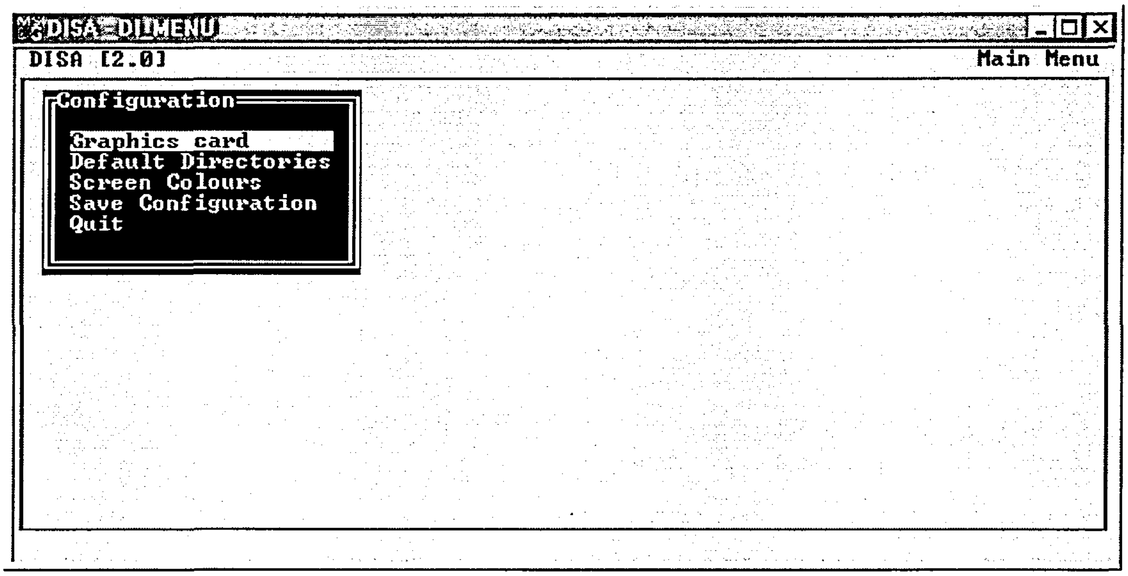


Figure 3.1 : Hardware Configuration menu

3.2.3 Hardware Configuration

In order to configure DISA for your system, the following information must be provided :

(a) Display device. Select the correct screen type by using the space-bar to "toggle" (i.e. activate and de-activate) between the following options :

Autodetect (default)
CGA
EGA (colour)
EGA (mono)
Hercules (mono)
ATT400 (Olivetti)
VGA

(b) File management. Use this option to specify the directory tree which you have created during installation. The default names are shown in Table 1 and Figure 3.2.

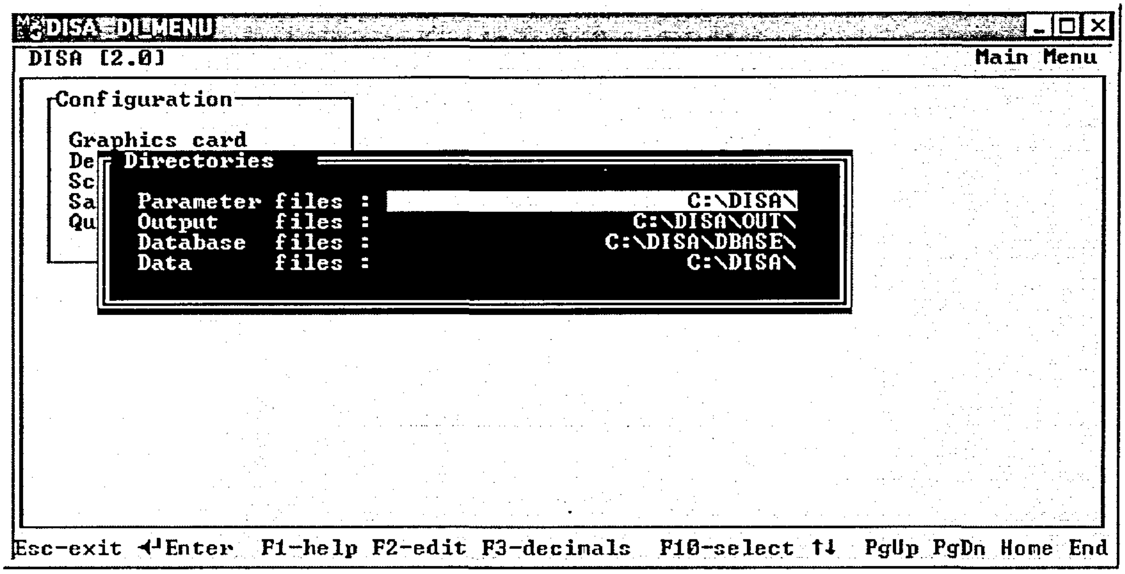


Figure 3.2 : DirectoryConfiguration screen

(c) Screen colours. If you have a colour monitor, the Text Palette input screen (Figure 3.3) can be used to customize background and foreground colours for input screens and menus.

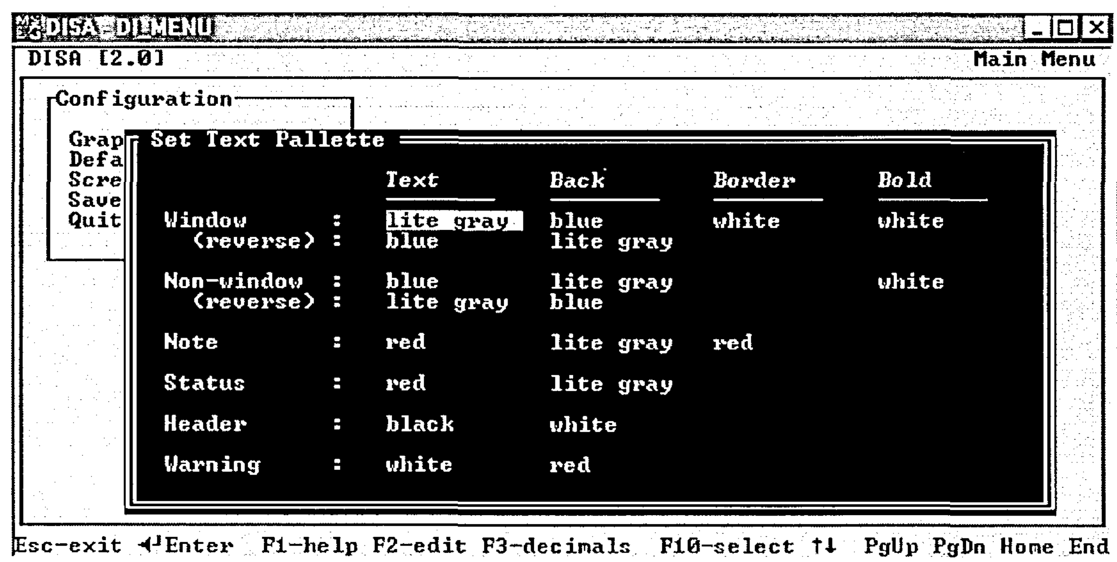


Figure 3.3 : Text Palette input screen

After making the necessary changes to the default values, save the hardware configuration by selecting the **Save Configuration** option on the Configuration menu (Figure 3.1). When this task has been completed, you will be returned to the DISA menu (Figure 3.4).

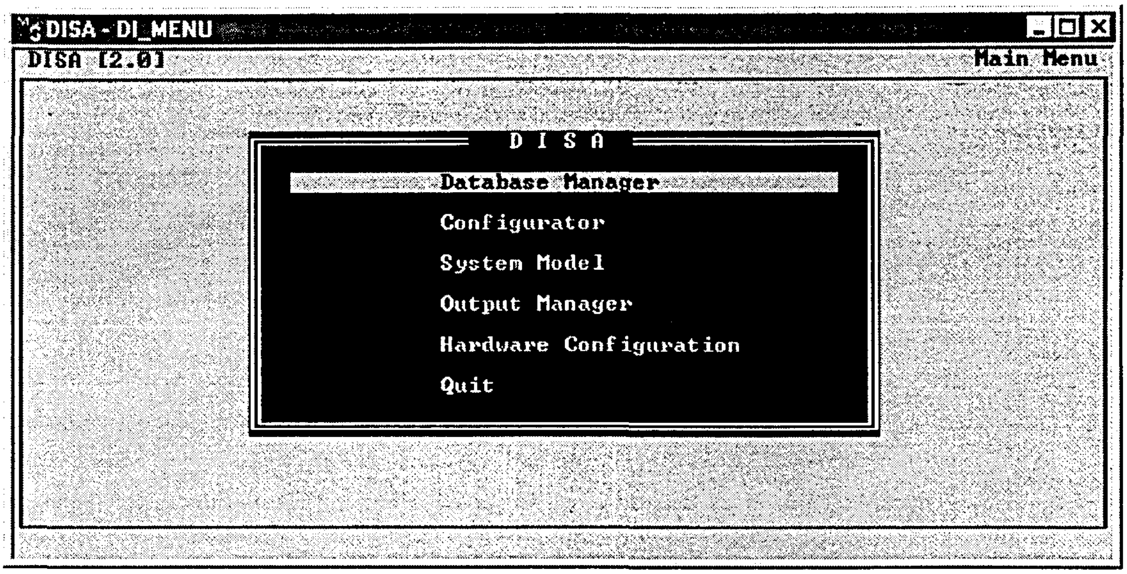


Figure 3.4 : DISA menu

4. IMPORTANT CONCEPTS

This section describes fundamental characteristics of the DISA model which will assist you in using the program effectively.

4.1 SYSTEM DESCRIPTION

The DISA model describes the catchment area being modelled in terms of a series of "return flow" cells overlain by a water supply distribution system. The water supply distribution system acts as the main driving force in the model and is described in terms of five modelling nodes :

(a) Abstraction nodes represent river and canal abstractions.

(b) Inflow nodes manage time series from areas outside the model boundary. They are also used to combine outflows from one or more neighbouring model cells.

(c) Farm dam nodes represent the distributed farm dam storage on individual return flow cells. Inflows from up to three other model elements can be specified.

(d) Canal nodes represent canal reaches overlying specific return flow cells.

(e) A routing node links any model element to upstream neighbours and calculates longitudinal dispersion of flows and salts in the river channel.

4.2 CONSTRUCTING A SMALL SYSTEMS NETWORK

To illustrate the use of modelling nodes, a schematic representation of a small system (Figure 4.1) will be used.

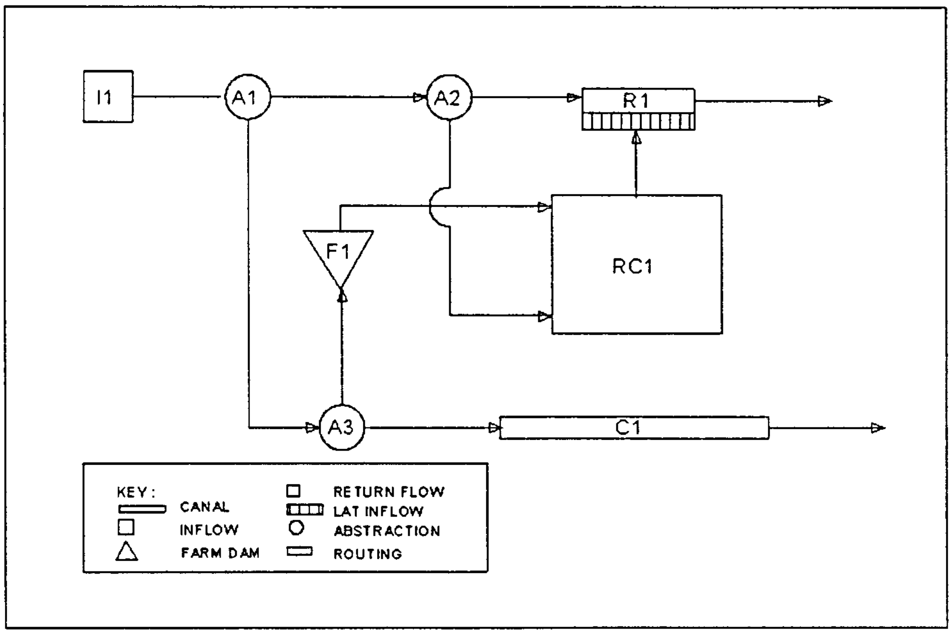


Figure 4.1 : Example of a system network

In this example, return flow cell RC1 is supplied with irrigation water via farm dam node F1 and abstraction node A2 which (in this instance) represents pumping from a river. The farm dam receives its water via abstraction node A3 from canal C1. routing node R1 receives lateral groundwater inflow from RC1 and upstream inflow from A2. Abstraction node A1 represents a diversion weir supplying water to canal C1. Flows and salts entering the system are represented by inflow node I1.

4.3 CALCULATION SEQUENCE

The DISA model operates on a daily time step. Certain routing and dynamic processes are calculated at sub-daily time steps. The entire system is simulated for one time step before proceeding to the next time step. Calculation of the individual modelling nodes proceeds according to a user defined sequence. By referring to the system description in Section 4.2, it can be seen that a valid calculation sequence could be :

I1 → A1 → A3 → C1 → F1 → A2 → RC1 → R1

It would also have been possible to calculate F1 prior to C1, as neither node depends on the results of the other. However, calculating F1 before I1, A1 or A3 would be impossible as F1 is directly or indirectly dependent on the results of the other three nodes.

4.4 CELL REFERENCES AND OUTPUT SETS

Modelling nodes can yield one or more sets of output. For example, a farm dam node can produce irrigation water in the form of a daily volume of water of a certain quality, as well as spillage and seepage volumes.

A target node is linked to supply nodes by setting up "pointers" to the supply nodes. Each of these pointers consists of a node reference and an output set number.

The **node reference** specifies the supply node which provides the required output.

The **output set** indicates which component of the output (spillage, seepage, outflow, etc.) is required from the supply node.

Output sets for the different modelling nodes are shown in Table 2.

Node	Output set number	Output component produced by node
Inflow	1	Combined upstream flows
Abstraction	1 2	Outflow after abstraction Abstraction
Farm Dam	1 2 3	Outflow (spill) Abstraction (irrigation) Seepage
Canal	1 2	Outflow Seepage
Routing	1 2	Outflow Sub-daily flow distribution
Return flow	1	Outflow (groundwater)

Table 2 : Node output sets

The nodes in the network example given in Section 4.2 are linked by the pointers as shown in Table 3.

Target node	Output component of supply node	Supply node reference	Supply node output set
A1	Outflow	I1	1
A3	Abstraction	A1	2
C1	Outflow	A3	1
F1	Abstraction	A3	2
A2	Outflow	A1	1
RC1	Irrigation abstraction Dam seepage Canal seepage Pumping abstraction	F1 F1 C1 A2	2 3 2 2
R1	Outflow Groundwater outflow	A2 RC1	1 1

Table 3 : Example network pointer links

5. THE DATABASE MANAGER

The Database Manager is used to combine and store daily records in a binary format. This facilitates rapid disk access and model run-time. In addition, a considerable saving in disk space is achieved.

5.1 TIME SERIES REQUIRED FOR MODEL OPERATION

The DISA model requires a number of time series that serve as external input to the catchment area being modelled.

Rainfall and evaporation time series are utilised in a data-economical way by allowing a number of return flow cells to make use of the same time series. This is achieved by using non-dimensionalised time series as input to the model.

During simulation. the time series are dimensionalised by multiplying the non-dimensional series with the MAP or MAE associated with the relevant return flow cell.

(a) Evaporation time series. Either A-Pan or symons Pan daily net evaporation records may be used. The records are non-dimensionalised by expressing the daily values as percentages of station mean annual evaporation.

(b) Rainfall time series. The records must be non-dimensionalised by expressing daily values as percentages of station mean annual precipitation.

(c) Flow time series. All flows entering the catchment boundary must be provided as records of daily average flows in m^3/s.

(d) Salinity time series. Daily total dissolved solids (TDS0 concentrations associated with the flows mentioned above, must be provided in mg/ℓ.

5.2 PREPARATION OF INPUT FILES

Time series are read into the Database Manager in the form of free format ASCII text files. Each line in the input file represents one month of daily values and must have the following format.

YY MM DV(1) DV(2) ... DV(n)

where **DV** denotes a data value and **n** is the number of days in the month.

5.3 CREATING A DATABASE

Once you have started DISA, the Database manager can be activated from the DISA menu. The **Database Manager** main menu (Figure 5.1) will appear on the screen.

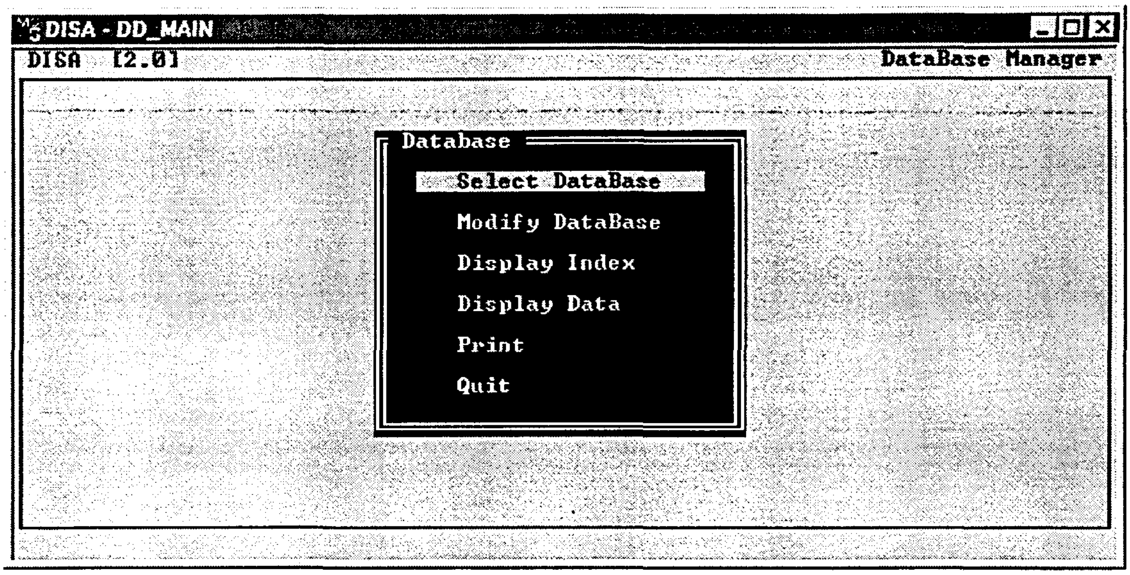


Figure 5.1 : Database Manager menu

Figure 5.2 shows a menu hierarchy which maps the relative positions of menus and input screens used by the Database Manager.

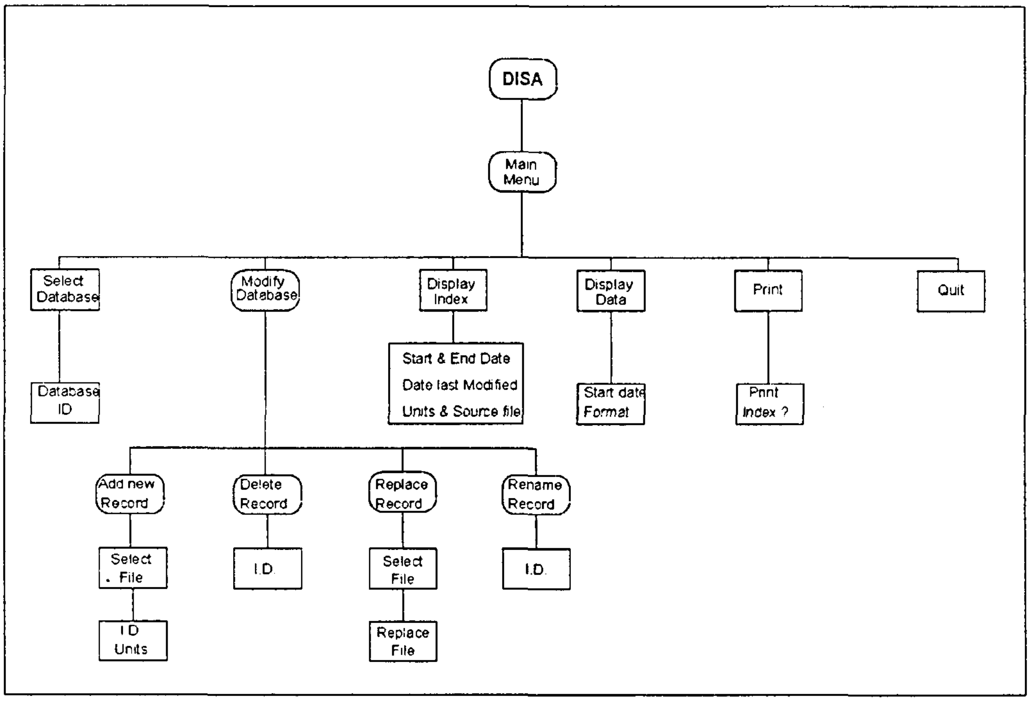


Figure 5.2 : Database Manager menu hierarchy

To create a database which will provide time series input for the system (as described in Section 4.2), follow these steps :

(a) From the main menu, highlight the **Select Database** option and press <ENTER>. You will be prompted for a database ID and starting date. When you have finished, press <ENTER> to return to the main menu.

(b) Select the **Modify Database** option from the main menu. the sub-menu shown in Figure 5.3 will appear on the screen.

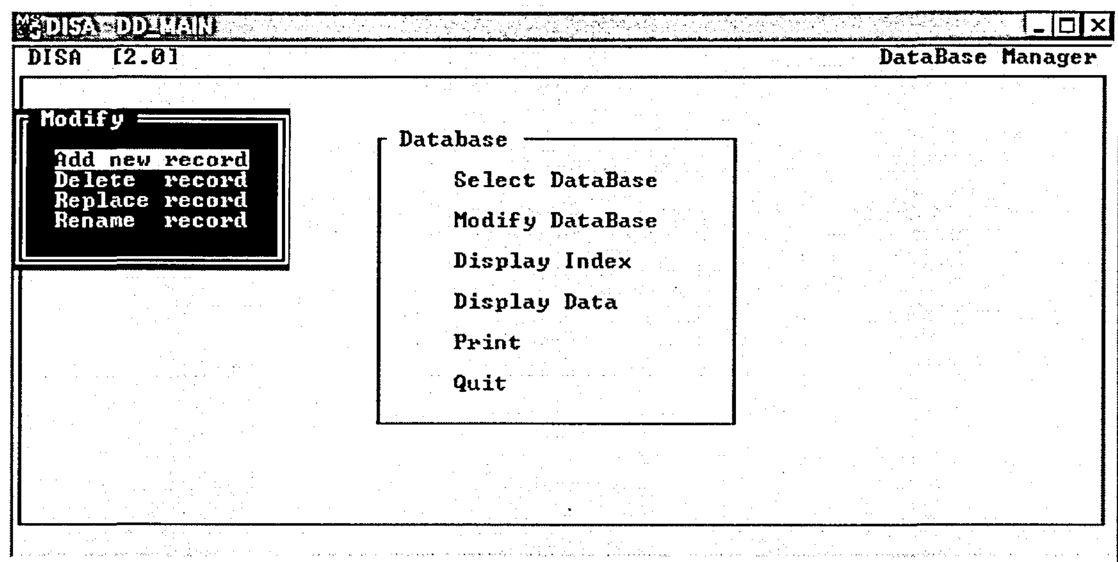


Figure 5.3 : Modify Database menu

(c) Select the **Add new record** option. A list of files in the default data directory will appear on the screen. Any one of the files can be selected by positioning the highlighted block over the file name and pressing <ENTER>. After the file has been read into memory, you will be prompted for a record ID. The default value is the file name and can be accepted by pressing <ENTER>.

(d) Repeat steps (b) and (c) for the rest of the files in the data directory.

(e) You can experiment by deleting, replacing or renaming records from the **Modify Database** menu. When you have finished, press <ESC> to return to the main menu.

(f) Select the **Display Index** option. A screen (see Figure 5.4) containing information on the database files which you have created will be displayed.

DISA - DD MAIN

DISA [2.0] DataBase Manager

DataBase ID : CFG3
Start date : 85-01-01
End date : 91-01-09

No. data sets : 31
No. sub files : 7
Date modified : 91-08-29
Time modified : 14:30

No	Data-Set ID	Units	Start Date	End Date	Date, Time Modified		Fil, Col		Source file
1	REGION49.RAI	[% map]	85-01-01	90-12-31	91-08-29	14:30	1	2	REGION49.RAI
2	REGION50.RAI	[% map]	85-01-01	90-12-31	91-08-29	14:31	1	3	REGION50.RAI
3	REGION51.RAI	[% map]	85-01-01	90-12-31	91-08-29	14:31	1	4	REGION51.RAI
4	REGION75.RAI	[% map]	85-01-01	90-12-31	91-08-29	14:32	1	5	REGION75.RAI
5	REGION49.EVP	[% mae]	85-01-01	91-01-09	91-08-29	14:32	2	1	REGION49.EVP
6	REGION50.EVP	[% mae]	85-01-01	91-01-09	91-08-29	14:33	2	2	REGION50.EVP
7	REGION51.EVP	[% mae]	85-01-01	91-01-09	91-08-29	14:33	2	3	REGION51.EVP
8	REGION75.EVP	[% mae]	85-01-01	91-01-09	91-08-29	14:34	2	4	REGION75.EVP
9	H2M01.SAL	[mg/l]	85-01-01	90-04-30	91-08-29	14:36	2	5	H2M01.SAL
10	H4R0401.SAL	[mg/l]	85-01-01	90-07-31	91-08-29	14:37	3	1	H4R0401.SAL

Esc ↑↓ PgUp PgDn Home End

Figure 5.4 : Database Index screen

5.4 VIEWING DATA

Data contained in the database can be viewed on the screen (Figure 5.5) by selecting the **Display Data** option on the main menu. Use the **<PG UP>**, **<PG DN>** and cursor keys to scroll the display. A hard copy of the data can be obtained by selecting the **Print** option from the main menu.

DISA - DD MAIN

DISA [2.0] DataBase Manager

1 : REGION49.RAI 3 : REGION51.RAI 5 : REGION49.EVP 7 : REGION51.EVP
2 : REGION50.RAI 4 : REGION75.RAI 6 : REGION50.EVP 8 : REGION75.EVP

Jul	Date	1	2	3	4	5	6	7	8
85	1	0.00	0.00	0.00	0.00	0.64	0.54	0.51	0.64
85	2	0.00	0.00	0.00	0.00	0.70	0.79	0.73	1.14
85	3	0.00	0.00	0.00	0.00	0.67	0.72	0.65	0.59
85	4	0.00	0.00	0.00	0.00	0.46	0.41	0.65	0.54
85	5	0.00	0.00	0.00	0.00	0.67	0.60	0.56	0.44
85	6	0.00	0.00	0.00	0.00	0.59	0.58	0.48	0.59
85	7	0.00	0.00	0.00	0.00	0.62	0.56	0.73	0.20
85	8	0.00	0.00	0.00	0.00	0.67	0.46	0.22	0.54
85	9	0.00	0.00	0.98	0.00	0.54	0.48	0.34	0.44
85	10	0.00	0.00	0.00	0.00	0.41	0.41	0.17	0.54
85	11	0.00	0.00	0.00	0.00	0.57	0.58	0.56	0.49
85	12	0.00	0.00	0.00	0.00	0.41	0.46	0.42	0.44
85	13	6.50	19.35	5.90	3.46	0.00	0.00	0.28	0.05
85	14	4.61	0.75	6.23	4.99	0.00	0.17	0.14	0.10
85	15	0.21	0.00	0.98	1.09	0.31	0.19	0.20	0.17
85	16	0.00	0.00	0.00	0.00	0.39	0.39	0.39	0.59
85	17	0.00	0.00	0.00	0.00	0.64	0.48	0.56	0.25

Esc ↑↓ ←→ PgUp PgDn Home End

Figure 5.5 : Data Display screen

When you have finished, select **Quit** to leave the Database Manager and return to the DISA menu.

6. THE SYSTEM CONFIGURATOR

The System Configurator is used to describe the system in terms of modelling node types, node sequencing, process parameters and global parameters. It also controls the selection of nodes for producing graphical and numeric output. The system description produced by the Configurator is saved in a parameter file for use by the System Model during simulation. Figure 6.1 shows the menu hierarchy of the Configurator.

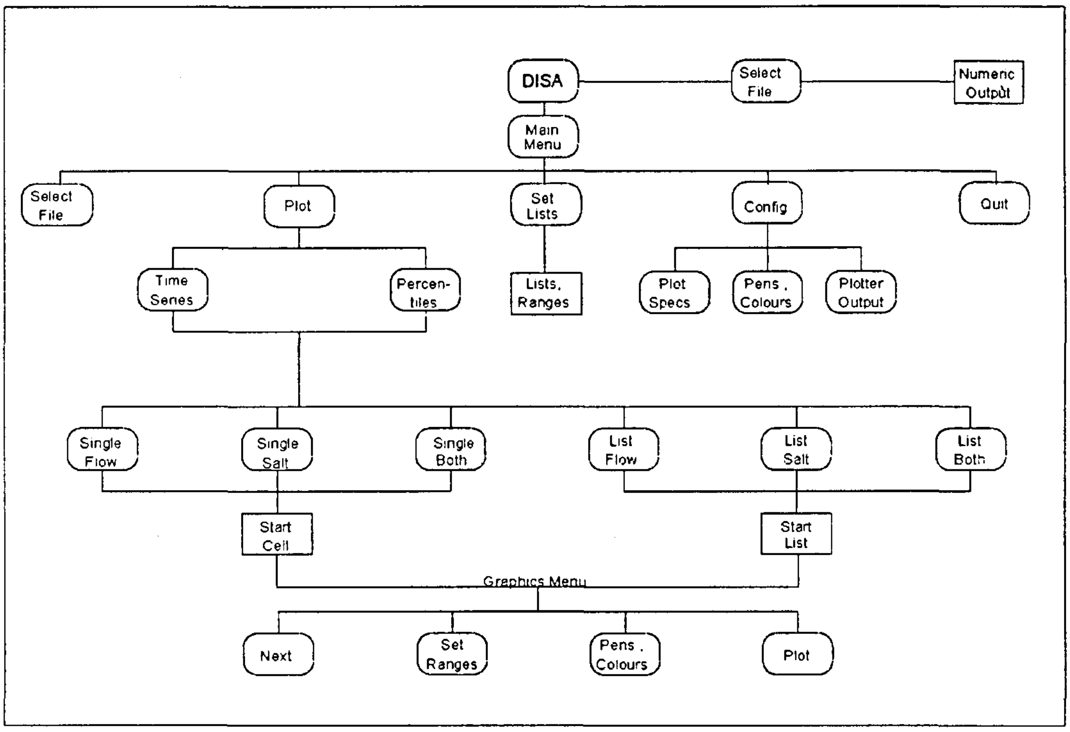


Figure 6.1 : Configurator menu hierarchy

To activate the Configurator, select the **System Configurator** option from the DISA Menu. The Main Menu (Figure 6.2) will appear on the screen.

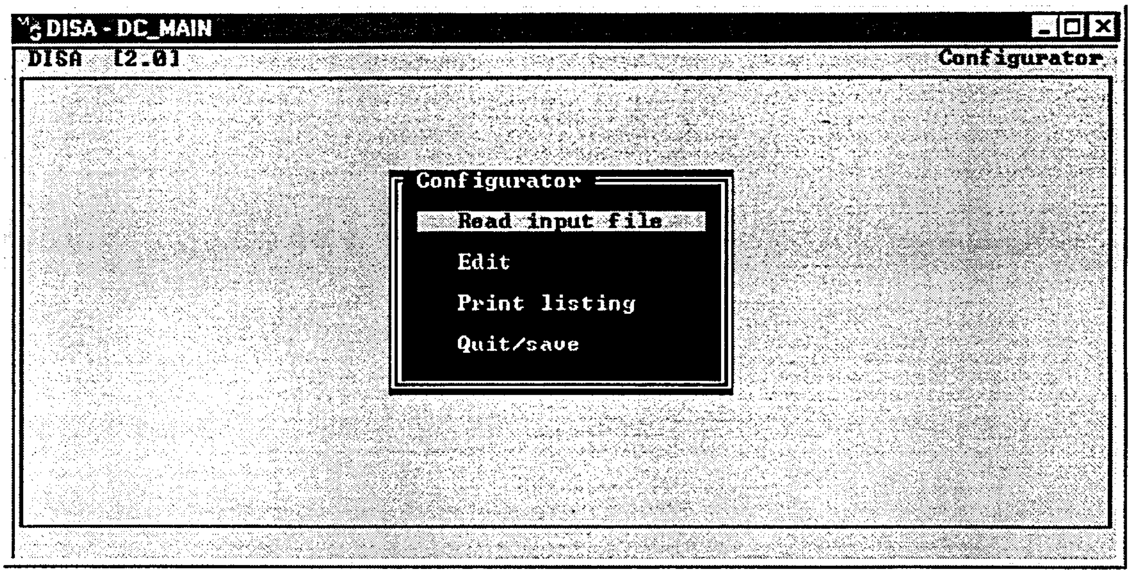


Figure 6.2 : System Configurator Main Menu

6.1 READING AN INPUT FILE

The system which is described in Section 4.2, has been configured and saved in the parameter file EXAMPLE.PAR. Read this file into the configurator by selecting the **Read Input File** option from the Configurator main menu. You will be prompted for a file search path (see Section 2.3). After the parameter file has been read into memory, select the **Edit** option on the main menu to commence editing. Sections 6.2 to 6.4 describe the various options available on the **Edit** menu.

6.2 EDIT RUN PARAMETERS

The **Run Parameters** screens shown in Figure 6.3 allows you to specify general information regarding model simulation.

Note :The Run ID is used during model runs to name output files. The default value is the parameter file name without an extension.

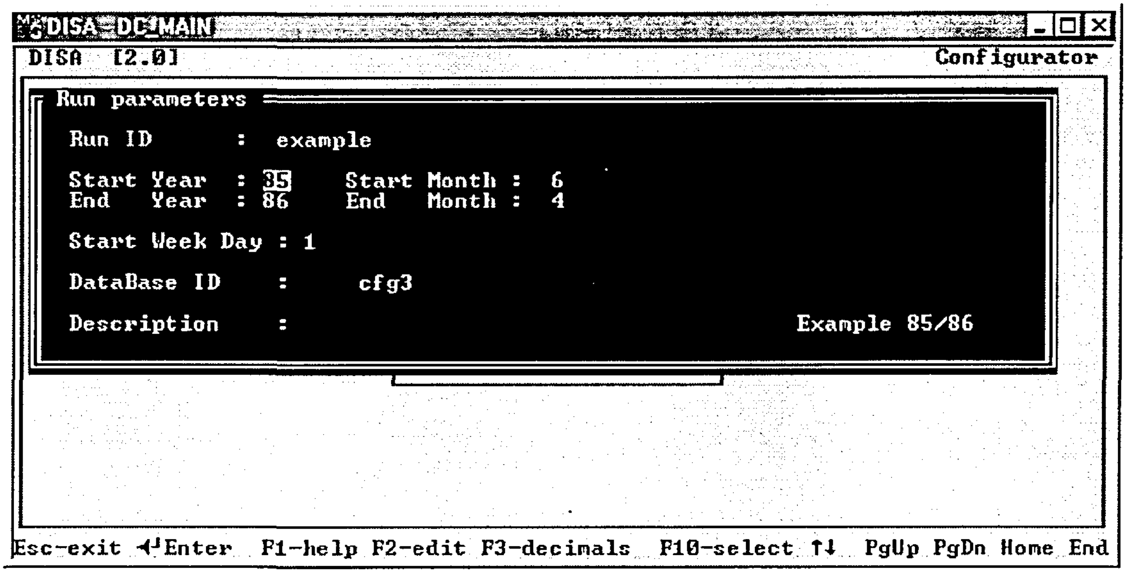


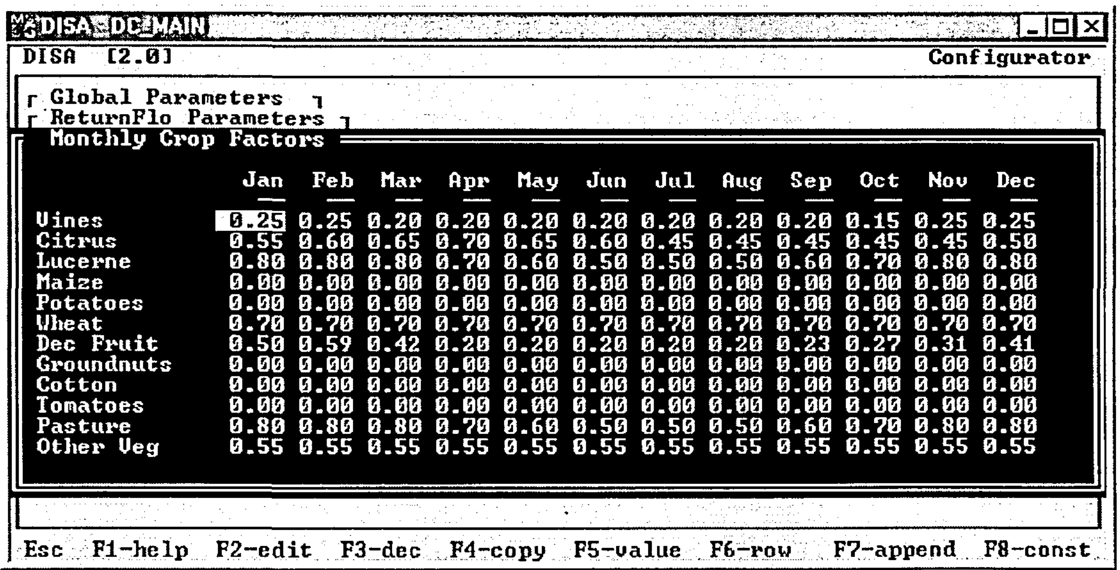
Figure 6.3 : Edit Run Parameters screen

6.3 EDIT GLOBAL PARAMETERS

The screens containing global parameters are illustrated in Figures 6.4 to 6.10. These screens are used to define properties that are constant for all nodes and cells in the system.

Note : The parameter file SKELETON.PAR contains the default global parameters that appear on the screens below. This file can be copied for use in setting up a new configuration file.

6.3.1 Return Flow Global Parameters



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Vines	0.25	0.25	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.15	0.25	0.25
Citrus	0.55	0.60	0.65	0.70	0.65	0.60	0.45	0.45	0.45	0.45	0.45	0.50
Lucerne	0.80	0.80	0.80	0.70	0.60	0.50	0.50	0.50	0.60	0.70	0.80	0.80
Maize	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Potatoes	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wheat	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Dec Fruit	0.50	0.59	0.42	0.20	0.20	0.20	0.20	0.20	0.23	0.27	0.31	0.41
Groundnuts	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cotton	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tomatoes	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pasture	0.80	0.80	0.80	0.70	0.60	0.50	0.50	0.50	0.60	0.70	0.80	0.80
Other Veg	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55

Figure 6.4 : Monthly Crop Factors

Crop factors as supplied on this screen are used to determine monthly crop water demands.

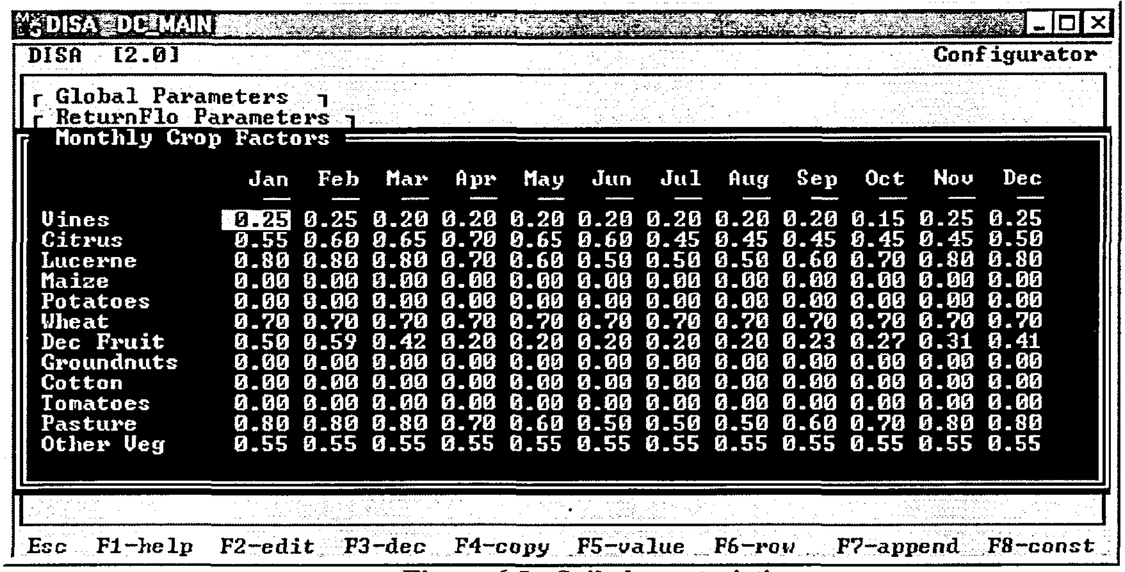


Figure 6.5 : Soil characteristics

Figure 6.5 is used for specifying soil water retention constants for a range of soil texture classes.

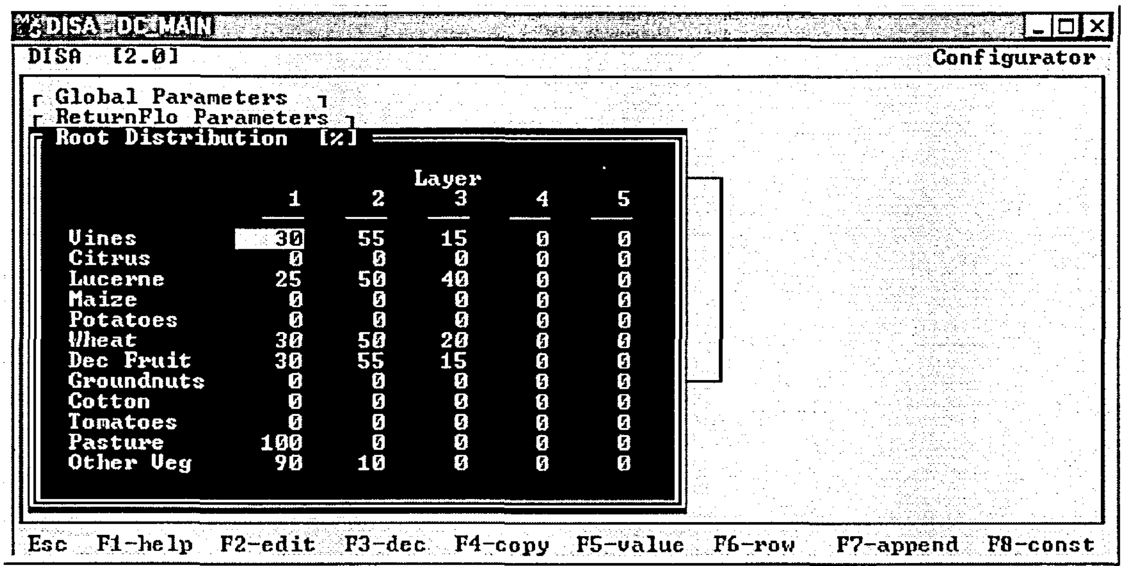


Figure 6.6 : Root Distributions

Note : Root distributions are specified as percentage of total mature volume per layer.

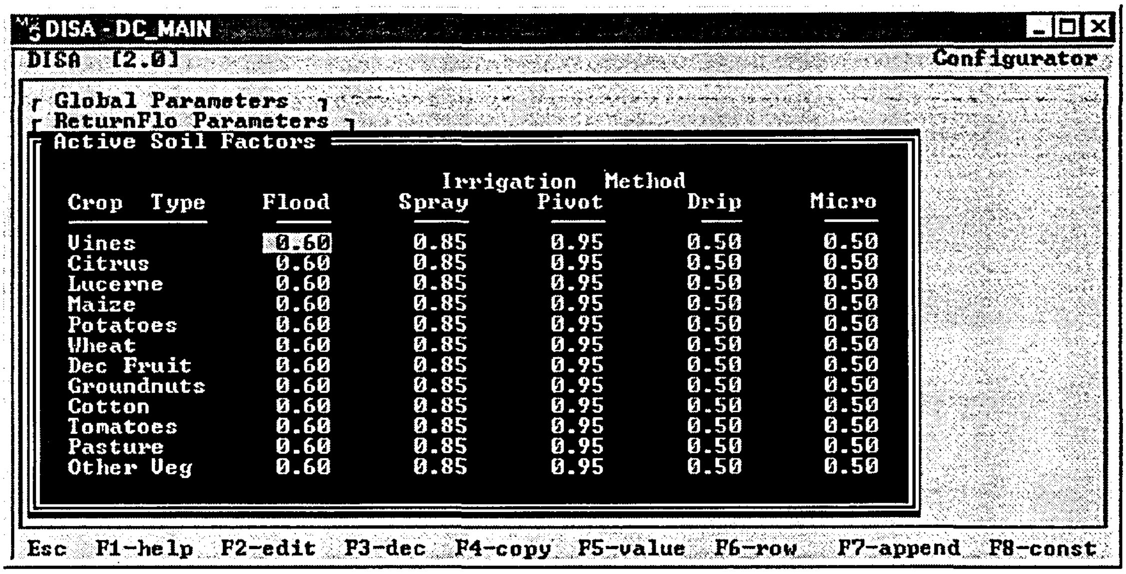


Figure 6.7 : Active Soil Factors

Active soil factors can be specified on the screen shown in Figure 6.7. These factors define the active (wetted) soil volume in the root zone as a fraction of the total soil volume under irrigation.

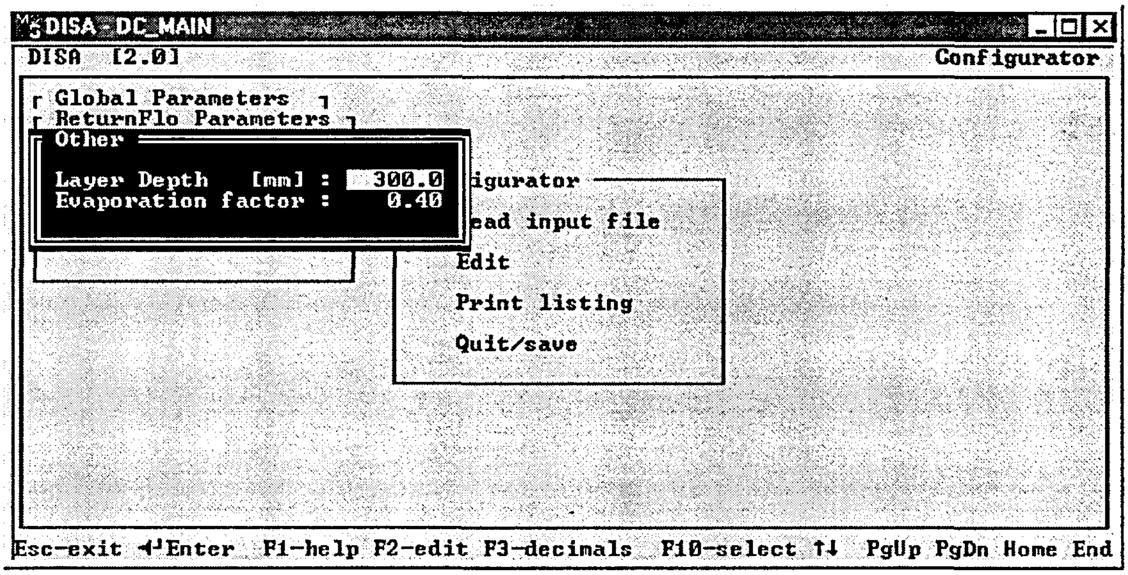


Figure 6.8 : Layer depth

Note : Selection of the layer depth must ensure an adequate definition of the rootzone (see Figure 6.6).

6.3.2 Output Flags

Figure 6.9 illustrates the use of output flags to control graphic and numeric output. The available options for flagging are :

1. **Monthly**. Monthly mass balance output consisting of flow volumes and salt tonnage wil be generated.

2. **Plot outflow/salt.** Daily outflows in m^3/s and associated salinities in mg/ℓ (output set 1) are written to a plot file. Any node type can be flagged for monthly output.

3. **Plot groundwater levels.** This flag can only be used with return flow cells containing groundwater bodies. Daily groundwater levels in millimetres and associated salinities (mg/Mℓ) are written to the plot file.

4. **Monthly deficits.** This flag can only be used with abstraction and farm dam nodes. Monthly deficit volumes, required volumes and the number of deficit days incurred per month are written to the same file.

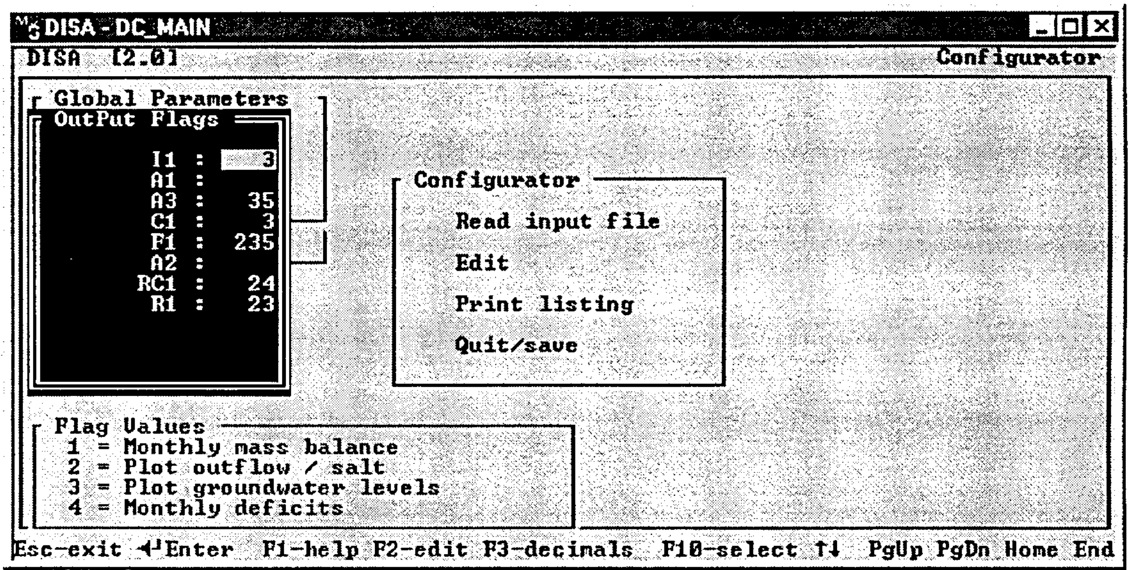


Figure 6.9 : Output flags

Note : Output files generated during simulation are assigned file names consisting of the Run ID (specified in the **Run Parameters** input screen), and one of the file name extensions listed in Table 4.

Cell / Node	**File name extension**
Return flow cell	.MRE
Routing node	.MRU
Abstract node	.MAB
Farm dam node	.MDA
Inflow node	.MIF
Canal node	.MCA

Table 4 : Output file name extensions

Plotting output for all nodes (Flags 2 and 3) are written to a combined plotting file with a file name extension of ".FSV".

6.3.3 Pan Evaporation Factors

Monthly pan evaporation factors can be entered on the screen shown in Figure 6.10. Values must be either A-Pan or Symons Pan factors, depending on the evaporation time series contained in the database. Note that the default values in parameter file SKELETON.PAR are A Pan factors.

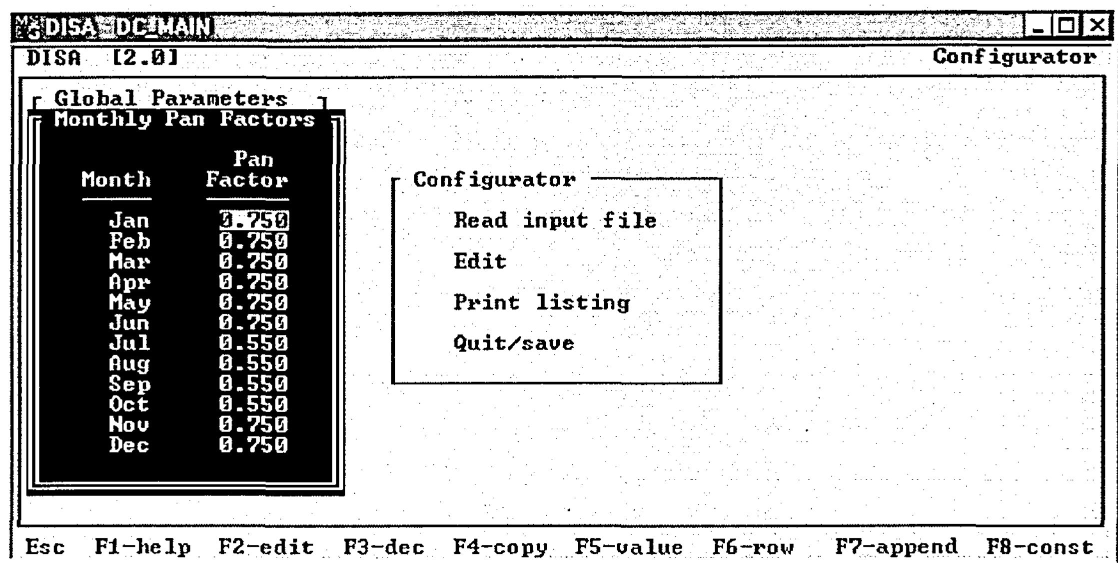


Figure 6.10 : Monthly pan factors

6.4 EDIT NODES

The **Edit nodes** option on the **Edit** menu can be used to edit individual nodes. On selecting this option, the **Select Node** screen shown in Figure 6.11 will be displayed.

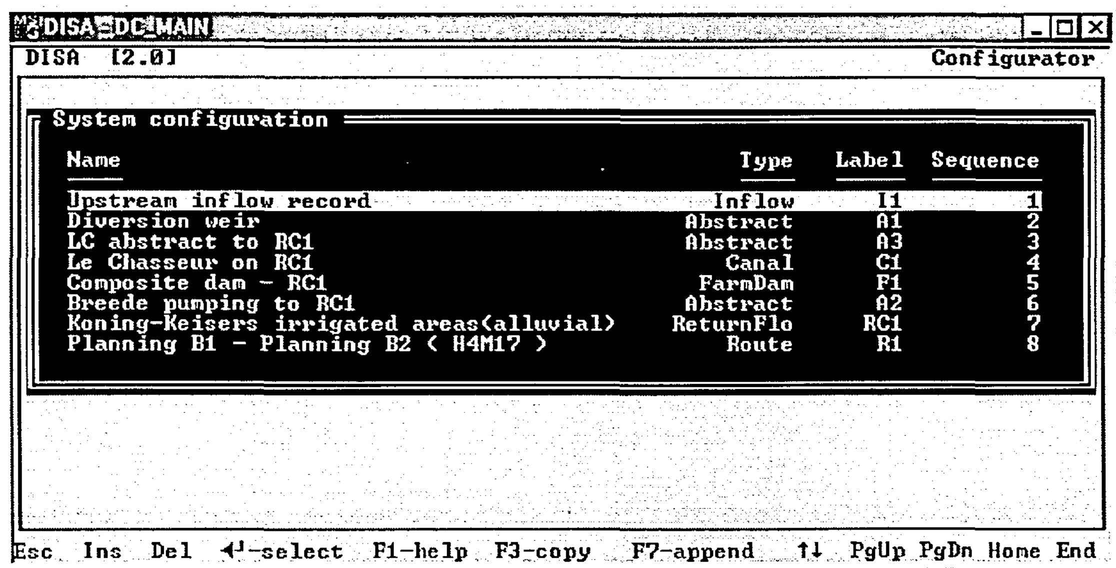


Figure 6.11 : Selected Node screen

The Select Node screen fulfils a number of important functions :

(a) You can think of this screen as a "viewport" into the rest of the configured network. It provides a convenient summary with descriptive names of all the nodes in the system. Nodes are displayed a page at a time according to the sequence in which calculation will take place. The **<PGUP>**, **<PGDN>** and cursor keys can be used to scroll through the list.

(b) It provides a full screen editing capability by allowing the copying, deleting, insertion and appending of nodes to the current list. The calculation sequence is automatically updated during editing. The status bar at the bottom of the screen (see Figure 6.11) indicates the keys which may be used for editing.

(c) Individual nodes can be selected for configuration by moving the highlight bar over the node and pressing **<ENTER>**.

After selection of a node for configuration, the menu shown in Figure 6.12 will be displayed.

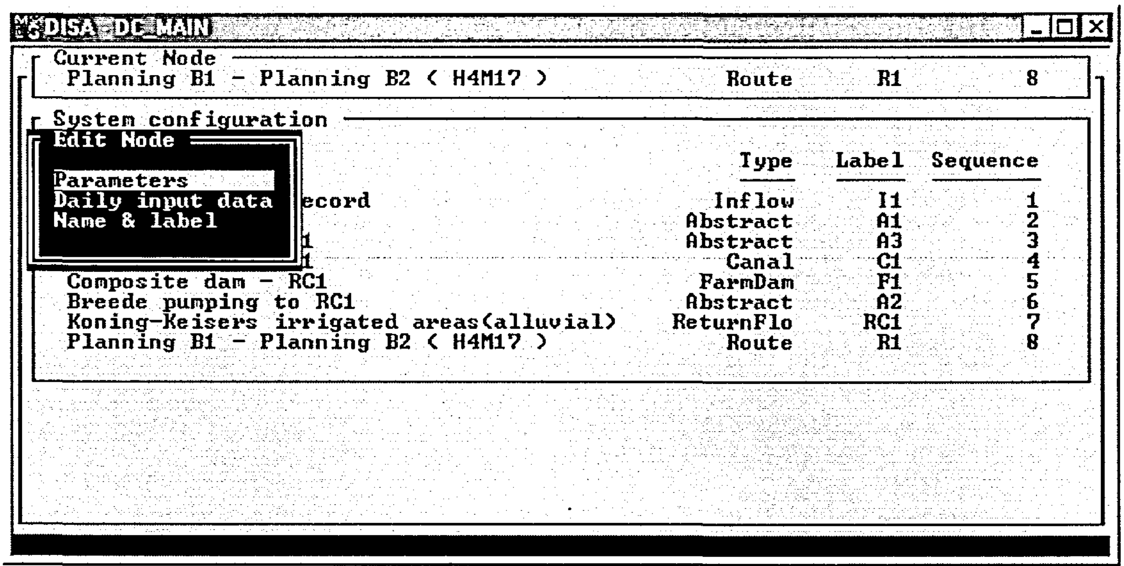


Figure 6.12 : Edit node menu

6.4.1 Daily Input Data

Figure 6.13 illustrates the **Daily Input Data** screen for a return flow cell. This screen is used to set up the interconnections or "pointers" between nodes (see Section 4.4).

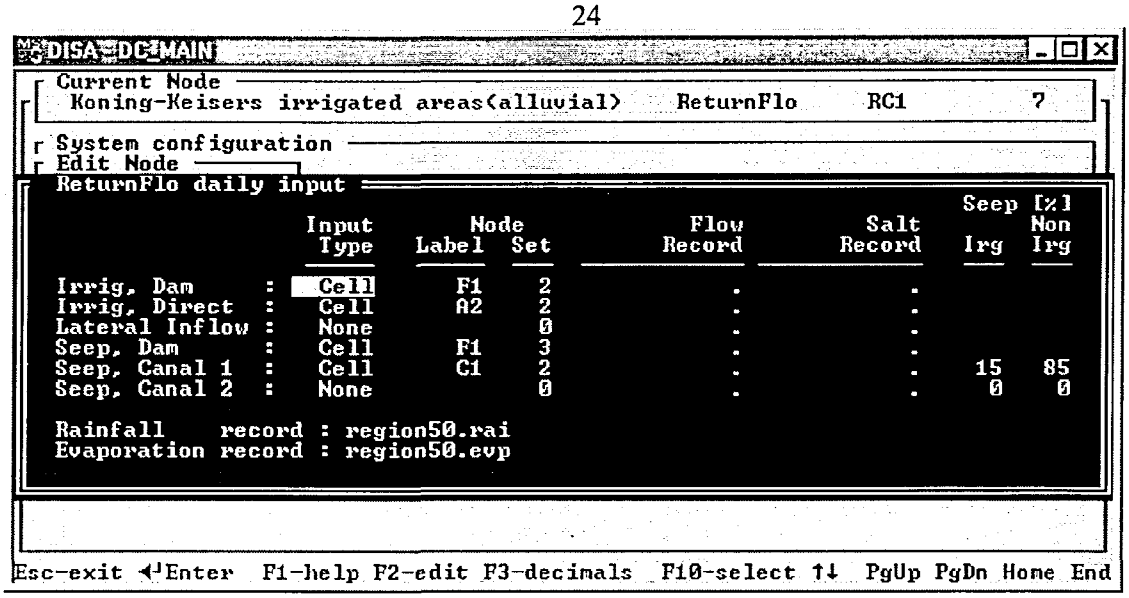


Figure 6.13 : Daily Input Data screen (Return flow cell)

6.4.2 Name and Label

This option can be used to change node (descriptive) names and reference labels. This screen is used most often when nodes are copied in the **Select Node** screen.

6.4.3 Edit Parameters

Configuration of individual nodes is done through a series of input screens for each type of node. All node types with the exception of inflow nodes are configured through a **General parameter** screen plus one or more subject specific screens. Inflow nodes need only be configured by filling in the Daily Input Data screen. Figures 6.14 to 6.23 show the various General parameter input screens.

(a) <u>Abstraction node parameters</u>

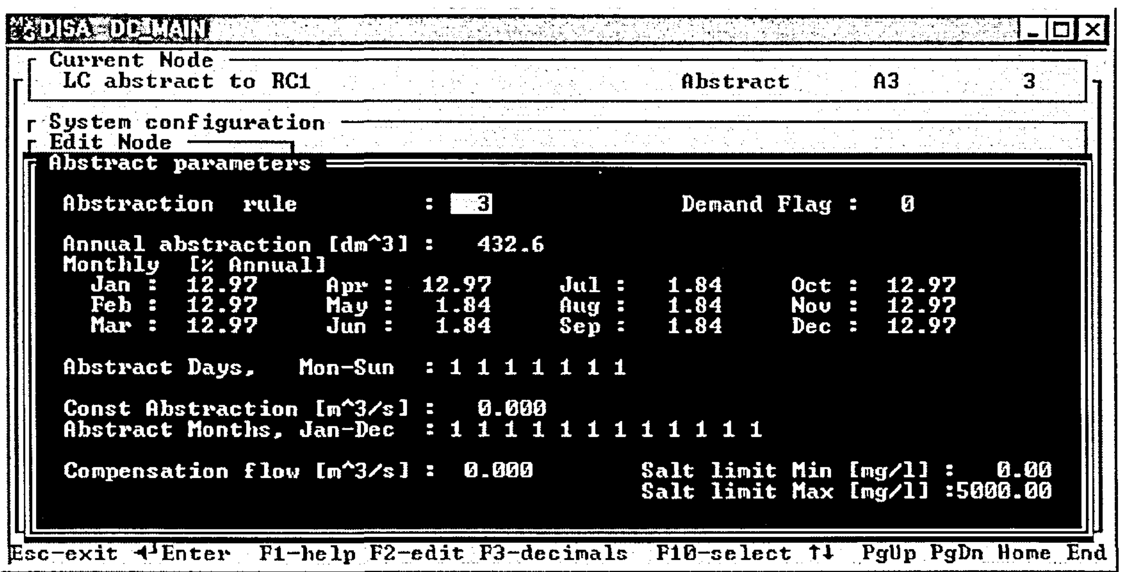


Figure 6.14 : Abstract parameters input screen

One of a range of operating rules for abstractions must be specified on this screen. Available rules are shown in Table 5.

Rule number	Description
1	Read daily abstractions from a database record
2	Constant daily abstraction
3	Monthly distribution with annual volume
4	Abstracting as much as possible to a monthly maximum

Table 5 : Abstraction operating rules

All rules implement checks on compensation flow and salinity abstraction limits.

(b) Farm dam node parameters

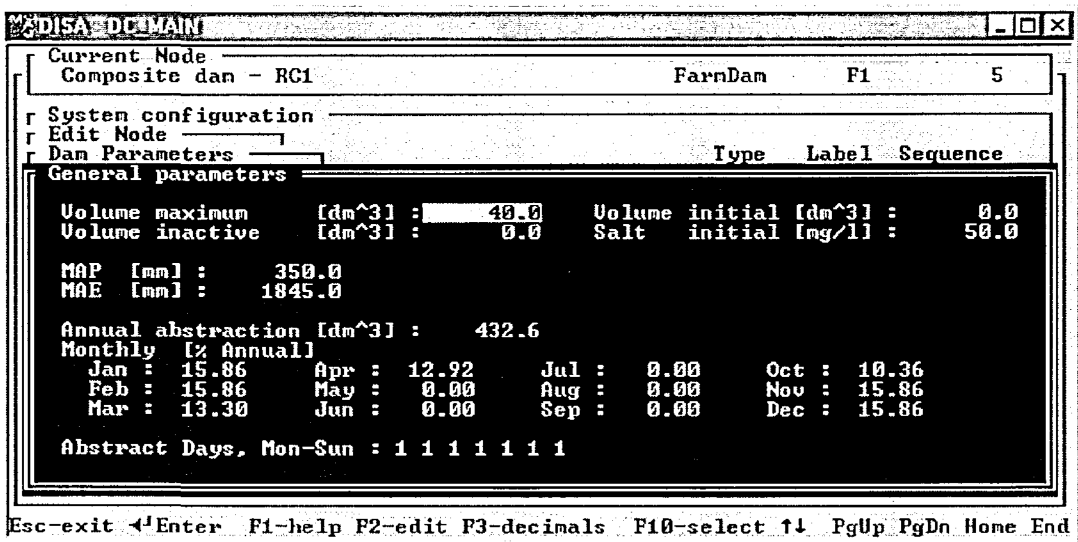


Figure 6.15 : Farm dam general parameters

Abstraction quantities specified on this screen represent irrigation abstractions. Operating rules are the same as those used with abstraction nodes (see (a) above). Farm dam area/capacity/ seepage relationships can be entered on the input screen shown in Figure 6.16.

(c) Canal parameters

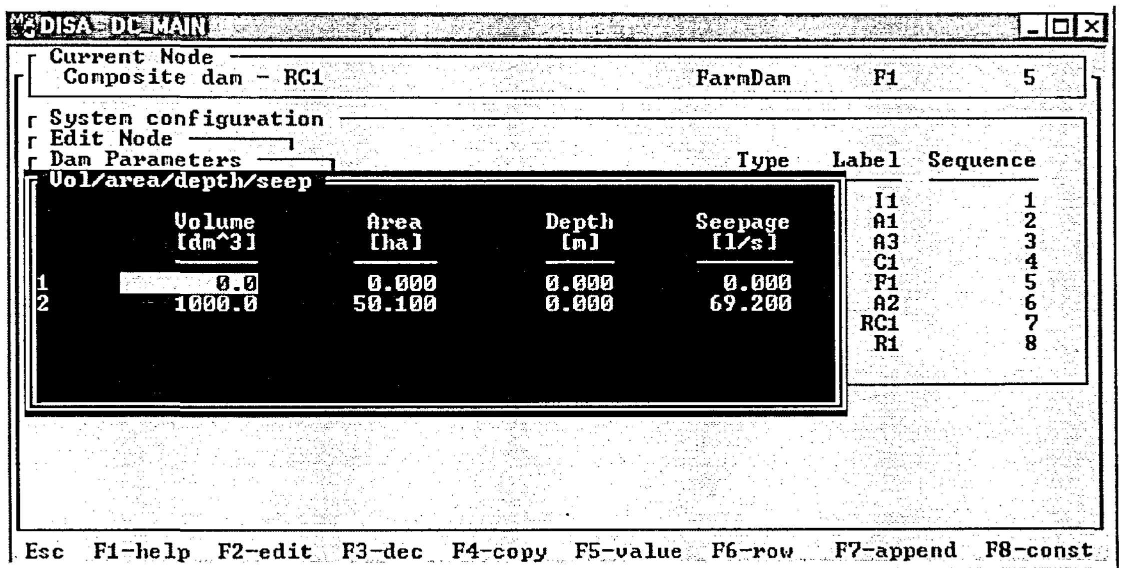


Figure 6.16 : Farm dam : Volume/Area/Depth/Seepage relationships

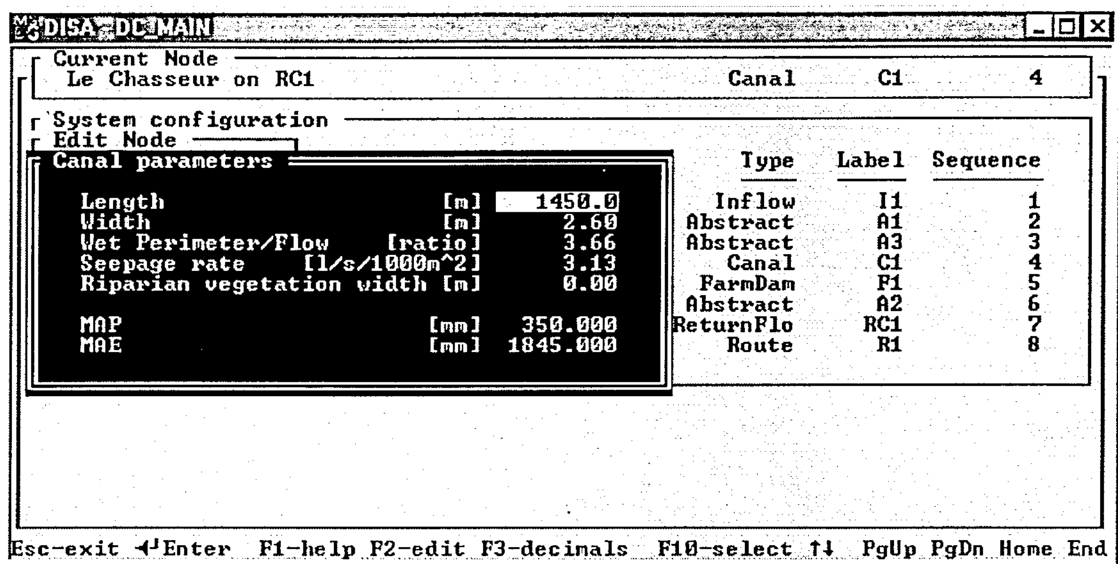


Figure 6.17 : Canal general parameters

(d) <u>Return flow cell parameters</u>

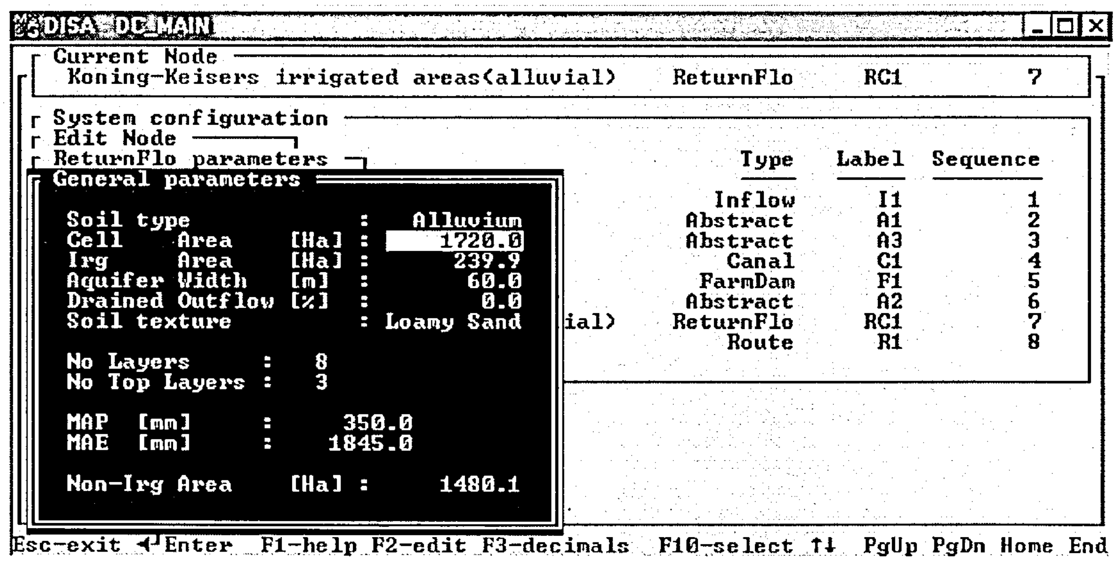


Figure 6.18 : Return flow cell general parameters

Aquifer widths need only be specified for return flow cells containing groundwater bodies (e.g. alluvial cells). The percentage of drained outflow only applies to terrace cells, and represents the portion of groundwater which drains directly to a surface collector or drain. the soil type and texture parameters are "toggle" values which can be changed by highlighting the parameter and pressing the space bar.

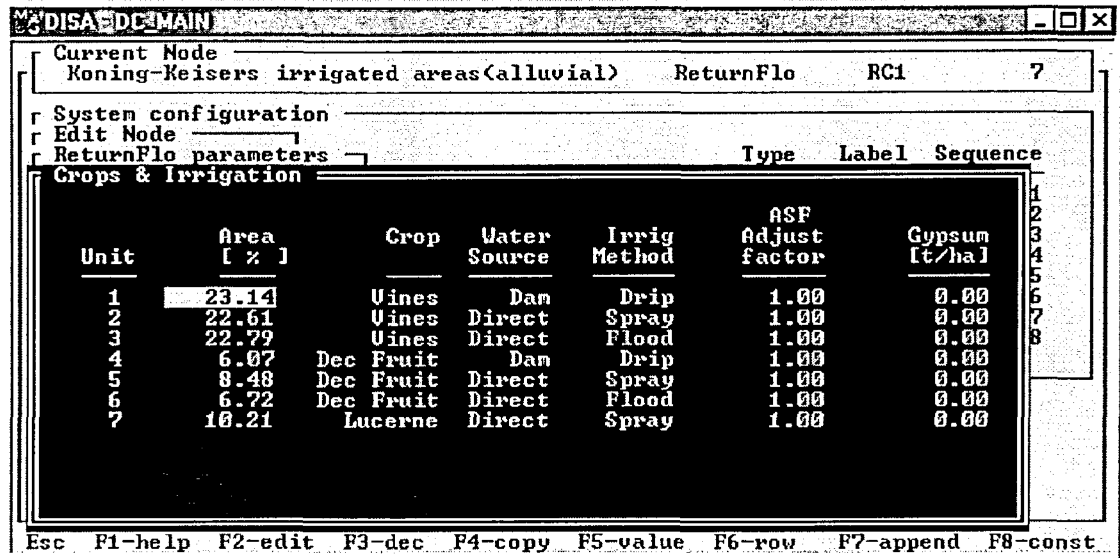


Figure 6.19 : Return flow cell : Crops and irrigation

Each row in the screen shown in Figure 6.19 represents an irrigated area (unit) on the return flow cell with a specific crop type, irrigation method and water source. Additional units can be specified by copying other units or by appending or inserting new units. The status bar at the bottom of the screen indicates the keys which may be used for editing. Crop types, water sources and irrigation methods are 'toggle" values.

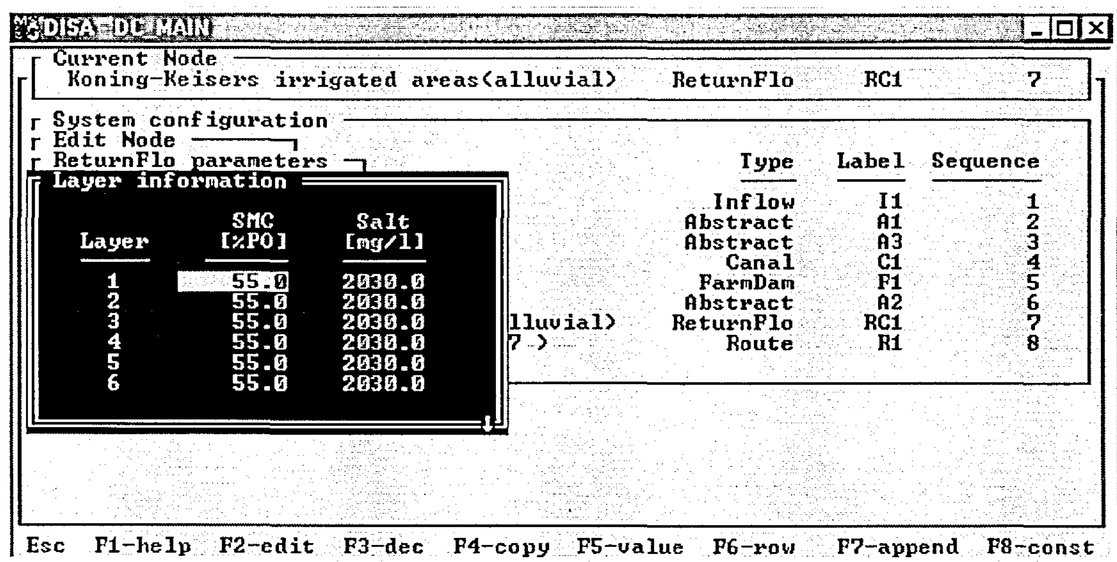


Figure 6.20 : Return flow cell : Initial soil moisture content

Initial soil moisture contents (expressed as a percentage of soil porosity), and groundwater salinities can be specified on the screen shown in Figure 6.20. These values represent starting conditions on the first day of simulation as specified on the **Run Parameters** screen.

(e) Routing node parameters

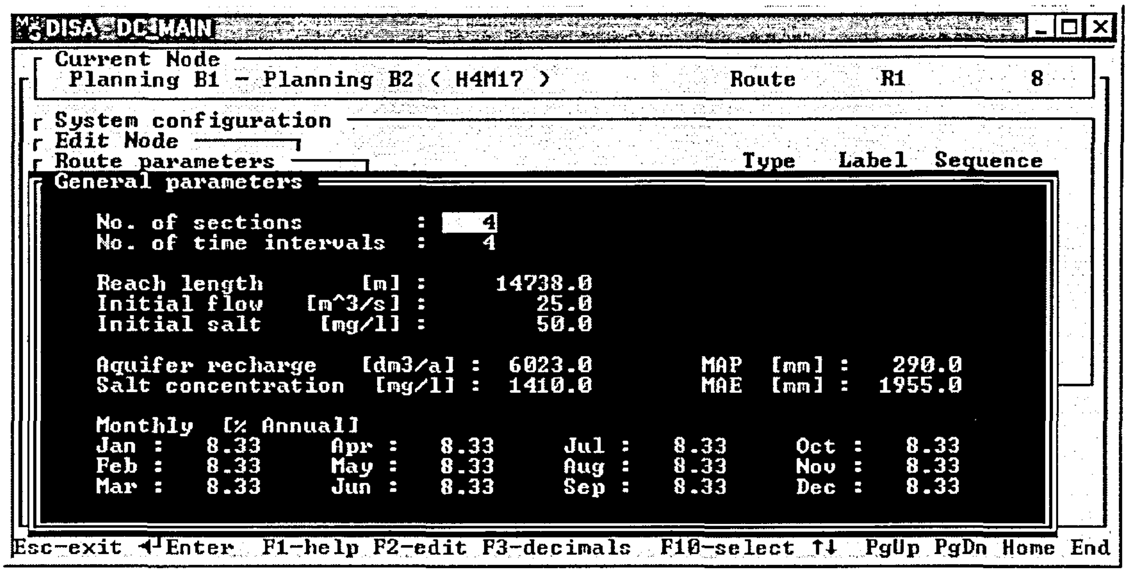


Figure 6.21 : Routing node : General parameters

The annual recharge volume and associated salinity specified on the screen shown in Figure 6.21 represents the fractured bedrock groundwater contribution to flows and salinities along the routing length.

Initial flow and salt values are used for defining boundary conditions on the first day of simulation. Routing nodes are the only modelling nodes which can operate on a sub-daily step. Selection of the number of time steps per day must take into account expected travel times through the reach.

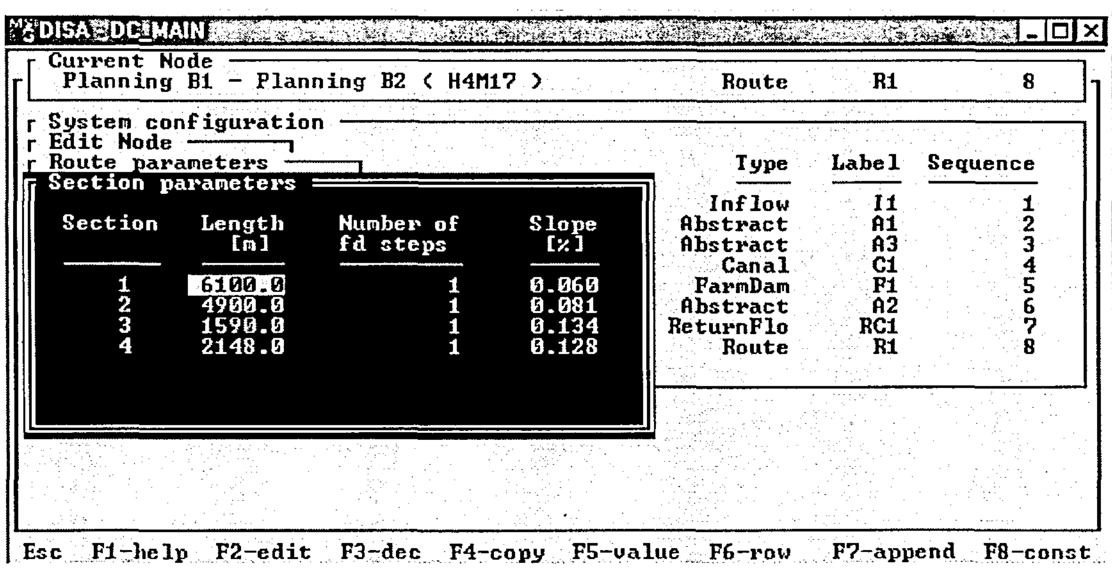


Figure 6.22 : Routing node : River section parameters

Note : The number of calculation intervals defines the number of calculation sub-sections between adjacent cross-sections. Average slopes between adjacent cross-sections must be specified as percentages.

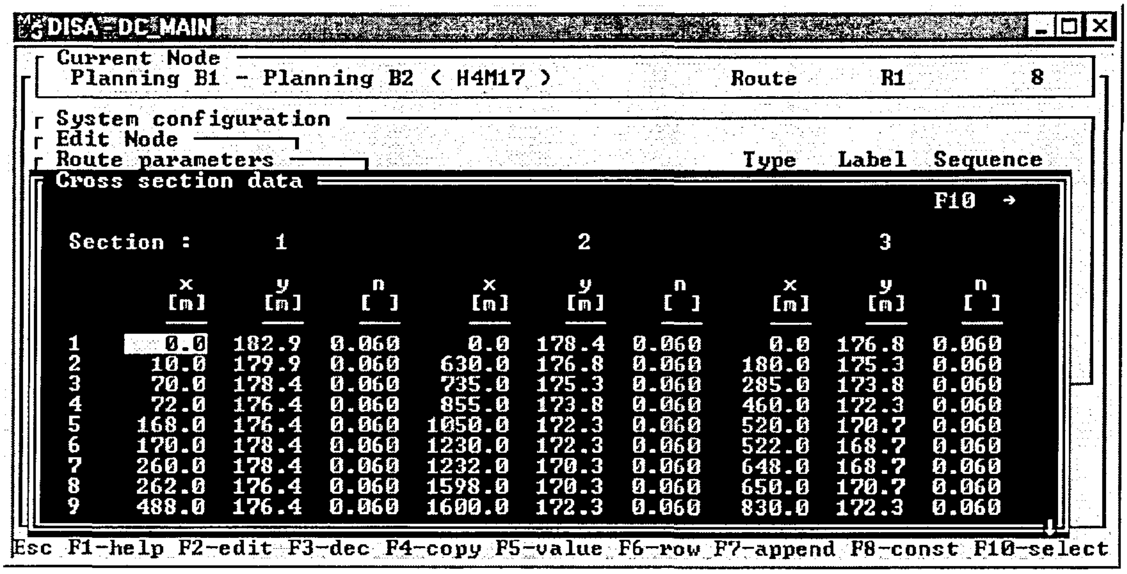


Figure 6.23 : Routing node : Cross-section geometry

Three cross-sections at a time can be entered on the screen shown in Figure 6.23. To view or add more corss-sections, you can "page" right and left by pressing the **<F10>** and **<ESC>** keys, respectively. Use the **<PGUP>** and **<PGDN>** keys to scroll data in the display screen.

8. THE OUTPUT MANAGER

The Output Manager presents graphical output in the form of flow and salinity time series and duration curves. Generated graphs can be downloaded to a HPGL compatible plotter or saved as HPGL (Hewlett Packard Graphics Language) disk files. Numeric output can be viewed by using the cursor keys to "browse" through output files.

Figure 8.1 shows the menu hierarchy of the Output Manager.

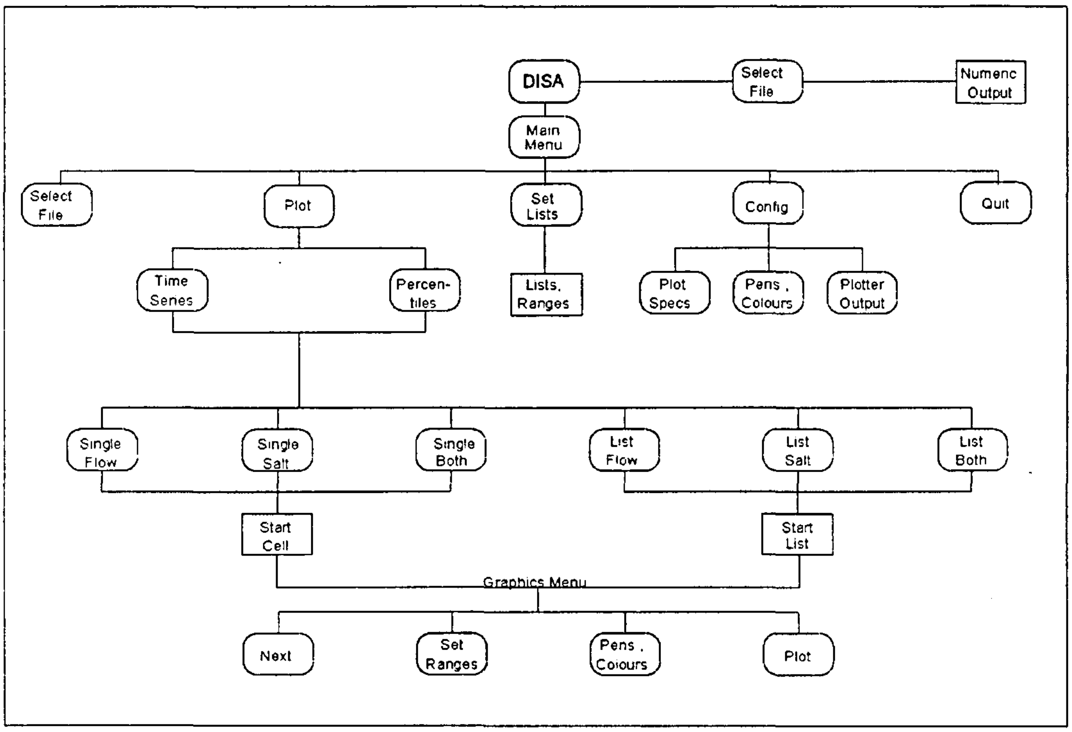


Figure 8.1 : Output Manager menu hierarchy

To activate the Output Manager, select the **Output Manager** option on the DISA menu. The entry menu shown in Figure 8.2 will appear on the screen, allowing you to view either numeric output (monthly results) or graphical output.

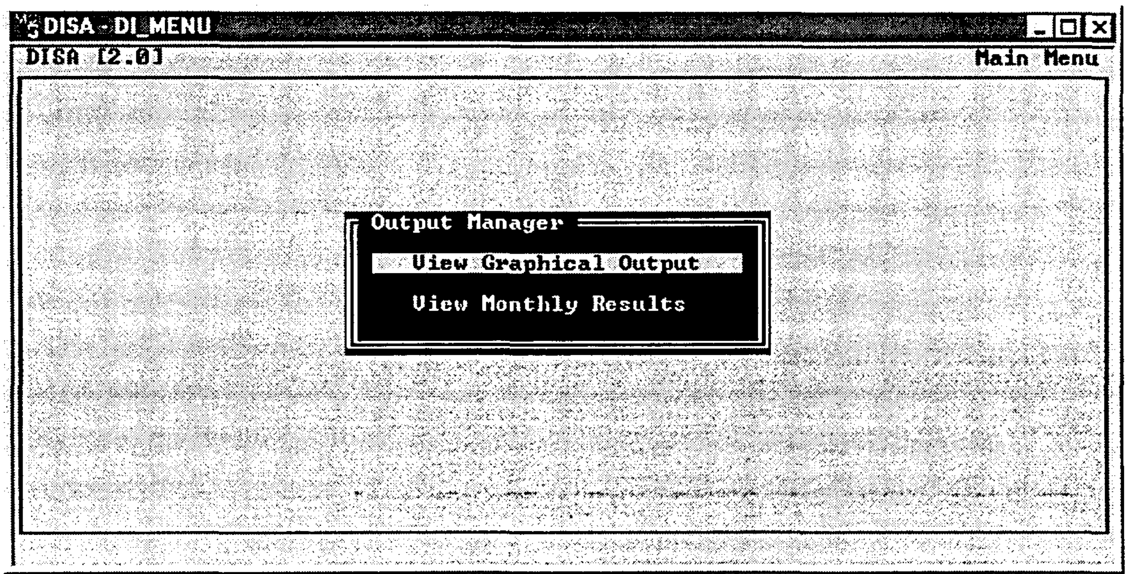


Figure 8.2 : Output Manager entry menu

7. THE SYSTEM MODEL

The System Model uses the database compiled by the Database Manager and a system description contained in a parameter file to perform a simulation. Only this parameter file must be selected in order to start a run. Output is generated according to the output flags specified in the parameter file (see Section 6.3.2).

7.1 STARTING A RUN

Select the **System Model** option from the DISA menu. After specifying the directory search path (see Section 2.3), you will be presented with a screen containing a list of available parameter files. Select the EXAMPLE.PAR parameter file. The run will commence and a status screen (see Figure 7.1), displaying run-time information will be displayed on the screen.

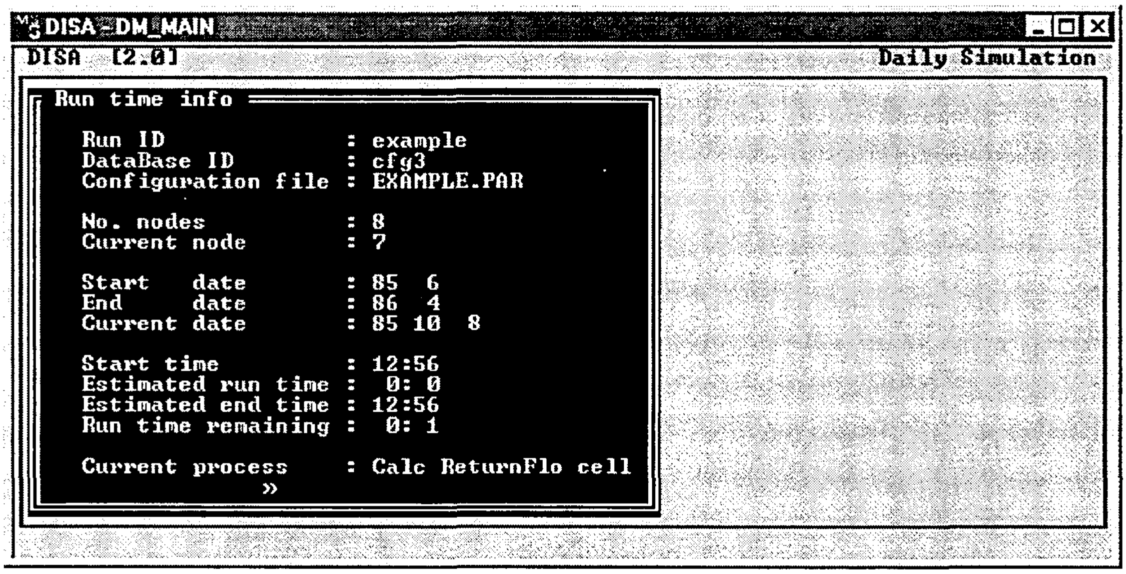


Figure 7.1 : Run-time information

7.2 RUN-TIME ESTIMATION

During a model run, the time remaining until completion is estimated and updated after every week of simulation.

A model run for a simulation period of 340 days and a system consisting of 70 return flow cells, 175 abstraction nodes, 35 inflow nodes, 24 canal nodes, 70 farm dam nodes and 10 routing nodes has a run time of approximately one hour. (Estimated for an AT machine with a math co-processor).

On completion, a flashing message will appear at the bottom of the information screen. pressing any key will return you to the DISA menu.

Select the **Select File** option from the main menu. After specifying the directory search path, a screen containing a list of available graphical output (.FSV) files will be displayed. Select the EXAMPLE.FSV file.

8.3 THE "PLOT LIST" CONCEPT

In order to plot output from a range of nodes on the same graph, plot lists must be defined. Figure 8.5 shows the input screen that is used for defining plot lists (Set Lists option on the Output Manager main menu).

Nodes are identified by the sequence in which they have been flagged for output in the Configurator (see Section 6.3.2). Output from nodes in the same list (plot ranges) will appear on the same graph.

Enter the lists as they are defined in Figure 8.5 on the Set Lists input screen. This will enable you to view the output generated by the System Model for the EXAMPLE.PAR configuration.

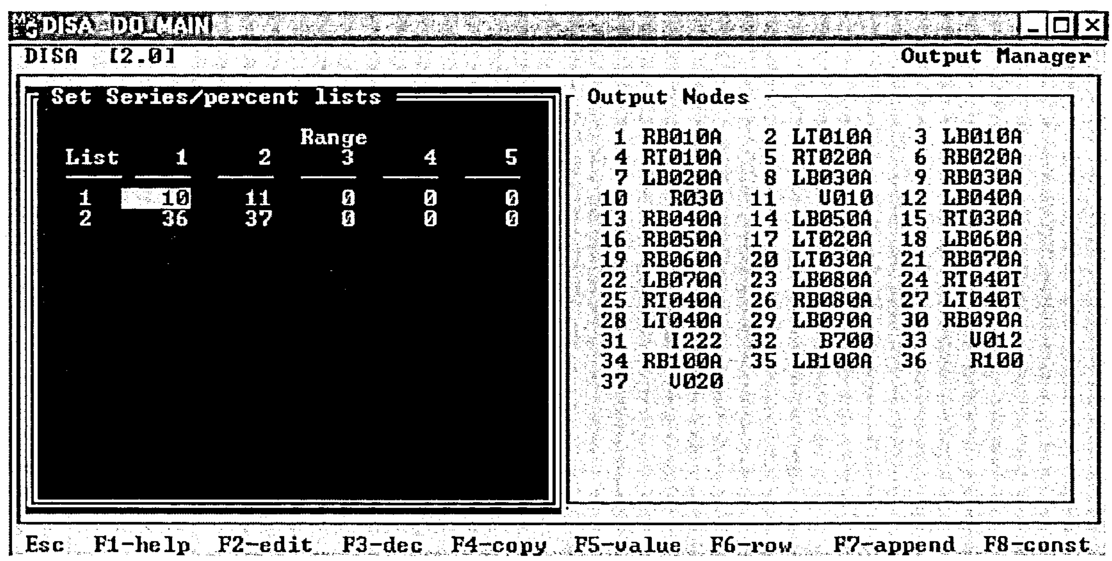


Figure 8.5 : Plot lists input screen

8.4 PLOT TYPE SELECTION

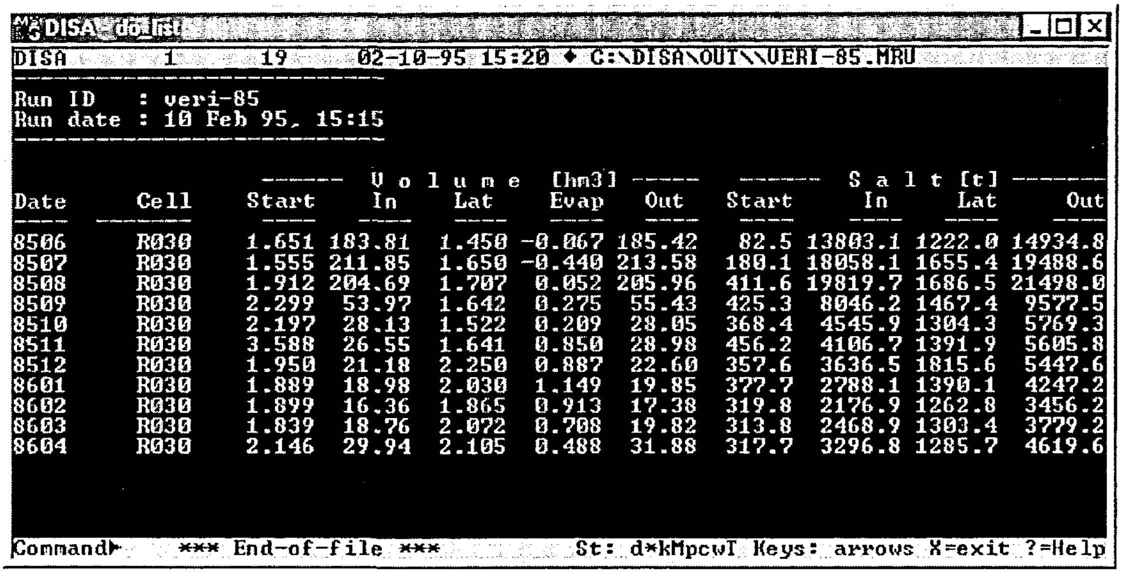
To generate either a time series or a duration curve (percentile) plot, follow these steps :

(a) Select the **Plot** option on the main menu. Time series or percentile plots can be selected from the **Plot Type** sub-menu.

(b) Apart from selecting time series or percentile plots, you can select between single or double box graphs (as shown in Figures 8.7 and 8.8), by using the sub-menu shown in Figure 8.6.

8.1 VIEWING NUMERIC OUTPUT

Select the **View Monthly Results** option from the entry menu. You will be prompted for a file search path (see Section 2.3). After selecting the required output file, it will be displayed in a window such as the one shown in Figure 8.3.



		Volume [hm3]					Salt [t]			
Date	Cell	Start	In	Lat	Evap	Out	Start	In	Lat	Out
8506	R030	1.651	183.81	1.450	-0.067	185.42	82.5	13803.1	1222.0	14934.8
8507	R030	1.555	211.85	1.650	-0.440	213.58	180.1	18058.1	1655.4	19488.6
8508	R030	1.912	204.69	1.707	0.052	205.96	411.6	19819.7	1686.5	21498.0
8509	R030	2.299	53.97	1.642	0.275	55.43	425.3	8046.2	1467.4	9577.5
8510	R030	2.197	28.13	1.522	0.209	28.05	368.4	4545.9	1304.3	5769.3
8511	R030	3.588	26.55	1.641	0.850	28.98	456.2	4106.7	1391.9	5605.8
8512	R030	1.950	21.18	2.250	0.887	22.60	357.6	3636.5	1815.6	5447.6
8601	R030	1.889	18.98	2.030	1.149	19.85	377.7	2788.1	1390.1	4247.2
8602	R030	1.899	16.36	1.865	0.913	17.38	319.8	2176.9	1262.8	3456.2
8603	R030	1.839	18.76	2.072	0.708	19.82	313.8	2468.9	1303.4	3779.2
8604	R030	2.146	29.94	2.105	0.488	31.88	317.7	3296.8	1285.7	4619.6

Figure 8.3 : Monthly results viewing window

Use the <UP>, <Down>, <Left> and <Right> cursor keys to browse through the output file. Use the <PGUP> and <PGDN> cursor keys to rapidly scroll through the file. Pressing <ESC> will return you to the **Select File** input screen. You may either select another file for viewing, or return to the DISA menu by pressing <ESC> again.

8.2 VIEWING GRAPHICAL OUTPUT FILES

Activate the Output Manager by selecting the **Output Manager** option on the DISA menu. Select the **View Graphical Output** option from the entry menu. The Output Manager main menu (Figure 8.4) will be displayed.

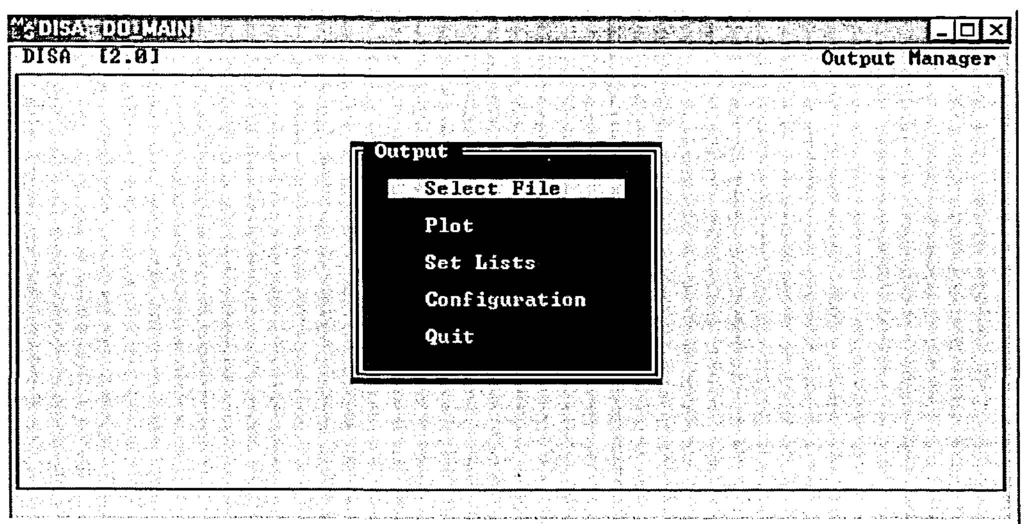


Figure 8.4 : Output Manager main menu

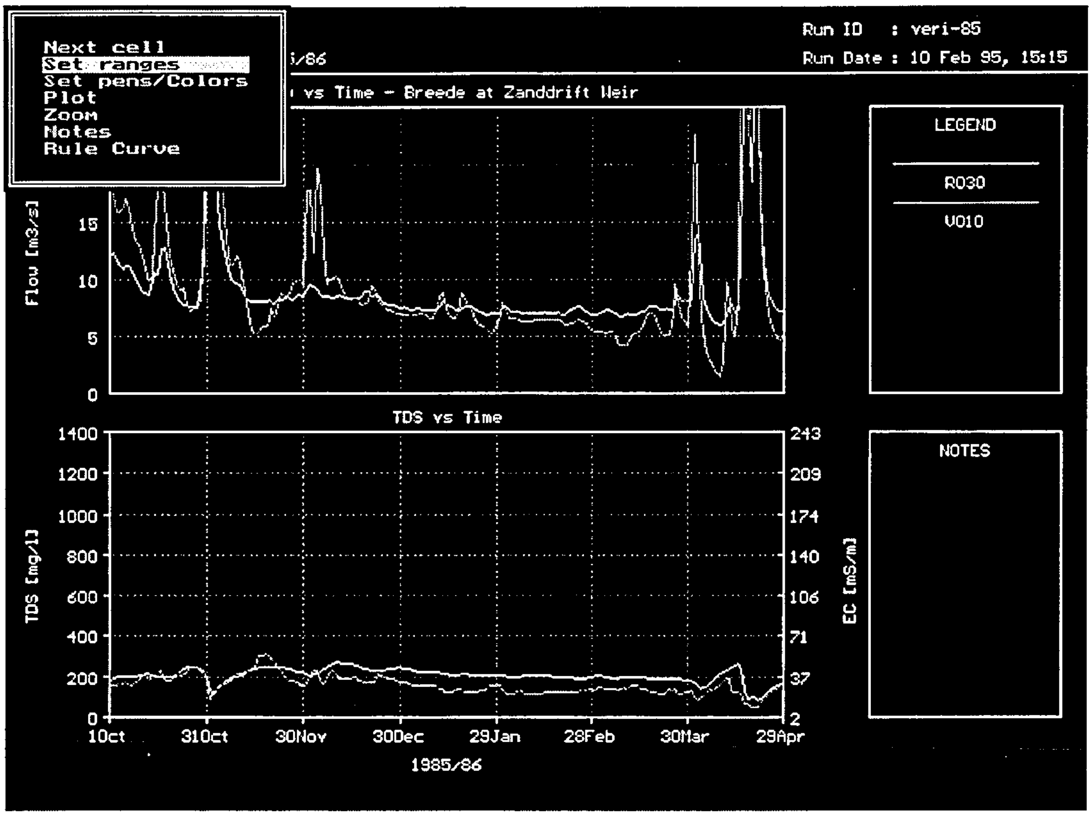


Figure 8.8 : Double box (time series) plot

Select option 6 (Double box, time series plot of a list of ranges) on the sub-menu.

(c) When prompted for the list number to plot, accept the default (List 1). The graphical output contained in the EXAMPLE.FSV file will be displayed on your screen.

8.5 GRAPHICS SCREEN "POP-UP" MENU

Changes to graph settings can be made without leaving the graphics screen. Figure 8.8 shows the graphics screen menu which can be accessed by pressing the space bar. The following options are available :

(a) **Next cell**. Output from the next node or list of nodes can be plotted without leaving the graphics screen.

(b) **Set ranges**. (See Figure 8.9). Plot titles, grid dimensions and axis ranges can be set by selecting this option.

(c) **Set pens/colours**. If more than one graph is displayed on the same screen, you can specify the colour and/or line style for each of the lines on the graph.

(d) **Plot**. the current graph can be spooled to a parallel or serially connected plotter or to a HPGL disk file.

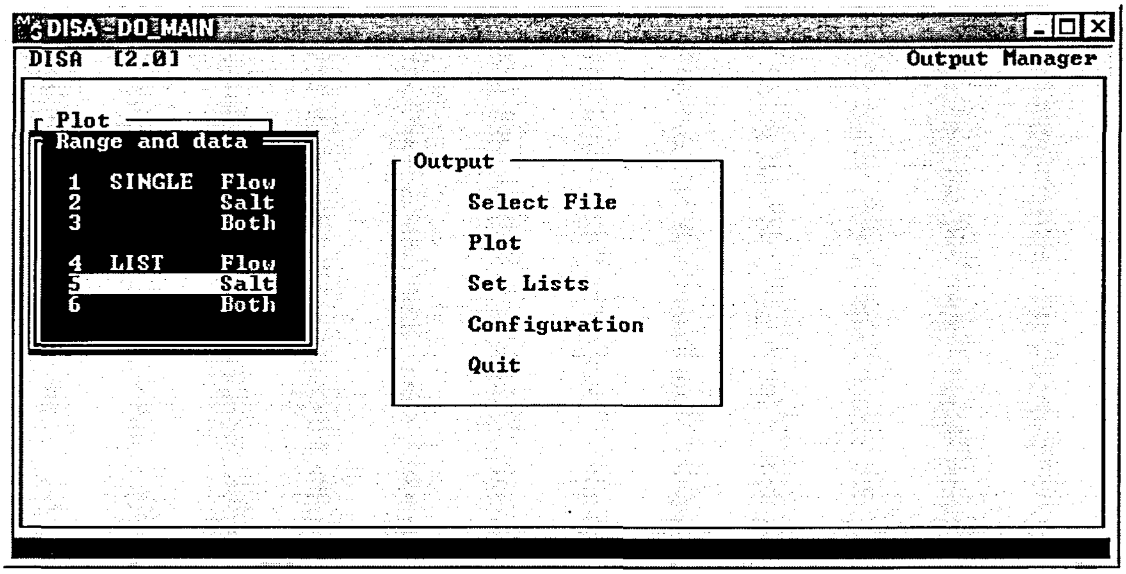


Figure 8.6 : Box selection sub-menu

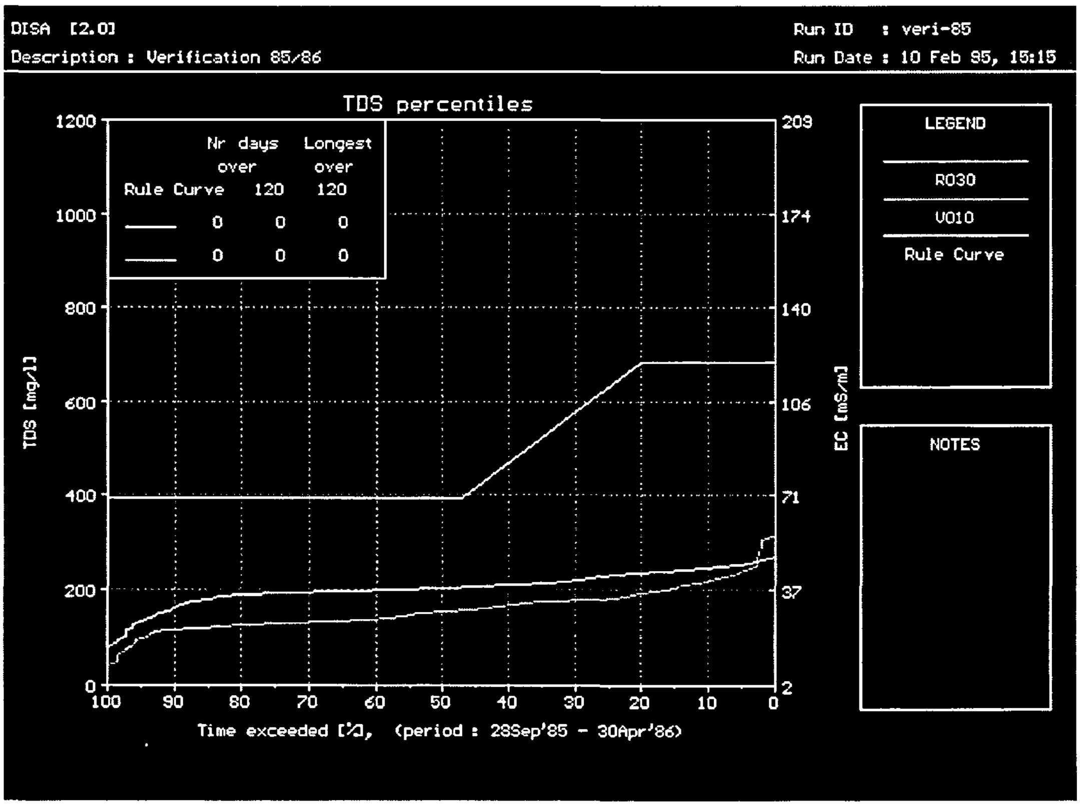


Figure 8.7 : Single box (percentile) plot

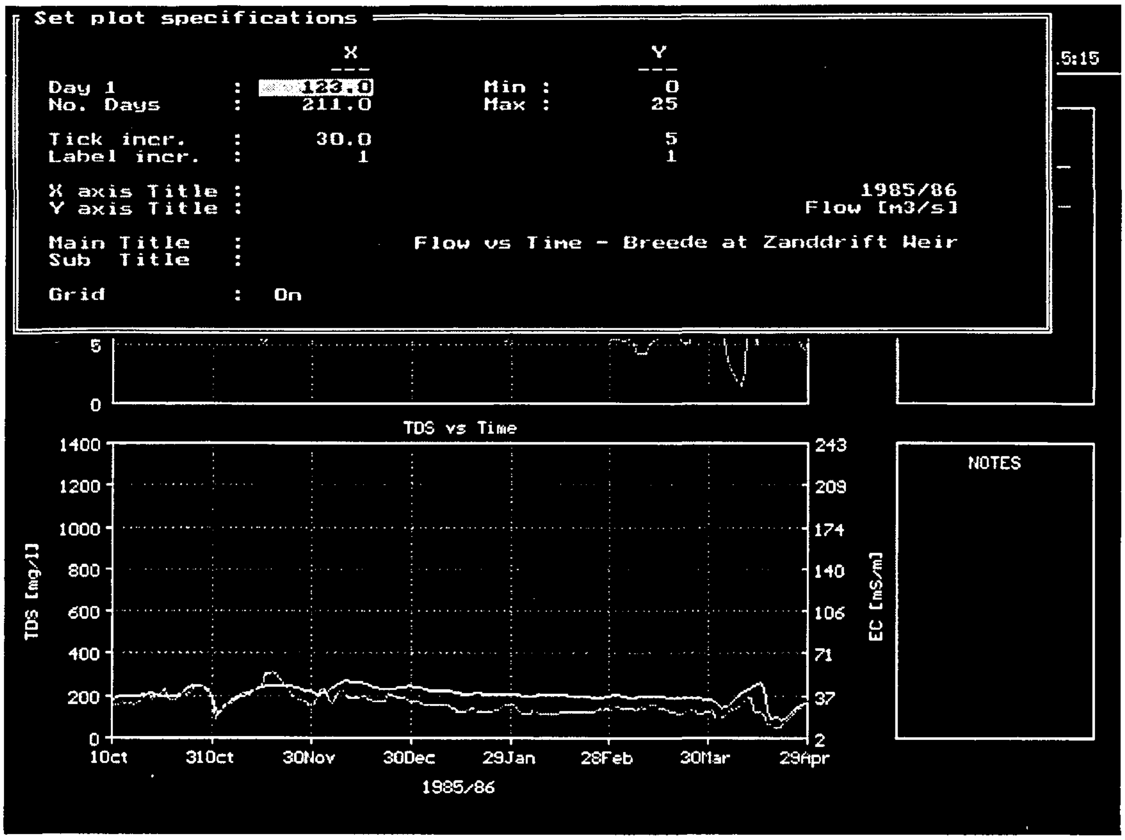


Figure 8.9 : Plot specifications input screen

Step back to the Output Manager main menu by using the **<ESC>** key. Selecting the **Quit** option will return you to the DISA menu.