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HYDROTEL 2.0 USER'S GUIDE.

HYDROTEL 2.0

USER'S GUIDE

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PART 1
GENERAL INFORMATION

PART 1 GENERAL INFORMATION

1.1 Software main characteristics and hardware requirements

Name:	HYDROTEL 2.0
Objective:	Simulation of streamflows using ground and remotely sensed data.
Programming languages:	"C".
Type of microcomputer:	IBM PC/XT or AT and compatibles with a mathematical co-processor.
Memory requirements:	640K.
Written by:	Jérôme Benoît, Claude Blanchette and Martin Montminy.
Developed by:	Jean-Pierre Fortin, Jean-Pierre Villeneuve, Jérôme Benoît, Claude Blanchette, Martin Montminy and Hilaire Proulx at INRS-Eau, Quebec, Canada. Claude Bocquillon and Roger Moussa, LHM, USTL, Montpellier, France.

1.2 Introduction

Considering, as others (Peck et al., 1981; Rango, 1985), that there was a need for the development of hydrological models compatible with remotely sensed data, INRS-Eau began such a development a few years ago. Work was undertaken on various aspects of hydrological modelling, namely: type of simulation for surface and sub-surface runoff as well as for channel routing, determination of basin topography from a digital elevation model (DEM), display and analysis of images on microcomputers, land-use determination for hydrological purposes, integration of weather radar and station data...

At the beginning, the model was seen as one program allowing determination of basin topography from DEM, land-use determination from the analysis of remotely sensed images and hydrological simulation and forecasting. As seen in figure 1.1, it was thought later on that the large number of tasks would be handled more easily by three interrelated software packages instead of one. The HYDROTEL package will be devoted to hydrological simulation and forecasting. As such, it will receive input data in the proper format from PHYSITEL (topography) and IMATEL (land-use and daily operational data (surface temperature, albedo, ...)).

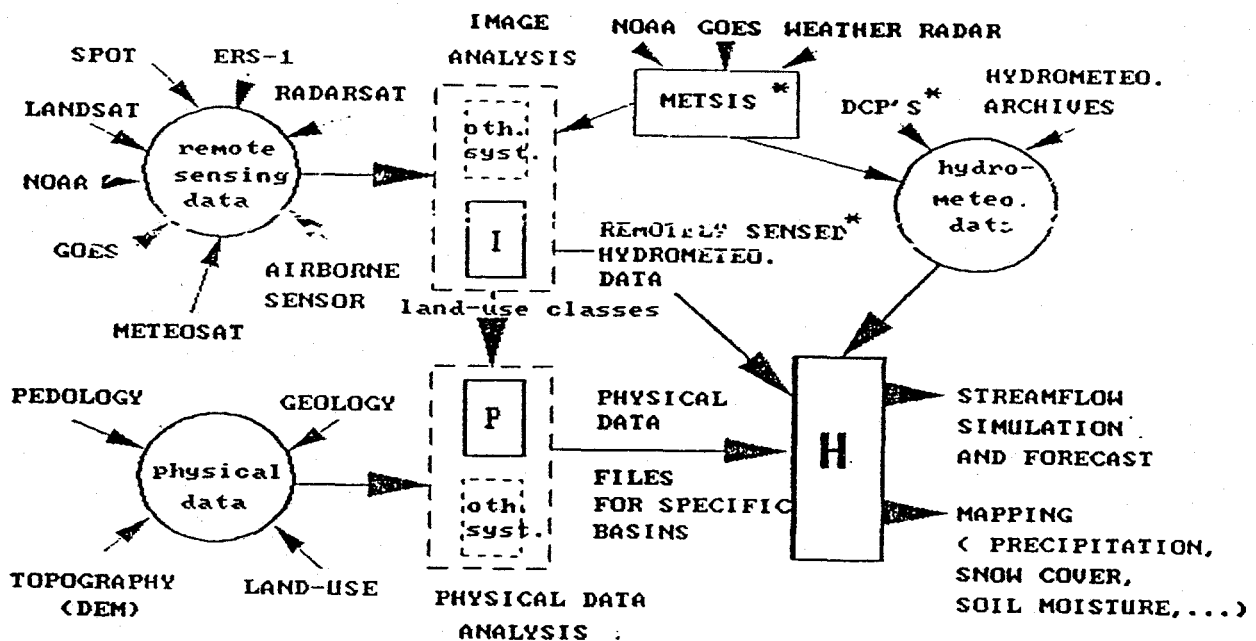


Figure 1.1 Integrated analysis of physical, remotely sensed and meteorological data for steamflow simulation and forecasting by PHYSITEL, IMATEL and HYDROTEL.

As seen by INRS-Eau the status of the current HYDROTEL version (V 2.0) is the following:

- HYDROTEL 2.0 structure has been conceived and programmed to answer users needs and facilitate the gradual addition of all wanted options to a fully "à la carte" model, as well as the input and output of G.I.S. and time dependent data;

- HYDROTEL 2.0 should be regarded as only a step in the development of the model originally conceived.
- HYDROTEL 2.0, allows the testing of any of the sub-models without having to include all parts of the water cycle (all sub-models) in a particular run, provided the appropriate input files are furnished.
- HYDROTEL 2.0 is presented with better data displays.
- HYDROTEL 2.0 stores simulation parameters for the next simulation so that the users does not have to go through the whole input process each time he wants to proceed to a new simulation. Only the parameters he wants to change need a new input.

1.3 Organization of the manual

Part "ONE" of the manual contents general information on HYDROTEL 2.0.

In part "TWO", the user is first told how to install the computer program. Information on the data set furnished with the program is then given. This data set is made available to the user to allow him to get acquainted with the model. Information on how to start the program is next given. This is followed by a detailed information, window by window, on the simulation choices, and input data.

A description of the main simulation methods available with HYDROTEL 2.0 is finally given in part "THREE", together with hints on how to select values for model parameters.

1.4 Software availability and information

The current version (2.0) of HYDROTEL is available only to Environment Canada and CCRS personnel participating in the testing of that version, to help defining the options that should be available in HYDROTEL (2.nn).

Agreements with other agencies is also possible.

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PART 2

THE HYDROTEL PROGRAM (2.0)

PART 2 THE HYDROTEL PROGRAM (2.0)

2.1 General model structure

Before getting into detailed informations on how to use the HYDROTEL model, it should be known first that it is a distributed model. This means that variables like rainfall, snowcover, snowmelt, evapotranspiration, soil moisture and ground water are spatially discretized, as are also surface and subsurface runoff and channel routing (figure 2.1). It is thus possible to keep track of what happens anywhere in a given basin at any time step.

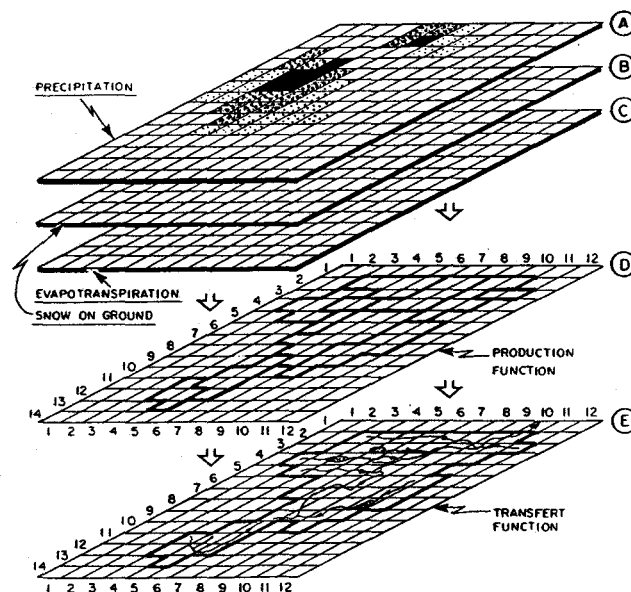


Figure 2.1 Spatial structure of the model.

Another main characteristic of HYDROTEL is that it is divided into modules, each offering a number of options. These modules are:

- INPUT (interactive input of all necessary data to run the model);
- PHYSIOGRAPHY (management and storage of topography and land use data);
- PRECIPITATION (divided into 2 sub-modules: interpolation of precipitations and snowcover and snowmelt simulation);

- EVAPOTRANSPIRATION (estimation of potential evapotranspiration);
- HYDROLOGY (divided into 3 sub-modules: vertical water budget, surface and subsurface runoff and channel routing);
- OUTPUT (screen display, files saving and retrieving, hard print);
- MAIN (management of all tasks).

A third characteristic of HYDROTEL is the possibility for the user to incorporate its own simulation options to those already available in the model. This characteristic should be very interesting for specific applications. This means that, if a user has developed a program for the simulation of a particular part of the hydrologic cycle, it could be possible for him to integrate it in the HYDROTEL program as a new user's defined option.

2.2 Getting started

This section gives all necessary informations to install the program on your microcomputer. A data set is also furnished with the model to help the user to get acquainted with it.

2.2.1 List of files on floppy disks

HYDROTEL 1.1 is sent on three 1.2 M floppy disks.

Content:

Disk #1: Program disk.

- . CONFIG.SYS
- . AUTOEXEC. BAT

- . KERNEL.SYS
- . HYDROTEL.EXE
- . HYDROTEL.ENM
- . HYDROTEL.MAK
- . \OBJ (compiled modules)
- . \BASINS (Clifton data for the year 1973).

Disk #2: Display and printer drivers disk.

Adage/Lexidata PG90 Model 30
 AT&T 6300/6310 - 640 x 400 Monochrome
 AT&T 6300/6310 - 640 x 400 Color
 Compaq Portable III Display
 DGIS High Performance Displays
 Hercules InColor Display
 Hercules Monochrome Graphics Adapter
 High Resolution EGA Displays
 IBM 8514/a 1024 x 768 Display
 IBM 8514/a 640 x 480 Display
 IBM Color Graphics Adapter - High Res. Mono.
 IBM Color Graphics Adapter - Med. Res. Color
 IBM Enhanced Graphics Adaptor - 4 modes
 IBM Personal System/2 - Mode 11
 IBM Personal System/2 - Mode 12
 IBM Personal System/2 - Mode 13
 Toshiba 3100 Lap Top Display

ADAGE30.SYS
 CGI6300B.SYS
 CGI6300C.SYS
 COMPAQ3.SYS
 CGIDGIS.SYS
 HERCINCO.SYS
 HERCBW.SYS
 HIRESEGA.SYS
 IBMAFH.SYS
 IBMAFL.SYS
 IBMBW.SYS
 IBMCO.SYS
 IBMEGA.SYS
 IBMVGA11.SYS
 IBMVGA12.SYS
 IBMVGA13.SYS
 T3100.SYS

HP laser jet
 EPSON LQ series
 EPSON *X series

LASERJET.SYS
 EPSONLQ.SYS
 EPSONX.SYS

Disk #3: Data disk.

. Results obtained with default values for:

C:\CLIFTON.TEM
 CLIFTON.PRE
 CLIFTON.FON
 CLIFTON.ETP
 CLIFTON.PRO
 CLIFTON.RUI
 CLIFTON.DEB

. \BASINS\

CLIFTON.ALT	CLIFTON.STN	M7022306.73	M7024624.73
CLIFTON.CLA	CLIFTON.TRO	M7022306.74	M7024624.74
CLIFTON.CLU	CLIFTON.TSO	M7027802.73	M7027802.74
CLIFTON.ICR	ALBEDO.YY	M7023312.73	M7028124.73
CLIFTON.IRO	HAU_VEG.YY	M7023312.74	M7028124.74
CLIFTON.MSK	PRO_RAC.YY	M7027372.73	M7028906.73
CLIFTON.NDS	INF_FOL.YY	M7027372.74	M7028906.74
CLIFTON.ORI	M7020885.73	M7027520.73	H0030242.73
CLIFTON.PCP	M7020885.74	M7027520.74	H0030242.74
CLIFTON.PTE	M7022280.73	M7024263.73	
CLIFTON.SOL	M7022280.74	M7024263.74	

2.2.2 Installing HYDROTEL 2.0

The AUTOEXEC.BAT and CONFIG.SYS files on your system should first be modified to run HYDROTEL 1.1:

- modifications to AUTOEXEC.BAT file

add: SET KERNEL=c:\HYDROTEL
 SET HYDROTEL=c:\HYDROTEL\BASINS

- modifications to CONFIG.SYS file

add: FILES=30

DEVICE=c:\dir\name.SYS

where: "dir" is the directory where the display driver is.

"name.SYS" is the code name of the display driver.

DEVICE=C:\dir\name.SYS

where: "dir" is the directory where the printer driver is

"name.SYS" is the code name of the printer driver.

DEVICE=\GSSCGI.SYS

Note: the previous command may be modified to:

DEVICE=\GSSCGI.SYS/T

In that case, only the essential parts of the GSS program are loaded when booting the computer, saving memory space for other programs run on the computer. It is then necessary to copy DRIVERS.EXE in c:\HYDROTEL. Otherwise, this is not necessary.

When the AUTOEXEC.BAT and CONFIG.SYS files are modified, one may proceed with the other files. Since paths to files are asked for in the menu, the user may copy the files in any directory or subdirectory.

The following procedure is suggested, but is not mandatory. It is assumed that the microcomputer has a hard disk and that the user is already on C:

1. create a new directory (or subdirectory) HYDROTEL, using the MS-DOS command MD;
2. change from the current directory (or subdirectory) to the new directory HYDROTEL, using the MS-DOS command CD;
3. copy all model files from disk #1 to that subdirectory;
4. make a subdirectory BASINS;

5. change to that subdirectory;
6. copy all data files from disk #1 (1973) or disk #3, to that subdirectory. You should now be ready to start the program.

2.2.3 Test data and structure of data files

In order to familiarize the user with HYDROTEL 2.0, a data set is included with the program. At the same time, it should be looked at as an example, for the preparation of other data sets.

Test basin: sub-basin of the Eaton river upstream of streamgauge station 030242 (located downstream of the bridge on highway 210, at Sawyerville. Figure 2.2 shows the position of the station on the map, together with those of meteorological stations and basins limits.

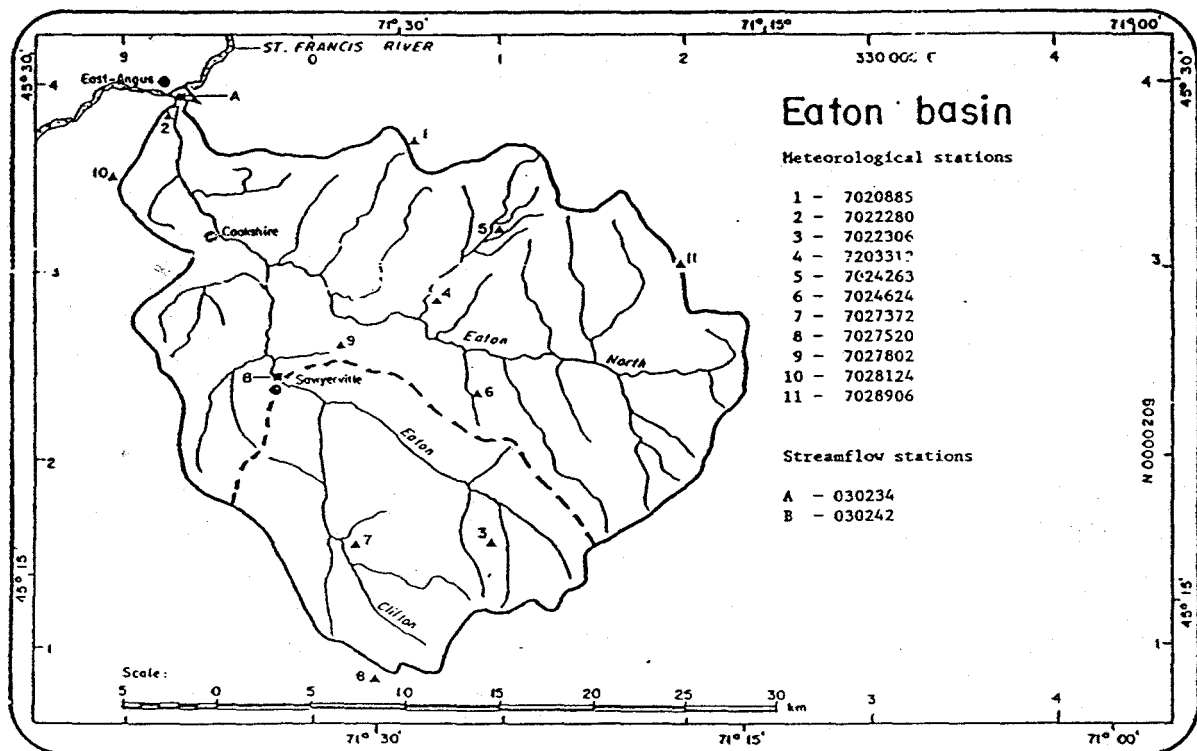


Figure 2.2 Streamflow and climatological stations on the Eaton basin.

Are included in the data set:

. topographic data:

- File names and content:
 - Clifton.ALT: mean altitude of each square (m);
 - Clifton.ORI: aspect of each square to eight points of the compass, identified 1 to 8 counterclockwise from East (= 1);
 - Clifton.PTE: slope of each square (m/m);
 - Clifton.MSK: basin mask;
 - Clifton.NDS: information on reach ends (identification number, UTM coordinates (m), altitude (m) and channel width (m));
 - Clifton.TRO: information on reaches (identification numbers for lower and higher ends (in that order), Manning's roughness coefficient).
- File structure for *.ALT, *.ORI, *.PTE, *.MSK:
 - line #1: file type: 1;
 - line #2: number of lines, number of columns;
 - line #3: UTM coordinates (Easting, Northing) of upper left corner, grid size (m);
 - line #4: title or comment identifying the file;
 - line #5 to 4 + (li X co): data (separated by blanks).
- File structure for *.NDS:
 - line #1: file type: 1;
 - line #2: number of reach ends;
 - line #3: title or comment identifying the file;
 - line #4 to (3 + number of reach ends): identification number, Easting, orthing, altitude (m), channel width (m).

- File structure for *.TRO:

- line #1: file type: 1;
- line #2: number of reaches (= number of reach ends - 1);
- line #3: title or comment identifying the file;
- line #4 to (3 + number of reaches): identification numbers for downstream and upstream ends, Manning's roughness coefficient.

- land-use data:

- File names and content:

- Clifton.CLA: spatial distribution of land-use classes;
- Clifton.CLU: time invariant characteristics of land-use classes;
- Albedo.YY: albedo values of each land-use class as a function of time for year "YY";
- Hau_veg.YY: height of each land-use class as a function of time, for year "YY";
- Pro_rac.YY: depth reached by the root system, of each land-use class, as a function of time, for year "YY";
- Inf_fol.YY: leaf-area index of each land-use class, as a function of time, for year "YY".

- File structure for *.CLA:

- line #1: file type: 1;
- line #2: number of lines, number of columns, number of classes;
- line #3: EAST, NORTH, class codes, TOTAL;
- line #4 to 3 + (li x co): UTM coordinates (Easting, Northing) of upper left corner, number of pixels belonging to each class, total number of pixels.

- suggested class identification and codes:

- bare fields: "champ";
- crops and pasture 1: "herbe";

- crops and pasture 2: "paill";
 - extracting areas: "gravi";
 - forested areas 1 (coniferous): "resin";
 - forested areas 2 (deciduous): "feuil";
 - highways and other impervious areas: "route";
 - surface waters 1: "eau1";
 - surface waters 2: "eau2";
 - urban areas: "urb" (not in use);
 - waste lands and bushes: "frich" and "coupe";
 - wet lands and marshes: "MAR" (not in use).
- File structure for *.CLU:
- line #1: file type: 5;
 - line #2: number of land-use classes, number of characteristics for each land-use class;
 - line #3: title or comment identifying the file;
 - line #4: Nom_COT COT CO ZS ZV ZP;
(Line #4 is considered as a comment. It is there only to help in the identification of the values below. The user can change the wording, but not the order).
 - line #5 to 4 + number of land-use classes: maximum fraction CO(I) of the relative water content at field capacity useful for land-use class I (LUC1), maximum depth at which vegetation of LUC I can pump water at a rate equal to $C_o(I)$, depth reached by the roots when the root system is fully developed at the surface, maximum depth of the root system at maturity.
(Remember that $ZV < ZP - ZS$. The order in which land-use classes are listed is not important, but the code names must be the same as that given in *.CLA).
- File structure for Albedo.YY, hau_veg.YY, Pro_rac.YY, Ind_fol.YY:
- line #1: file type: 2;

- line #2: number of land-use classes, number of days (N of D) for which values are available, year;
- line #3: title or comment identifying the file;
- line #4: Month, Day, land-use class (LUC) code (1), LUC code (2), ..., LUC code (#LUC).
- line #5 to 4 + N of D: actual values for month, day and LUC (same order as decided in line #4).

(The order in line #4 is not important, but the code names must be the same as that given in *.CLA. The extension "YY" should be changed to that of the actual year .eg. "73").

. Soil data:

- File names and content:

- Clifton.SOL: hydraulic characteristics of soil types;
- Clifton.TSO: spatial distribution of soil types in the watershed.

- File structure for *.SOL:

- line #1: file type: 3;
- line #2: number of soil types, number of characteristics for each soil type;
- line #3: title of comment identifying the file;
- line #4: Name Thetas Thetacc Thetaph KS PSIS Lambda Alpha
(Line #4 is considered as a comment. It is there only to help in the identification of the values below. The user can change the wording, but not the order.
- line #5 to 4 + number of soil types: code name, water content at saturation (m^3m^{-3}), water content at field capacity (m^3m^{-3}), water content at the permanent wilting point (m^3m^{-3}), hydraulic conductivity (mh^{-1}), matrix potential at θ_s (m), pore size distribution, coefficient in eq. 3.28.

- File structure for *.TSO:
 - line #1: file type: 4;
 - line #2: number of lines, number of columns;
 - line #3: UTM coordinates (Easting, Northing), spatial resolution (m);
 - line #4: title or comment identifying the file.
 - line #5 to 4 + (number of line -1):
 - code (0,0) - - - - - code (0, ncol-1)
 - |
 - |
 - code (nlig -1,0) - - - - - code (nlig-1, ncol-1)

where the code values correspond to entries in file *.SOL. A code value of "0" corresponds to the first soil type, a code value of "1" corresponds to the second soil type in *.SOL and so on.

Streamflow and meteorological data available for use in the simulation:

- List of meteorological stations:
 - file name: Clifton.STM:
 - file structure:
 - line #1: file type: 1;
 - line #2: number of meteorological stations;
 - line #3: title or comment identifying the file;
 - line #4 to (3 + number of stations) identification number, longitude (degrees and minutes), latitude (degrees and minutes), altitude (m);
- List of streamflow stations:
 - file name: Clifton.STH
 - file structure:
 - line #1: file type: 1;
 - line #2: number of streamflow stations;

- line #3: title or comment identifying the file;
- line #4 to (3 + number of stations): identification number, longitude (degrees and minutes), latitude (degrees and minutes), altitude (m);

. INRS data formats

- streamflow data (ms) at streamgauge station 030242 for 1973 and 1974, beginning on the 1st of January of each year;
 - file name: H030242.YY (H station identification.year):
 - file structure:
 - line #1: station identification, year, number of valid values;
 - line #2 to 32: 366 daily streamflows. Missing data (including February 29): - 1000.
- meteorological data (maximum daily air temperature, minimum daily air temperature, rainfall, snowfall), for 1973 and 1974, beginning on the 1st of January of each year, at the following stations:
 - 7020885 Bury;
 - 7022280 East-Angus;
 - 7022306 Eaton 2nd Branch;
 - 7023312 Island Brook;
 - 7024263 Lawrence;
 - 7024624 Maple Leaf East;
 - 7027372 St-Isidore d'Auckland;
 - 7027520 St-Malo d'Auckland;
 - 7027802 Sawyerville Nord;
 - 7028124 Sherbrooke A;
 - 7028906 West Ditton.

- file name: M7020885.YY (M station identification.year):
- file structure:
 - line #1: station identification, year, numbers (4) of valid data for maximum temperature, minimum temperature, rain and snow respectively, latitude in degrees and minutes, longitude in degrees and minutes, altitude (m), station identification;
 - line #2 to 17: 366 maximum temperature (°C);
 - line #18 to 33: 366 minimum temperature (°C);
 - line #34 to 49: 366 rainfall values (10^{-1} mm);
 - line #50 to 65: 366 snowfall values (10^{-1} cm).
- missing data:
 - temperatures: -99;
 - rainfall or snowfall: -1.
- . Environment Canada data formats
 - Format for streamflow data (from Environment Canada card format 79-041 (daily discharges)

Daily discharges for each month are stored on three 80 columns lines.

General format for each line:

Column's

- 1 code for type of data and units. Q-daily discharges in cubic metres per second
- 2-8: station number, e.g. 08AA023
- 9-11: year, e.g. "968" for 1968
- 12-13: month, e.g. "b7" for July

- 14: code for time interval
- 1: daily figures from day 1 to day 20
 - 2: daily figures from day 11 to day 20
 - 3: daily figures from day 21 to day 31
- 15-80: ten or eleven 6 - character data fields

Comments:

- Each data field has six positions.
The first five positions contain daily discharge data, right justified with a decimal point if necessary; the sixth position contains a symbol.
- Whenever data are missing the value "-9999" is entered in positions 1-5 and position 6 contains a blank.
- The first line contains 10 days from day 1 to 10; columns 75-78 are not used; the number of days in the month, e.g. "30" for November, is typed in columns 79-80.
- The second line contains 10 days from day 11 to 20; columns 75-80 are not used.
- The third line contains 11 days from day 21 to 31; the figure "-1111" is written in the appropriate field for days that do not apply to the months e.g. 30 and 31 for February 1968, and position 6 contains a blank.
- Format for meteorological data (from Format documentation for the digital archive of canadian climatological data).
- Daily values: Daily values are archived as 232 character long monthly records.
- File structure:

Column(s)

- 1-7: station identification (alphanumeric)
- 8-10: year, e.g. "973" for 1973 (numeric)

- 11-12: month, e.g. 01 = JAN. etc (numeric)
- 13-15: elements number (numeric)
- 16-232: 31 7-character groups structured as follows:
 - 1st character: sign "-" = negative
"0" = positive
 - 2nd to 6th character: data value (numeric)
 - 7th character: Flag (alphanumeric)

- File content (depending on element number):

The following elements are read and used in HYDROTEL 2.0

- maximum temperature: 001 (.1°C)
- minimum temperature: 002 (.1°C)
- Total precipitation: 012 (.1mm)

- Hourly values:

Hourly values are archived as 185 character long daily records.

- File structure:

Column(s)

- 1-7: station identification (alphanumeric)
- 8-10: year, e.g. "973" for 1973 (numeric)
- 11-12: month, e.g. 01 = JAN. etc (numeric)
- 13-14: day (numeric)
- 15-17: element number (numeric)
- 18-185: 24 7-character groups structured as follows:
 - 1st character: sign "-" = negative
"0" = positive
 - 2nd to 6th character: data value (numeric)
 - 7th character: Flag (alphanumeric)

- File content (depending on element number):

The following elements are read and used in HYDROTEL 2.0

- wind: 076 (km h^{-1})
- relative humidity: 080 (%)
- bright sunshine: 133 (.1 h)
- global solar radiation: 061 (.001 = MJ/m^2)

. Intermediate results

- Format for values on squares:

The following variables are concerned:

- temperatures (*.TPX and *.TPN)
- rain (*.PRE)
- snowmelt (*.FON)
- potential evapotranspiration (*.ETP)
- outflow (*.PRO)
- runoff (*.RUI)

- File structure:

- line #1: file type: 1 (integer)
- line #2: number of lines, number of columns in the grid (integers)
- line #3: UTM coordinates (Easting, Northing) of upper left corner (long integers), grid size (m) (integer)
- line #4: simulation period:
 - starting year (integer)
 - starting day (integer)
 - duration in days (integer)
- line #5: title or comment identifying the file
- line #6 to end of file: groups of daily values, one for each day of the simulation, structured as follows:
 - First line in the group: number of days since the beginning of the simulation ("o" for the first day).

- All other lines in the group: (li X co) values recorded by lines to facilitate display.
- Format for streamflow values in reaches.

The following file is concerned:

Streamflows (*.DEB)

- File structure:
 - line #1: file type: 1 (integer)
 - line #2: number of reaches (integer)
 - line #3: simulation period
 - starting year (integer)
 - starting day (integer)
 - duration in days (integer)
 - line #4: title or comment identifying the file
 - line #5 to end of file: groups of daily values, one for each day to of the simulation, structured as follows:
 - First line in the group: number of days since the beginning of the simulation ("o" for the first day).
 - All other lines in the group:
 - reach identification number (integer)
 - lateral input (real)
 - streamflow at downstream mode (real)

. Initial settings of state variables

- Initial settings for the vertical water budget (file *.PIS).
- File structure:
 - line #1: file type: 1 (integer)
 - line #2: number of lines, number of columns in the grid (integers)

- line #3: UTM coordinates (Easting, Northing) of upper left corner (long integers), grid size (m) (integer)
- line #4: title or comment identifying the file
- line #5 to end of file: three groups of (li X co) values corresponding respectively to water levels in the soil (1), ground water (2) and lakes and marshes (3) reservoirs in the CEQUEAU vertical water budget option.

. Initial settings for surface and sub-surface runoff (file *.RIS)

- File structure:
 - line #1: file type: 1 (integer)
 - line #2: number of lines, number of columns in the grid (integers)
 - line #3: UTM coordinates (Easting, Northing) of upper left corner (long integers), grid size (m) (integer)
 - line #4: title or comment identifying the file
 - line #5 to end of file: (li X co) runoff values (real)

. Initial settings for streamflows in reaches (file *.CIS)

- File structure:
 - line #1: file type: 1 (integer)
 - line #2: number of reaches (integer)
 - line #3: title or comment identifying the file
 - line #4 to end of file:

For line #i corresponding to reach j

- index number for downstream end (different from identification number)
- index number for upstream end
- downstream flow (real)
- upstream flow (real)
- lateral inflow (real)

- Outflow coefficient: type the outflow coefficient.
- Fraction of PET taken in saturated zone: type the nominal fraction of potential evapotranspiration taken from the saturated zone.
- Reference level for fraction of PET (mm): type the reference level (in millimeters) for which the effective fraction of evapotranspiration taken from the saturated zone reservoir is that given above.

When this is done, leave the sub-menu by pressing "F10" (accept and save the new values) or "ESC" (no change to previously stored values).

2.3.5.4.1.4 Sub-menu #3.4.1.4: lakes and marshes (figure 2.43)

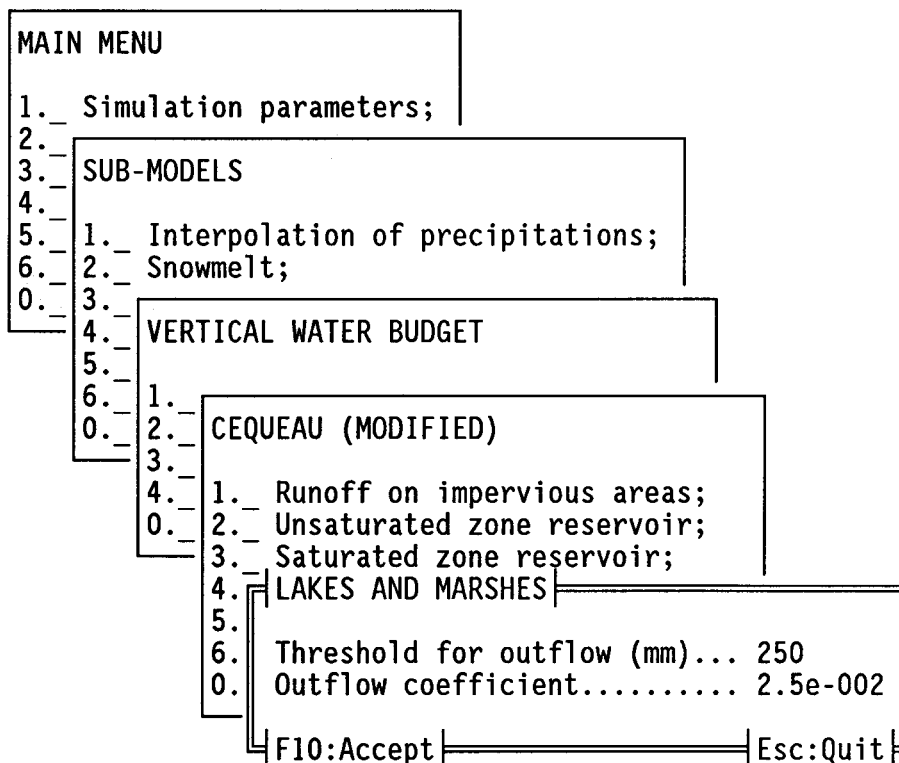


Figure 2.43 Sub-menu #3.4.1.4: lakes and marshes.

2.3 Using HYDROTEL (2.0)

2.3.1 Starting HYDROTEL 2.0

Your files should now be in the proper directories or sub-directories, including your own basin files or the test files.

If you are not there, first come back (change) to c:\HYDROTEL.

Now, type "HYDROTEL" and the main menu will appear on the screen.

If "/T" has been added to the command "DEVICE=\GSSCGI.SYS" in the CONFIG.SYS file, when in c:\HYDROTEL, type "DRIVERS" before typing "HYDROTEL". Typing "DRIVERS/R" when going out of HYDROTEL 2.0 will free memory space for other programs.

It should be mentioned at this stage that a tree structure has been developed for menus. The menus are written in a logical order so that even an unfamiliar user should normally be able to go through all steps in the initialization process easily.

2.3.2 Main menu

The main menu contains 7 options (figure 2.3). To choose an option, first go to that option using the arrows on the keyboard. Then, push the "ENTER" key. The sub-menu needed to define that option will appear.

When the last simulation is finished, you can go out of HYDROTEL by choosing the "End of simulation" option and pressing "ENTER".

From the main menu, it is possible to go to "DOS" to use DOS commands and come back to HYDROTEL. This may be useful to edit files, for instance.

```
MAIN MENU

1._ Simulation parameters;
2._ Data input;
3._ Sub-models;
4._ Data Output;
5._ Run;
6._ DOS shell;
0._ End of simulation.
```

Figure 2.3 Main menu.

2.3.3 Sub-menu #1.0: simulation parameters

Sub-menu #1 (figure 2.4) contains 3 options. Each of these options leads you to a new sub-menu in which simulation parameters are defined. You can return to the previous (main) menu (by selecting option "0" followed by the "ENTER" key).

```
MAIN MENU

1._ SIMULATION PARAMETERS
2._
3._ 1._ Path to files;
4._ 2._ Temporal parameters;
5._ 3._ Spatial parameters;
6._ 0._ Return to previous menu.
0._
```

Figure 2.4 Sub-menu #1.0: simulation parameters.

2.3.3.1 Sub-menu #1.1: paths to files

Informations on paths to files used by HYDROTEL have to be given here (figure 2.5):

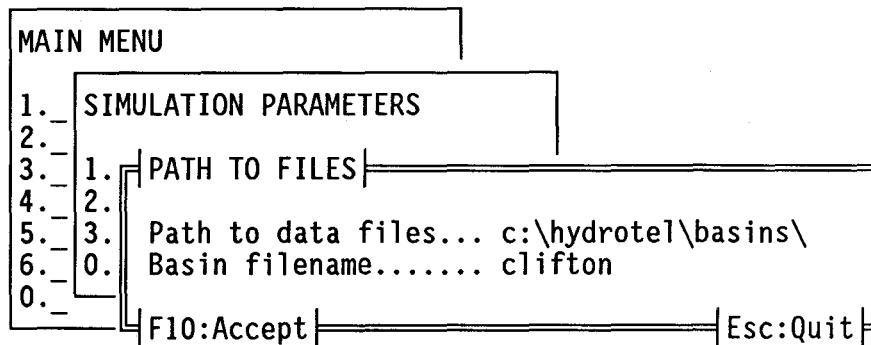


Figure 2.5 Sub-menu #1.1: paths to files.

- path to data files: it has been suggested in section 2.2 to group data files in a particular sub-directory. The path to files in that sub-directory should be given here;
- basin filename: this is the name under which all data files for a particular basin will be identified. As an example, the general name for all data in the set furnished with the program is "CLIFTON". Particular files are identified by "CLIFTON.***", with the stars corresponding to letters and/or numbers identifying the specific file.

At any time in that sub-menu you can quit the initialization process by pushing "ESC". The paths and basin name appearing on the screen remains in effect. No change is made to the previously stored name.

Normally, once the information is given you want to confirm or accept it. Press "F10". The paths to files are stored for later use by the program and return to the previous sub-menu #1.0 is done automatically.

2.3.3.2 Sub-menu #1.2: temporal parameters

Back to sub-menu #1.0, go to the next option "Temporal parameters" and press "ENTER" to get sub-menu #1.2 (figure 2.6):

- start of simulation (YY MM DD): year (last two digits), month and day of the first day of the simulation;
- duration (NN): the number of consecutive days in the simulation;
- time step (days): only one time step is allowed with HYDROTEL 2.0: 1 day.

All those values are entered by going to the proper line with the arrows on the keyboard and typing the appropriate values. When this is done, accept (and save) the values by pressing F10.

If you want to leave the menu without change, press "ESC".

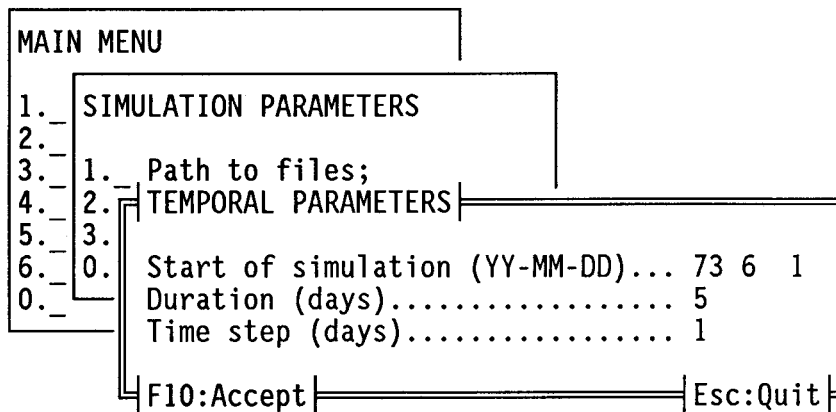


Figure 2.6 Sub-menu #1.2: temporal parameters.

TABLE 2.1 Julian days.

DAY	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	DAY
1	1	32	60	91	121	152	182	213	244	274	305	335	1
2	2	33	61	92	122	153	183	214	245	275	306	336	2
3	3	34	62	93	123	154	184	215	246	276	307	337	3
4	4	35	63	94	124	155	185	216	247	277	308	338	4
5	5	36	64	95	125	156	186	217	248	278	309	339	5
6	6	37	65	96	126	157	187	218	249	279	310	340	6
7	7	38	66	97	127	158	188	219	250	280	311	341	7
8	8	39	67	98	128	159	189	220	251	281	312	342	8
9	9	40	68	99	129	160	190	221	252	282	313	343	9
10	10	41	69	100	130	161	191	222	253	283	314	344	10
11	11	42	70	101	131	162	192	223	254	284	315	345	11
12	12	43	71	102	132	163	193	224	255	285	316	346	12
13	13	44	72	103	133	164	194	225	256	286	317	347	13
14	14	45	73	104	134	165	195	226	257	287	318	348	14
15	15	46	74	105	135	166	196	227	258	288	319	349	15
16	16	47	75	106	136	167	197	228	259	289	320	350	16
17	17	48	76	107	137	168	198	229	260	290	321	351	17
18	18	49	77	108	138	169	199	230	261	291	322	352	18
19	19	50	78	109	139	170	200	231	262	292	323	353	19
20	20	51	79	110	140	171	201	232	263	293	324	354	20
21	21	52	80	111	141	172	202	233	264	294	325	355	21
22	22	53	81	112	142	173	203	234	265	295	326	356	22
23	23	54	82	113	143	174	204	235	266	296	327	357	23
24	24	55	83	114	144	175	205	236	267	297	328	358	24
25	25	56	84	115	145	176	206	237	268	298	329	359	25
26	26	57	85	116	146	177	207	238	269	299	330	360	26
27	27	58	86	117	147	178	208	239	270	300	331	361	27
28	28	59	87	118	148	179	209	240	271	301	332	362	28
29	29	*	88	119	149	180	210	241	272	302	333	363	29
30	30		89	120	150	181	211	242	273	303	334	364	30
31	31		90		151		212	243		304		365	31

* For leap years, add 1 to julian day after February 28th.

2.3.3.3 Sub-menu #1.3: spatial parameters

Back to sub-menu #1.0, go to the next option "Spatial parameters" and press "ENTER" to get sub-menu #1.3 (figure 2.7):

- upper left corner (UTM): enter the upper left corner of the rectangular grid containing the basin, in UTM coordinates. Note: this will be change in later versions of HYDROTEL to use other coordinate systems more suitable to large basins;
- lower right corner (UTM): enter the lower right corner of the rectangular grid containing the basin, in UTM coordinates;
- resolution (m): enter grid size in meters. No more than 40 squares are allowed in either direction, N-S or E-W, leading to a 40 x 40 matrix, of which only 900 squares can be within the basin. This number is much larger than needed.

When this is done, accept (and save) the values by pressing "F10".

```

MAIN MENU
1. SIMULATION PARAMETERS
2.
3. 1. Path to files;
4. 2. Temporal parameters;
5. 3. SPATIAL PARAMETERS
6. 0.
0.

    UTM zone..... 19
    Upper left corner (UTM).... 295000    5026000
    Lower right corner (UTM)... 316000    5007000
    Resolution (m)..... 1000

    F10:Accept | Esc:Quit
  
```

Figure 2.7 Sub-menu #1.3: spatial parameters.

If you want to leave the menu without change, press "ESC".

Back to sub-menu #1.0 (figure 2.4), go to "Return to previous menu" and press "ENTER" to go back to the "main menu".

2.3.4 Sub-menu #2.0: data input

Sub-menu #2.0 (figure 2.8) leads the user to windows in which he will be able to provide the informations on input data needed for the simulation.

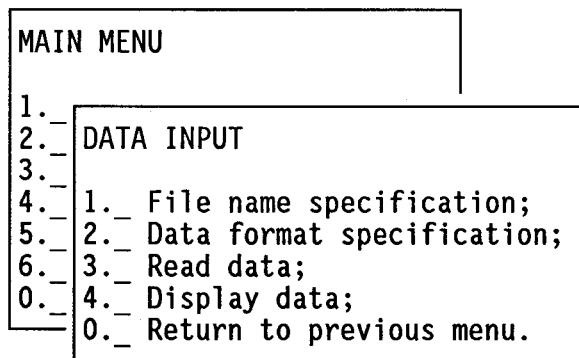


Figure 2.8 Sub-menu #2.0: data input.

2.3.4.1 Sub-menu #2.1: file name specification

Sub-menu #2.1 leads to three sub-menus in which the necessary file informations can be given for basin data, initial settings and intermediate data.

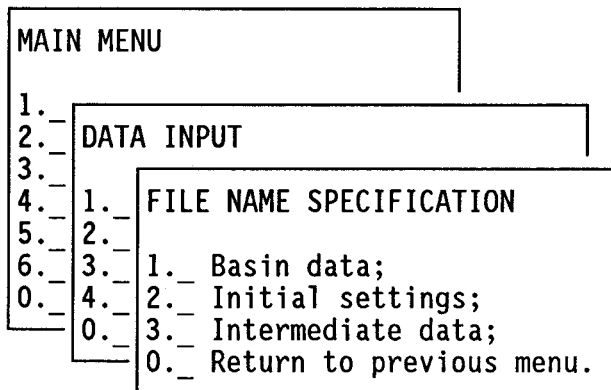


Figure 2.9 Sub-menu #2.1: file name specification.

2.3.4.1.1 Sub-menu #2.1.1: basin data

Appropriate file names corresponding to all types of basin data listed in sub-menu 2.1.1 (figure 2.10) should appear in that window.

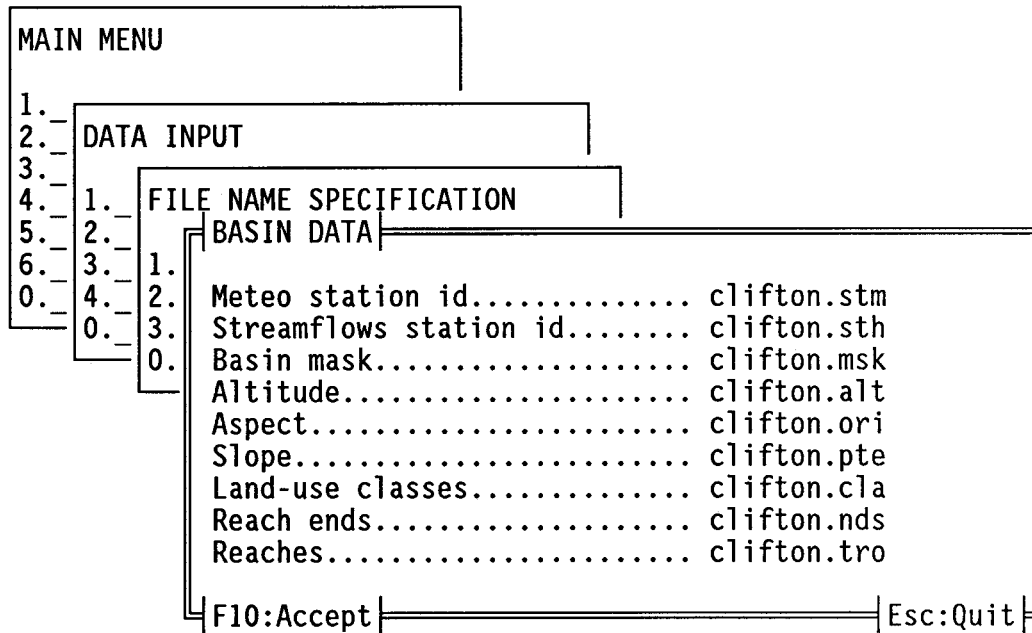


Figure 2.10 Sub-menu #2.1.1: basin data.

2.3.4.1.2 Sub-menu #2.1.2: initial settings

Initial values can be given to variables representing the hydrologic state of the basin at the beginning of the simulation. File names are given here. Otherwise, the initial settings default to zero ("0") for surface and subsurface runoff and channel routing. In the case of the vertical budget, initial values can be also given in sub-menu 3.4.1.5. Informations on how to determine these initial values are given in the section on "initialization of state variables" at the end of Part 2.

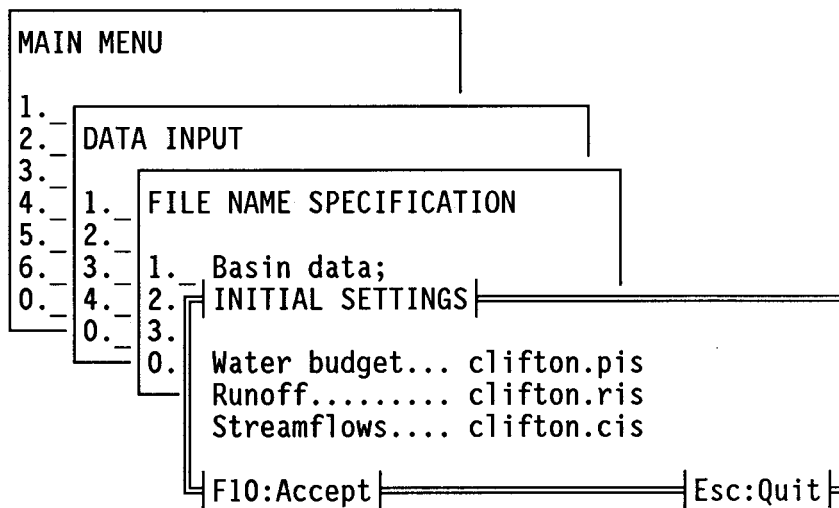


Figure 2.11 Sub-menu #2.1.2: initial settings.

2.3.4.1.3 Sub-menu #2.1.3: intermediate data

Names of the files containing intermediate data are given here (figure 2.12).

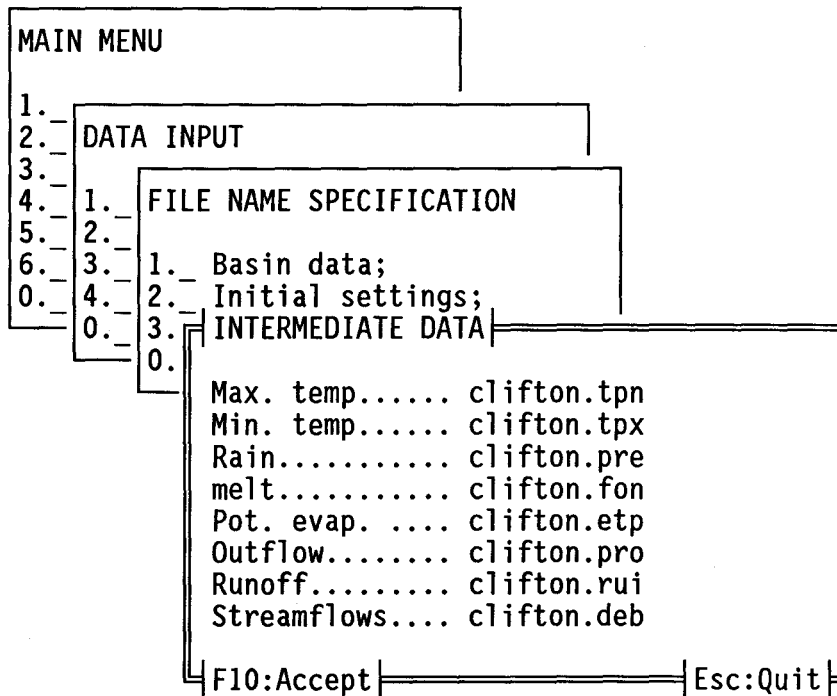


Figure 2.12 Sub-menu #2.1.3: intermediate data.

2.3.4.2 Sub-menu #2.2: data format specification

Data formats to read the various files are chosen in the menus accessed from menu 2.2 (figure 2.13). Further format options will be provided in later versions. For HYDROTEL 1.1 all files are ASCII text files.

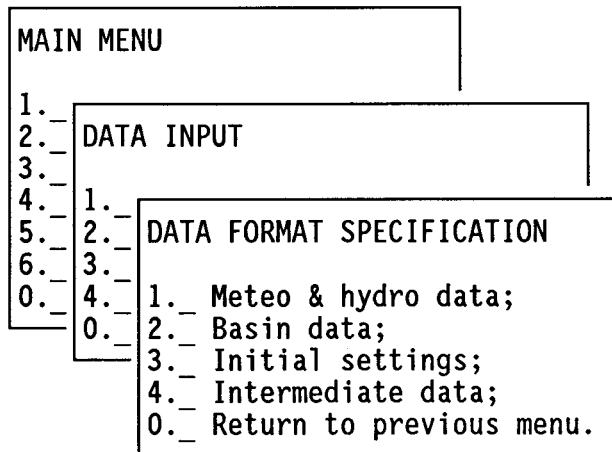


Figure 2.13 Sub-menu #2.2: data format specification.

2.3.4.2.1 Sub-menu #2.2.1: hydrological and meteorological data

Environment Canada or INRS data formats can be chosen, using the "space" bar.

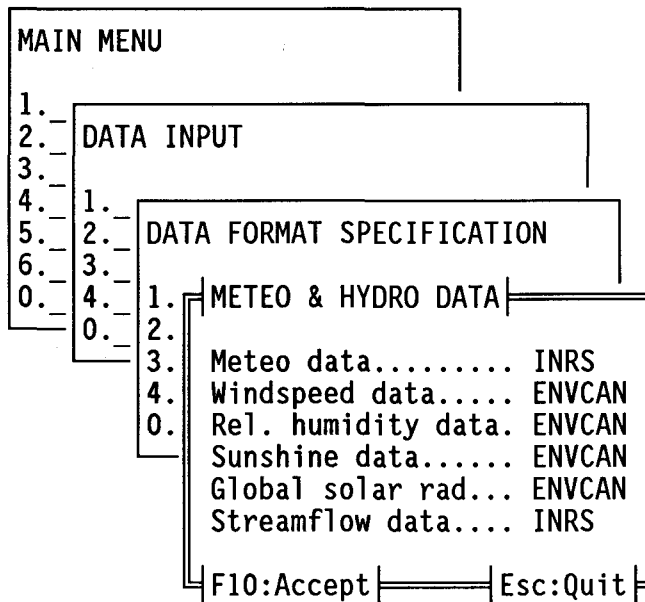


Figure 2.14 Sub-menu #2.2.1: hydrological and meteorological data.

2.3.4.2.2 Sub-menu #2.2.2: basin data.

Only INRS ASCII text file format is available with HYDROTEL 1.1 (figure 2.15).

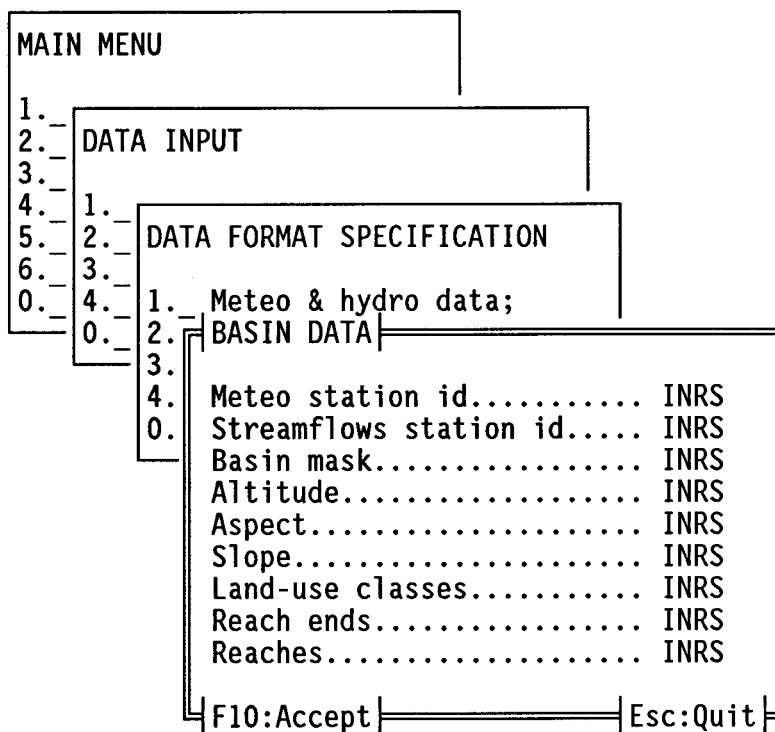


Figure 2.15 Sub-menu #2.2.2: basin data.

2.3.4.2.3 Sub-menu #2.2.3: initial settings

Only INRS ASCII text file format is available with HYDROTEL 2.0 (figure 2.16).

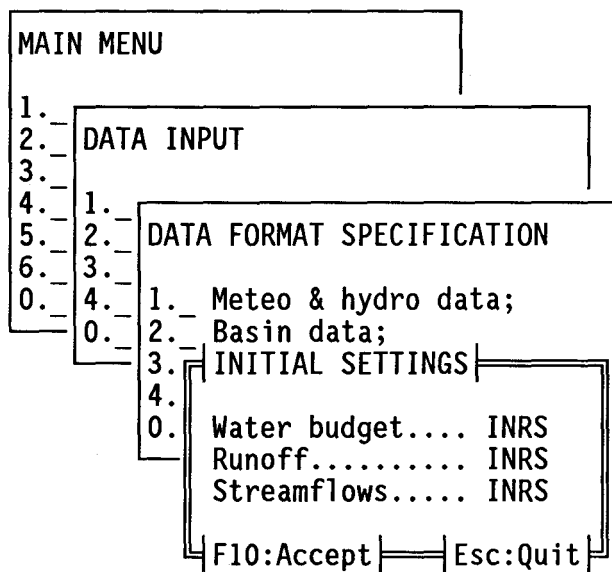


Figure 2.16 Sub-menu #2.2.3: initial settings.

2.3.4.2.4 Sub-menu #2.2.4: intermediate data

Only INRS ASCII text file format is available with HYDROTEL 2.0 (figure 2.17).

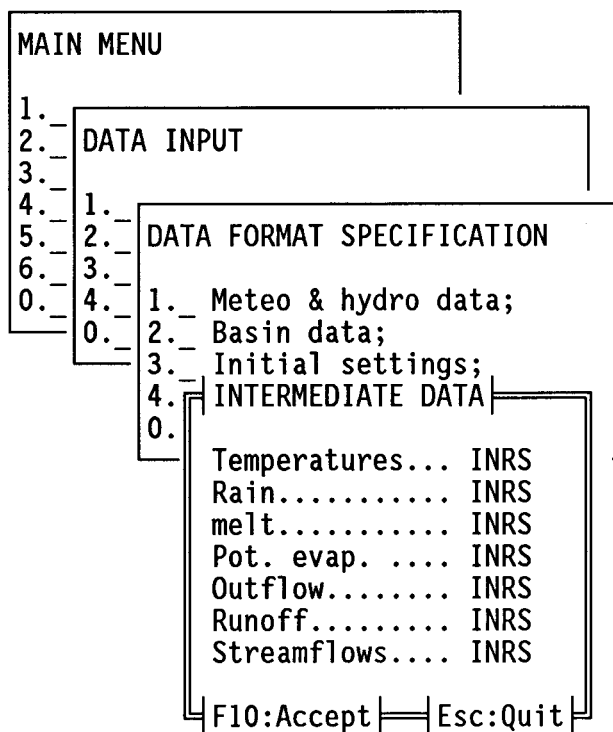


Figure 2.17 Sub-menu #2.2.4: intermediate data.

2.3.4.3 Sub-menu #2.3: read data

With HYDROTEL 2.0, sub-menu 2.3 (figure 2.18) is optional. Basin data will be read automatically, but not initial settings of the state variables. This sub-menu will be used in later versions to permit data input from more than one file for each variable. This will allow, for instance integration of two groups of files on contiguous basins, if not already done by PHYSITEL.

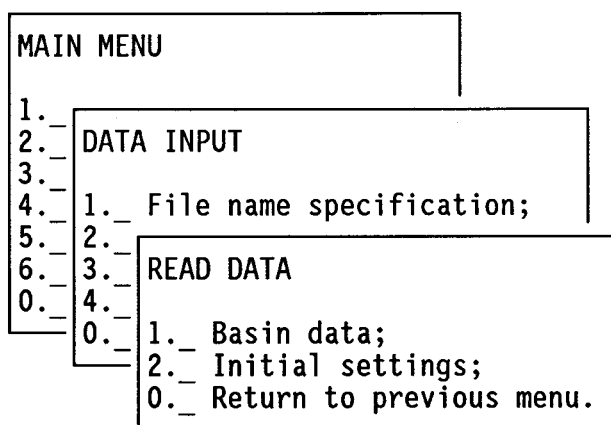


Figure 2.18 Sub-menu #2.3: read data.

2.3.4.3.1 Sub-menu #2.3.1: basin data

With HYDROTEL 2.0, sub-menu 2.3.1 (figure 2.19) is optional. Data will be read automatically.

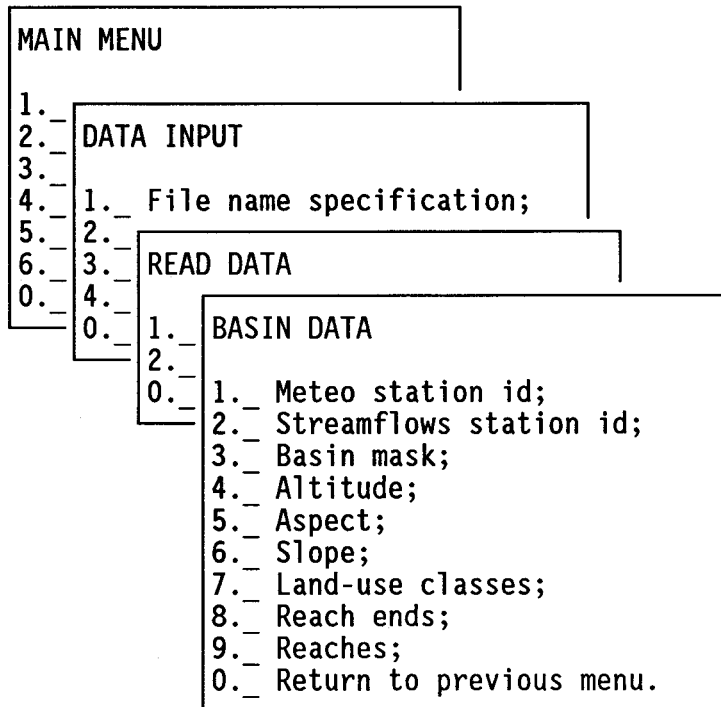


Figure 2.19 Sub-menu #2.3.1: basin data.

2.3.4.3.2 Sub-menu #2.3.2: initial settings

With HYDROTEL 2.0, sub-menu 2.3.2 (figure 2.20) is optional. If the user wants to initialize the state variables with values computed in a previous run, he must select the corresponding options. Otherwise, runoff and streamflow values will default to zero and water budget variables will have to be read at sub-menu 3.4.1.5.

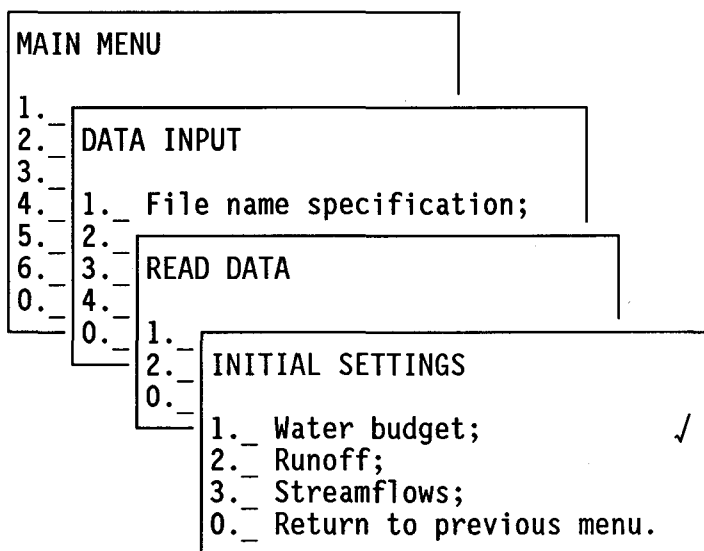


Figure 2.20 Sub-menu #2.3.2: initial settings.

2.3.4.4 Sub-menu #2.4: display data

If one wants to have a visual representation of files containing basin data, he can select any of the options in sub-menu 2.4 (figure 2.21). The selected variable will be displayed on the screen, together with an appropriate legend.

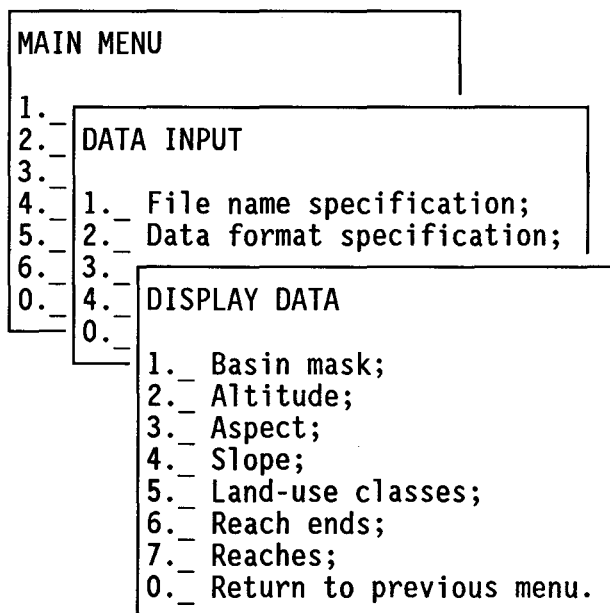


Figure 2.21 Sub-menu #2.4: display data.

2.3.5 Sub-menu #3.0: sub-models

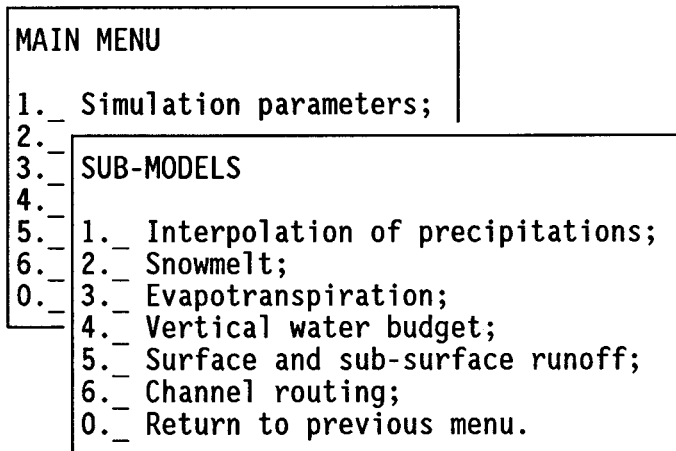


Figure 2.22 Sub-menu #3.0: sub-models.

All options (figure 2.22) can be selected by moving to each of those options and pressing "ENTER". After typing all necessary data, in the sub-menus corresponding to those options return to the "main menu" by selecting option "0" and pressing "ENTER". It is possible to "by pass" any of the submodels. In HYDROTEL 2.0, intermediate data corresponding to the output from that sub-model has then to be read.

2.3.5.1 Sub-menu #3.1: interpolation of precipitation

See section 3.2 for more informations.

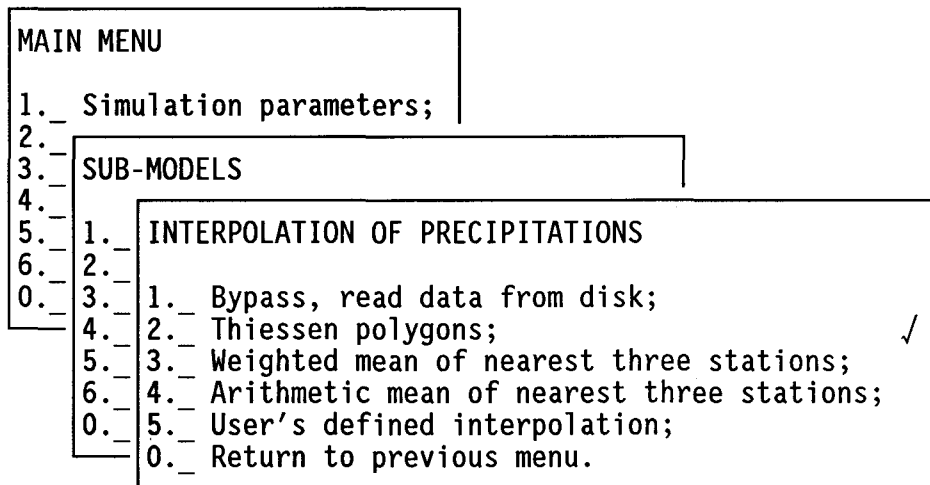


Figure 2.23 Sub-menu #3.1: interpolation of precipitation.

Five options are available for the interpolation of precipitations (figure 2.23). Select one of those and press "ENTER". After typing the input values, return to "sub-menu 3.0" by selecting option "0" and pressing "ENTER".

Option 1 allows the user to bypass interpolation of precipitation by reading instead precipitation matrices obtained from a previous run or elsewhere, for example from weather radar or satellite data. Precipitation values are read from the file specified in sub-menu 2.1.3 (intermediate data). It will be also possible for the user to write its own interpolation submodel, following the instructions given in this user's guide.

2.3.5.1.1 Sub-menu #3.1.1: Thiessen polygons (figure 2.24)

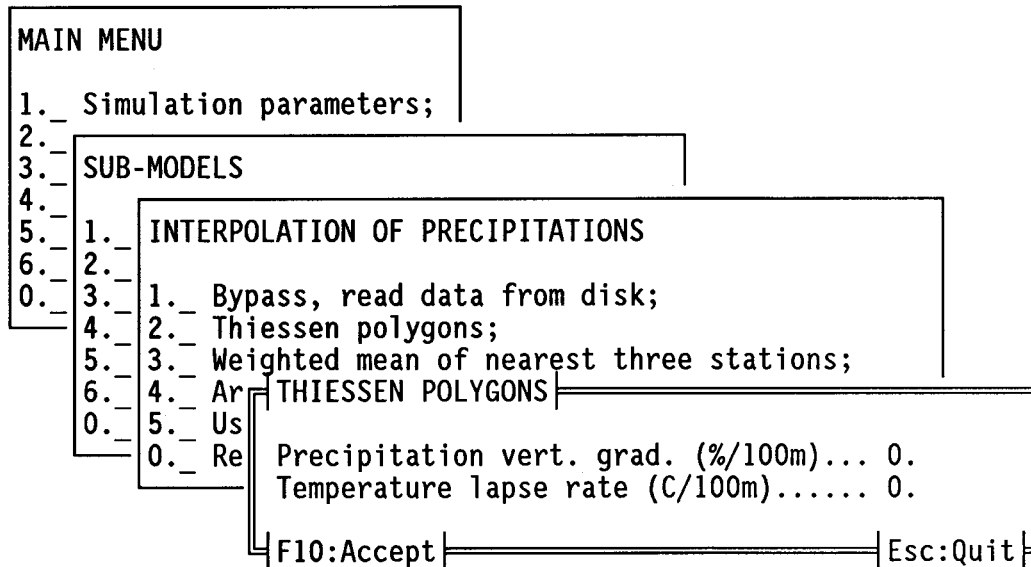


Figure 2.24 Sub-menu #3.1.1: Thiessen polygons.

- Precipitation: vertical gradient (%/100 m): type the main vertical gradient of precipitations, in % per 100 meters. Type "0", if you consider that the vertical distribution of stations can take care of the gradient.
- Temperature: lapse rate (°C/100 m): type the temperature lapse rate in degrees Celcius per 100 meters. Type "0", if you consider that the vertical distribution of stations can take care of the lapse rate.

When this is done, leave the sub-menu by pressing "F10" (accept and save the new values) or "ESC" (no change to previously stored values).

2.3.5.1.2 Sub-menu #3.1.2: weighted mean of nearest three stations

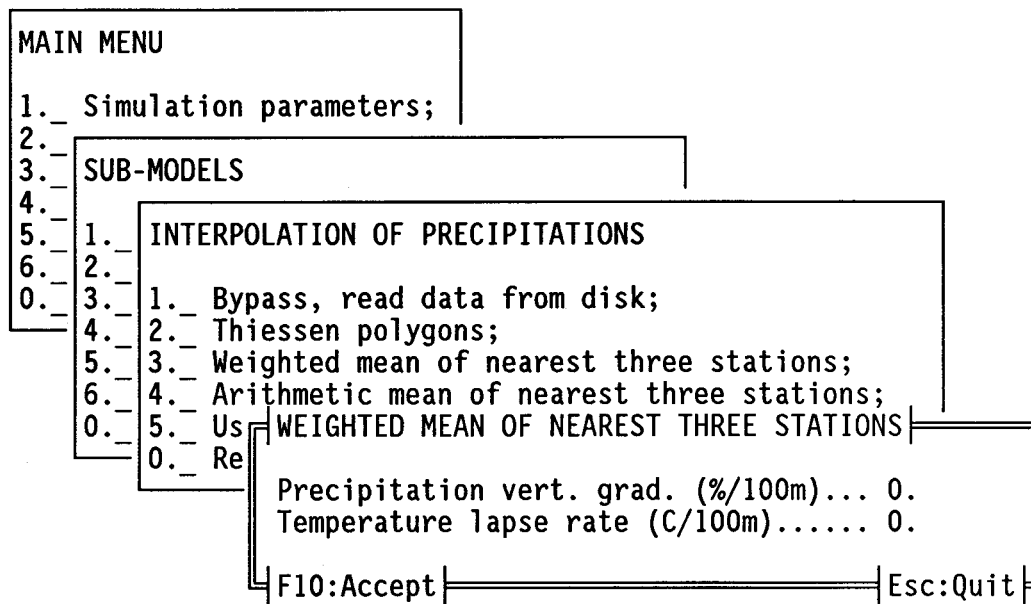


Figure 2.25 Sub-menu #3.1.2: weighted mean of nearest three stations.

As seen in figure 2.25, this sub-menu is similar to 3.1.1. The information given is 2.3.5.1.1 applies.

2.3.5.1.3 Sub-menu #3.1.3: arithmetic mean of nearest three stations

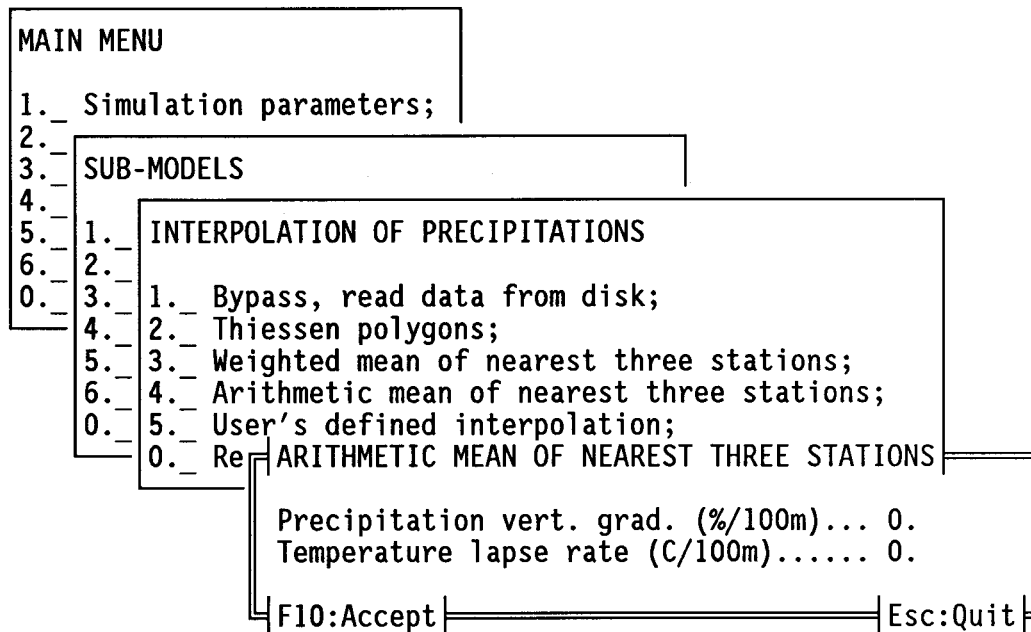


Figure 2.26 Sub-menu #3.1.3: arithmetic mean of nearest three stations.

As seen in figure 2.26, this sub-menu is similar to 3.1.1. The information given in 2.3.5.1.1 applies.

2.3.5.2 Sub-menu #3.2: snowmelt

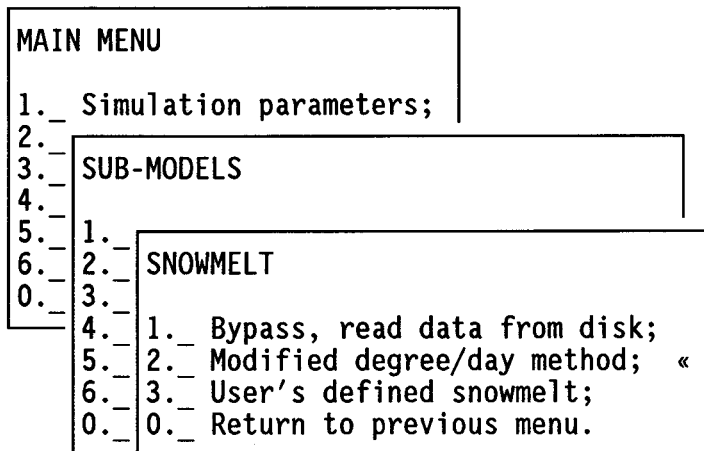


Figure 2.27 Sub-menu #3.2: snowmelt.

Three options are currently available for snowcover simulation and melting (figure 2.27). Select one and press "ENTER".

Option 1 allows the user to bypass the snowmelt sub-program by reading instead melt water matrices obtained from a previous run or elsewhere. Values are read from the file specified in sub-menu 2.1.3 (intermediate data). It will be also possible for the user to write its own snowmelt subprograms, following the instructions given in this user's guide.

2.3.5.2.1 Sub-menu #3.2.1: modified degree-day method (figure 2.28)

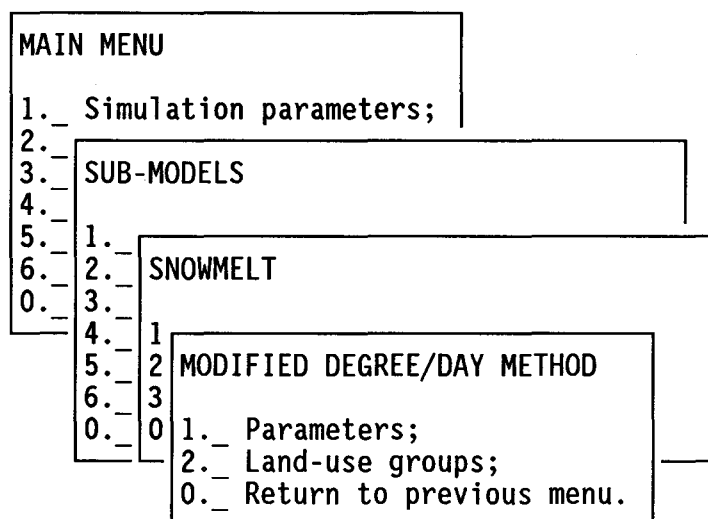


Figure 2.28 Sub-menu #3.2.1: modified degree-day method.

Sub-menu 3.2.1 (figure 2.28) is essentially an intermediate menu. Option 1 "parameters", gives access to the menu in which values of the parameters of the snowmelt sub-model are determined. Option 2, "land-use groups", allows integration of original land-use groups to suit the sub-model.

2.3.5.2.1.1 Sub-menu #3.2.1.1: parameters (figure 2.29)

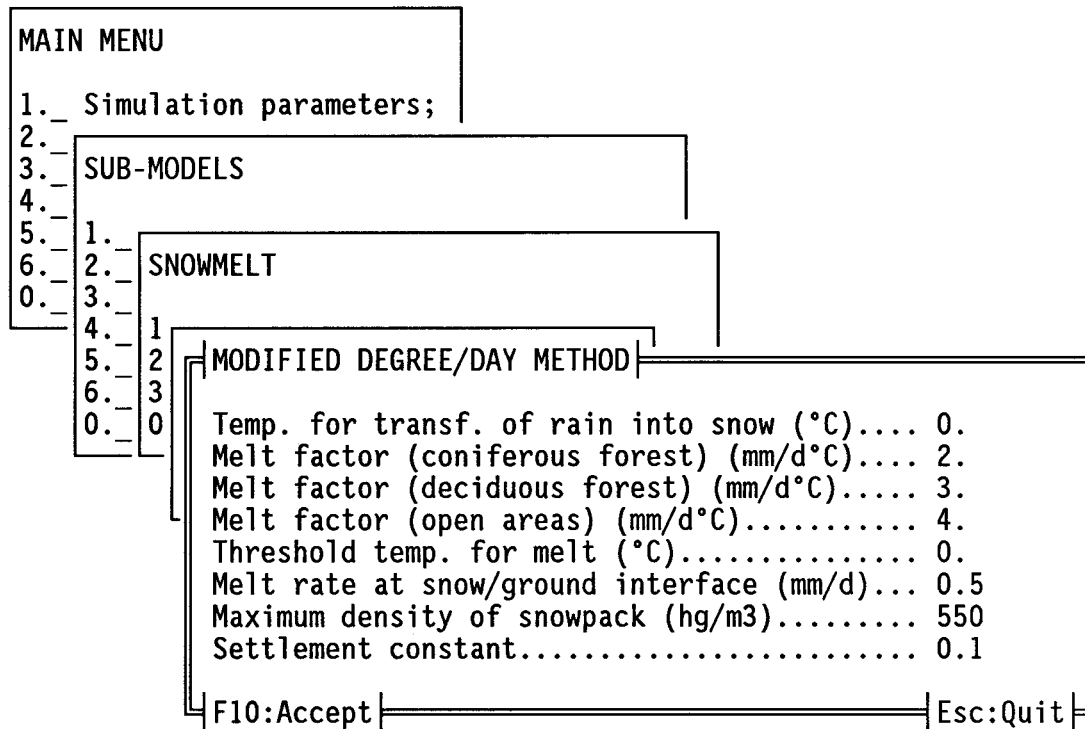


Figure 2.29 Sub-menu #3.2.1.1: parameters.

See section 3.3 for more informations.

- Temperature for transformation of rain into snow ($^{\circ}\text{C}$): type the threshold temperature ($^{\circ}\text{C}$) for the transformation of rain into snow.
- Melt factor (coniferous forest) ($\text{mm}/\text{d}^{\circ}\text{C}$): type melt factor for coniferous forests, in millimeters per day and degree Celcius.
- Melt factor (deciduous forest) ($\text{mm}/\text{d}^{\circ}\text{C}$): type melt factor for deciduous forests;
- Melt factor (open areas) ($\text{mm}/\text{d}^{\circ}\text{C}$): type melt factor for open areas.

- Threshold temperature for melt ($^{\circ}\text{C}$): type threshold temperature for melt, in degrees Celcius.
- Melt rate at snow/ground interface (mm/d): type estimated mean constant melt rate at snow/ground interface, in millimeters per day.
- Maximum density of snowpack (kg/m^3): type estimated maximum density of snowpack, in kilograms per cubic meters.
- Settlement constant: type the settlement constant (smaller than one).
- Hour zone: Atlantic (1);
East (2);
Center (3);
Prairies (4);
West (5).

When this is done, leave the sub-menu by pressing "F10" (accept and save the new values) or "ESC" (no change to previously stored values).

2.3.5.2.1.2 Sub-menu #3.2.1.2: land-use groups

Land-use groups corresponding to the types of land-uses needed in the snowmelt sub-model are defined in sub-menu 3.2.1.2 (figure 2.30). Three land-use groups are considered for snowmelt, namely: coniferous forest, deciduous or broad-leaved forest and open areas.

MAIN MENU	
1._	Simulation parameters;
2._	
3._	SUB-MODELS
4._	
5._	1._
6._	2._ SNOWMELT
0._	3._
	4._ 1
	5._ 2 MODIFIED DEGREE/DAY METHOD
	6._ 3

CLASS CODE (SEPARATED BY "+") FOR CONIFEROUS FOREST
RESIN

CLASS CODE (SEPARATED BY "+") FOR BROAD-LEAVED FOREST
FEUIL

Figure 2.30 Sub-menu #3.2.1.2: land-use groups.

As required in the menu, type the class code(s) of the land-use class(es) corresponding to "coniferous forest", separated by a "+" sign. Then, press "ENTER" to proceed to the next group "broad-leaved forest". Again, type the class code(s) corresponding to "broad-leaved forest" and press "RETURN". The original land-use classes that have not been assigned to either "coniferous" or "broad-leaved" forest, are assigned automatically to "open areas".

2.3.5.3 Sub-menu #3.3: evapotranspiration

In HYDROTEL 2.1, the user will be allowed to choose between formulae for the determination of potential or actual evapotranspiration. Of course, this choice will depend on the options available and chosen for the simulation of the vertical water-budget.

For the moment select option 1, potential evapotranspiration, in sub-menu 3.3 (figure 2.31).

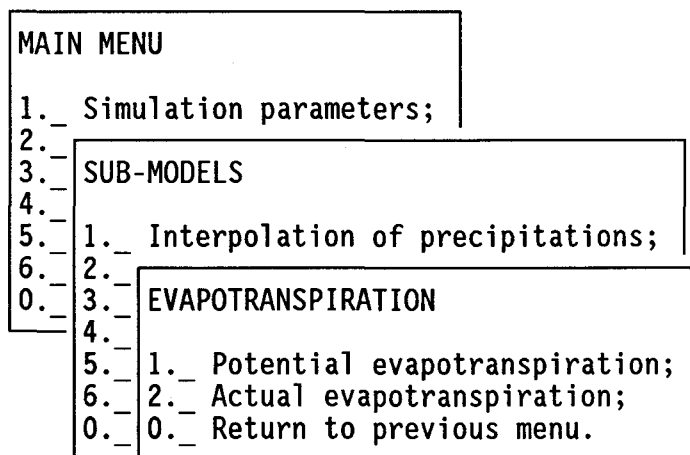


Figure 2.31 Sub-menu #3.3: evapotranspiration.

2.3.5.3.1 Sub-menu #3.3.1: potential evapotranspiration

Seven options are currently available for the estimation of potential evapotranspiration (figure 2.32). Select one and press "ENTER".

MAIN MENU	
1._	Simulation parameters;
2._	
3._	SUB-MODELS
4._	
5._	1._ Interpolation of precipitations;
6._	2._
0._	3._ EVAPOTRANSPIRATION
	4._
	5._ 1._ POTENTIAL EVAPOTRANSPIRATION
	6._ 2._
	0._ 0._
	1._ Bypass, read data from disk;
	2._ THORNTHWAITE P.E.; ✓
	3._ LINACRE P.E.;
	4._ PENMAN P.E.;
	5._ PRIESTLY TAYLOR P.E.;
	6._ User's defined P.E. 1;
	7._ User's defined P.E. 2;
	0._ Return to previous menu.

Figure 2.32 Sub-menu #3.3.1: potential evapotranspiration.

Option 1 allows the user to bypass the PET sub-programs by reading instead PET matrices obtained from a previous run or elsewhere. Values are read from the file specified in sub-menu 2.1.3 (intermediate data).

Options 2 to 5 are suggested to the user, to choose from, depending on available data at the meteorological stations listed in file *.STM. The Penman equation should be the most accurate, but requires more informations than the other ones.

Two more user's defined options are available, if equations other than those offered are preferred.

2.3.5.3.1.1 Sub-menu #3.3.1.1: Thorthwaite PE (figure 2.33)

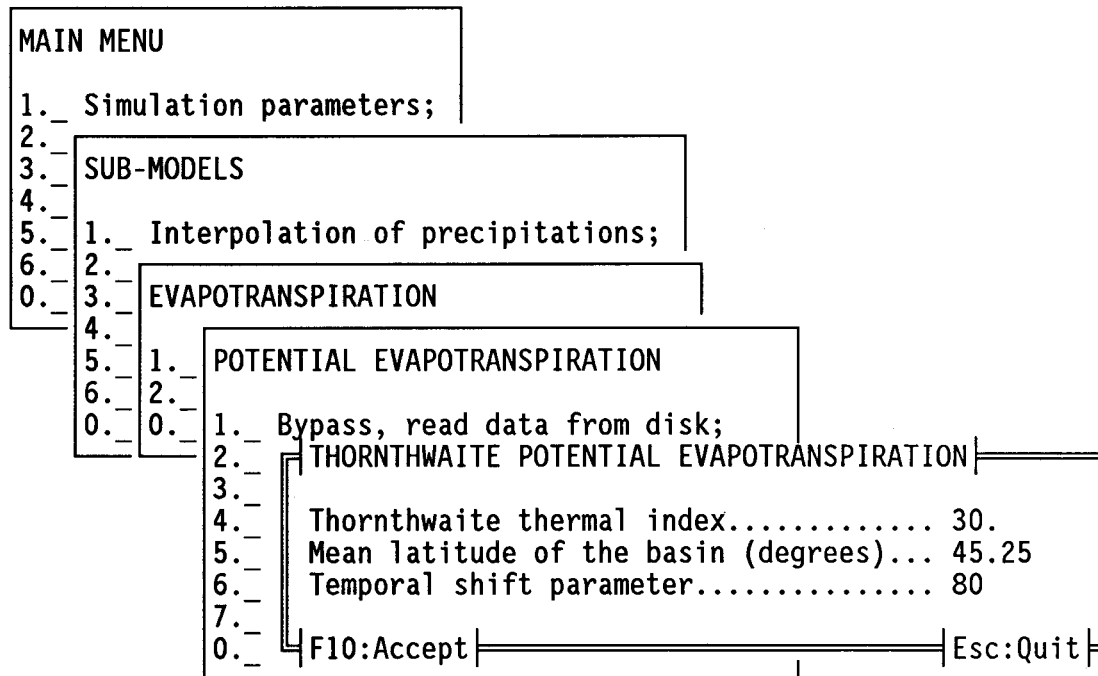


Figure 2.33 Sub-menu #3.3.1.1: Thorthwaite PE.

See section 3.4.1.1 for more informations Thorthwaite PE. The following informations must be entered.

- Thorthwaite thermal index: type Thorthwaite thermal index value.
- Mean latitude of the basin (degrees): type mean latitude of the basin, in degrees and hundredths of a degree.
- Temporal shift parameter: type temporal shift parameter in days.

When this is done, leave the sub-menu by pressing "F10" (accept and save the new values) or "ESC" (no change to previously stored values).

2.3.5.3.1.2 Sub-menu #3.3.1.2: Linacre P.E. (figure 2.34)

MAIN MENU	
1._	Simulation parameters;
2._	
3._	SUB-MODELS
4._	
5._	1._ Interpolation of precipitations;
6._	2._
0._	3._ EVAPOTRANSPIRATION
4._	
5._	1._ POTENTIAL EVAPOTRANSPIRATION
6._	2._
0._	0._
1._	Bypass, read data from disk;
2._	LINACRE POTENTIAL EVAPOTRANSPIRATION
3._	
4._	File name of albedo values..... albedo.73
5._	Mean latitude of the basin (degrees)... 45.25
6._	Linear approximation for $(\Delta/\Delta + \gamma) = (A + B \cdot T)$
7._	-intersect for $T = 0^\circ\text{C}$ 0.4
0._	-slope ($1/^\circ\text{C}$) 1.25e-002
	Mean temperature of coldest month($^\circ\text{C}$).. -10
	Mean temperature of warmest month($^\circ\text{C}$).. 20
F10:Accept Esc:Quit	

Figure 2.34 Sub-menu #3.3.1.2: Linacre P.E.

See section 3.4.1.2 for more informations on Linacre P.E. The following informations must be entered:

- File name of Albedo values: give the filename of the albedo file (see file structure in section 2.2.3).
- Mean latitude of the basin (degrees): type mean latitude of the basin, in degrees and hundredths of a degree.

- Linear approximation for $(\Delta/\Delta + \gamma) = (A + B * T)$
 - intersect for $T = 0^{\circ}\text{C}$: enter the proper value.
 - slope ($^{\circ}\text{C}^{-1}$): enter the proper value.
- Mean temperature of coldest month ($^{\circ}\text{C}$): enter the proper value, with a "-" for temperatures below 0°C .
- Mean temperature of warmest month ($^{\circ}\text{C}$): enter the proper value.

Press "F10" to confirm the values and leave the menu.

2.3.5.3.1.3 Sub-menu #3.3.1.3: Penman P.E. (figure 2.35)

MAIN MENU	
1. _	Simulation parameters;
2. _	
3. _	SUB-MODELS
4. _	
5. _	1. _ Interpolation of precipitations;
6. _	2. _
0. _	3. _ EVAPOTRANSPIRATION
4. _	
5. _	1. _ POTENTIAL EVAPOTRANSPIRATION
6. _	2. _
0. _	0. _
	1. _ Bypass, read data from disk;
	2. _ THORNTHWAITE P.E.;
	PENMAN POTENTIAL EVAPOTRANSPIRATION
	File name of albedo values..... albedo.73
	File name of land-use heights..... hau_veg.73
	Value of A and B in $RG = IGA(A+B*h/H)$ A: 0.2
	(not used if file RG available) B: 0.55
	Height of wind observation(m)..... 10.
	Wind function: AERODYNAMIC RESISTANCE
F10:Accept Esc:Quit	

Figure 2.35 Sub-menu #3.3.1.3: Penman P.E.

See section 3.4.1.3 for more informations on Penman P.E. The following informations must be entered:

- File name of albedo values: give the filename of the Albedo file (see file structure in section 2.2.3).
- File name of land-use heights: give the filemane of the land-use heights (see file structure in section 2.2.3).
- Values of A and B in $RG = IGA (A + B * h/H)$ A:
(not used if RG available) B:

Enter the proper values.

- Height of wind observations (m): enter the height of the anemometer.
- Wind function:
 - aerodynamic resistance
 - empirical

The user can select either wind function by pressing the "space bar".

Press "F10" to confirm the values and leave the menu.

2.3.5.3.1.4 Sub-menu #3.3.1.4: Priestley-Taylor P.E. (figure 2.36)

MAIN MENU	
1. _	Simulation parameters;
2. _	
3. _	SUB-MODELS
4. _	
5. _	1. _ Interpolation of precipitations;
6. _	2. _
0. _	3. _ EVAPOTRANSPIRATION
	4. _
	5. _ 1. _ POTENTIAL EVAPOTRANSPIRATION
	6. _ 2. _
	0. _ 0. _
	1. _ Bypass, read data from disk;
	2. _ THORNTHWAITE P.E.;
	3. _ LINACRE P.E.;
	4. _ PENMAN P.E.;
	PRIESTLEY-TAYLOR POTENTIAL EVAPOTRANSPIRATION
	File name of albedo values..... albedo.73
	Value of A and B in $RG = IGA(A+B*h/H)$ A: 0.2
	(not used if file RG available) B: 0.55
	Value of \bar{A} in $ETP = \bar{A} * Eeq$ 1.26
	F10:Accept Esc:Quit

Figure 2.36 Sub-menu #3.3.1.4: Priestley-Taylor P.E.

See section 3.4.1.4 for more informations on Penman P.E. The following informations must be entered:

- File name of albedo values: give the filename of the Albedo file (see file structure in section 2.2.3).

- Values of A and B in $RG = IGA (A + B * h/H)$ A:
(not used if RG available) B:

Enter the proper values.

- Value of α in $ETP = \alpha * E$ eq: enter the proper value.

Press "F10" to confirm the values and leave the menu.

2.3.5.4.2 Sub-menu #3.3.2: actual evapotranspiration

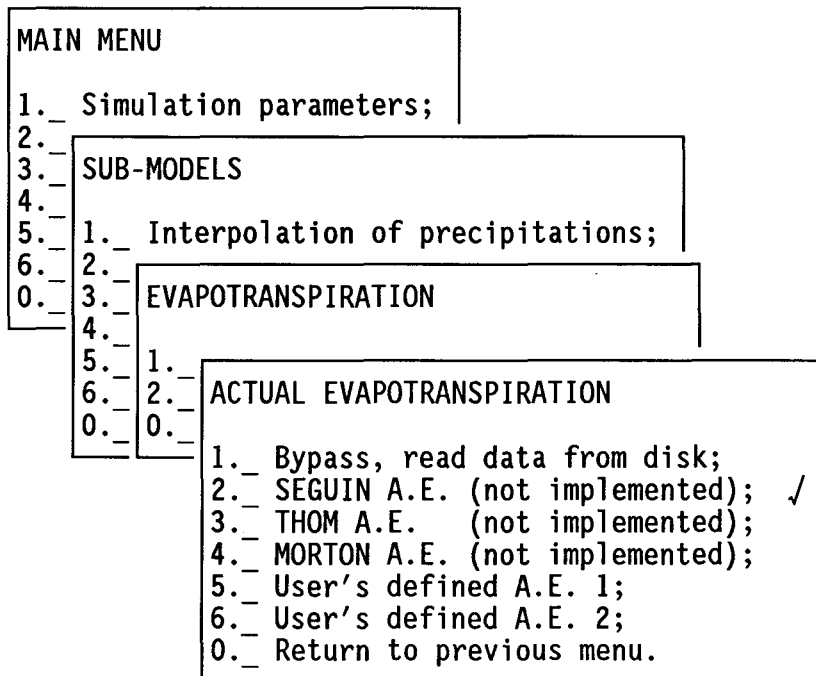


Figure 2.37 Sub-menu #3.3.2: actual evapotranspiration.

None of the options are implemented in HYDROTEL 2.0. Please wait for the next version.

2.3.5.4 Sub-menu #3.4: vertical water budget

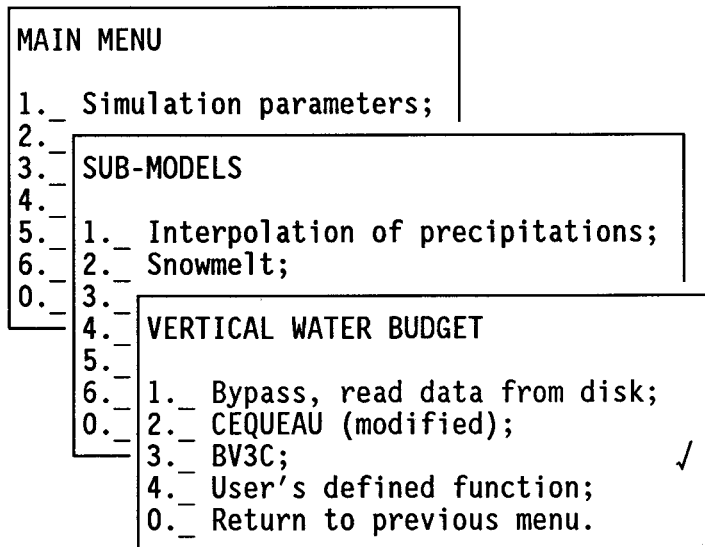


Figure 2.38 Sub-menu #3.4: vertical water budget.

Four options are currently available for the estimation of the vertical water budget on each square (figure 2.38). Select one and press "ENTER". After typing input values in each of the derived sub-menus, return to "sub-menu 3.0" by selecting option "0" and pressing "ENTER".

Option 1 allows the user to bypass the "vertical water budget sub-program" by reading instead "outflow" matrices computed in a previous run or elsewhere. Values are read from the file specified in sub-menu 2.1.3 (intermediate data). It will be also possible for the user to write its own vertical water budget, following the instructions given in this user's guide.

2.3.5.4.1 Sub-menu #3.4.1: CEQUEAU (modified)

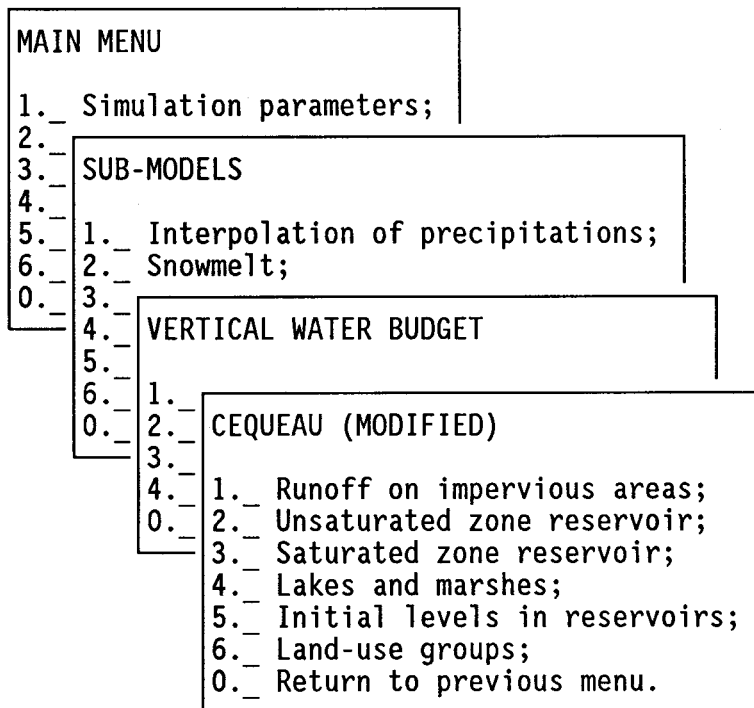


Figure 2.39 Sub-menu #3.4.1: input data for CEQUEAU.

See section 3.5.1 for more informations.

The usual separation of the terrestrial part of the hydrologic cycle into components has been used to group the parameters of the CEQUEAU function (figure 2.39). This should facilitate the identification of each parameter and the estimation of realistic values, based on the user's knowledge of the physical characteristics of the basin.

After typing all necessary data in the sub-menus corresponding to those options, return to "sub-menu 3.4" by selecting option "0" and pressing "ENTER".

2.3.5.4.1.1 Sub-menu #3.4.1.1: runoff on impervious areas (figure 2.40)

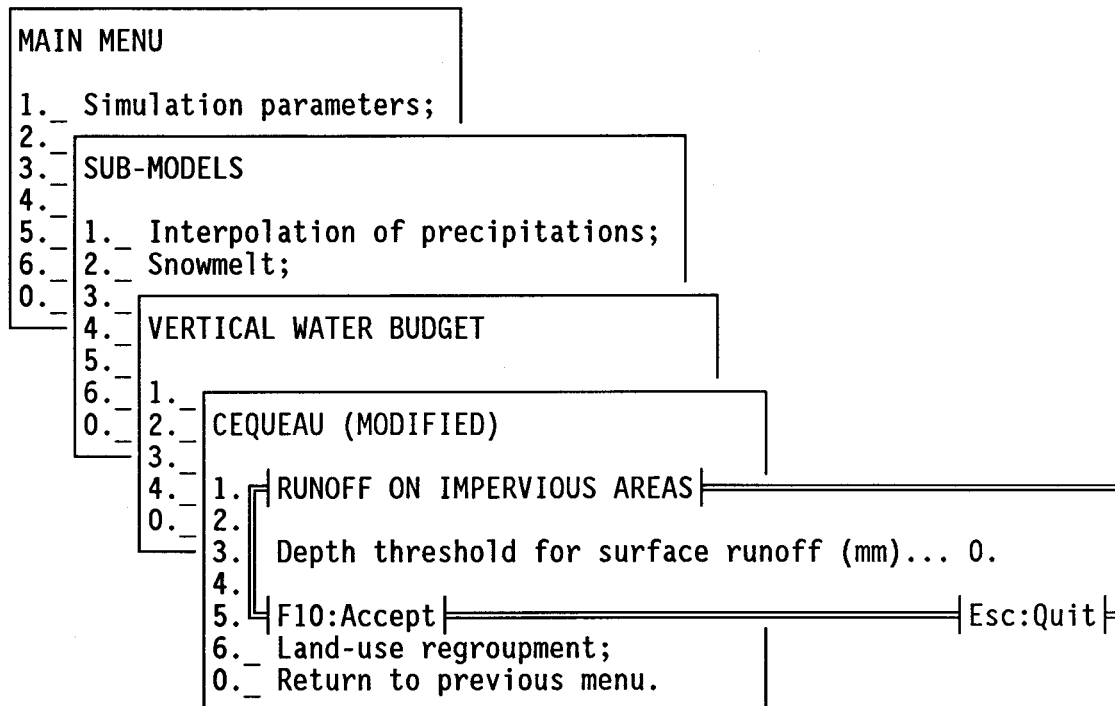


Figure 2.40 Sub-menu #3.4.1.1: runoff on impervious areas.

- Depth threshold for surface runoff (mm): type the depth threshold (in millimeters) water available for infiltration must reach, in order to produce runoff on impervious areas.

When this is done, leave the sub-menu by pressing "F10" (accept and save the new values) or "ESC" (no change to previously stored values).

2.3.5.4.1.2 Sub-menu #3.4.1.2: unsaturated zone reservoir (figure 2.41)

MAIN MENU	
1. _	Simulation parameters;
2. _	
3. _	SUB-MODELS
4. _	
5. _	1. _ Interpolation of precipitations;
6. _	2. _ Snowmelt;
0. _	3. _
	4. _ VERTICAL WATER BUDGET
	5. _
	6. _
	0. _
	2. _ CEQUEAU (MODIFIED)
	3. _ UNSATURATED ZONE RESERVOIR
	4. _
	0. _
	1. _
	2. Capacity of the reservoir (mm)..... 75.
	3. Threshold for sub-surface runoff (mm)..... 60.
	4. Runoff coefficient..... 0.35
	5. Threshold for percolation (mm)..... 60.
	6. Percolation coefficient..... 0.15
	0. Maximum rate of percolated water (mm/d)... 10.
	Threshold for PET (mm)..... 60.
	F10:Accept Esc:Quit

Figure 2.41 Sub-menu #3.4.1.2: unsaturated zone reservoir.

- Capacity of the reservoir (mm): type the maximum depth of water which can be stored in the reservoir (in millimeters).
- Threshold for sub-surface runoff (mm): type the threshold level water must reach before any surface runoff begin (in millimeters).
- Runoff coefficient: type the runoff coefficient.
- Threshold for percolation (mm): type the threshold level (in millimeters), water must reach before any percolation to the saturated zone reservoir occurs.

- Percolation coefficient: type the percolation coefficient.
- Maximum rate of percolated water (mm/d): type the maximum amount (millimeters) of percolated water allowed each day.
- Threshold for PET (mm): type the threshold level (millimeters) over which evapotranspiration occurs at potential rate.

When this is done, leave the sub-menu by pressing "F10" (accept and save the new values) or "ESC" (no change to previously stored values).

2.3.5.4.1.3 Sub-menu #3.4.1.3: saturated zone reservoir (figure 2.42)

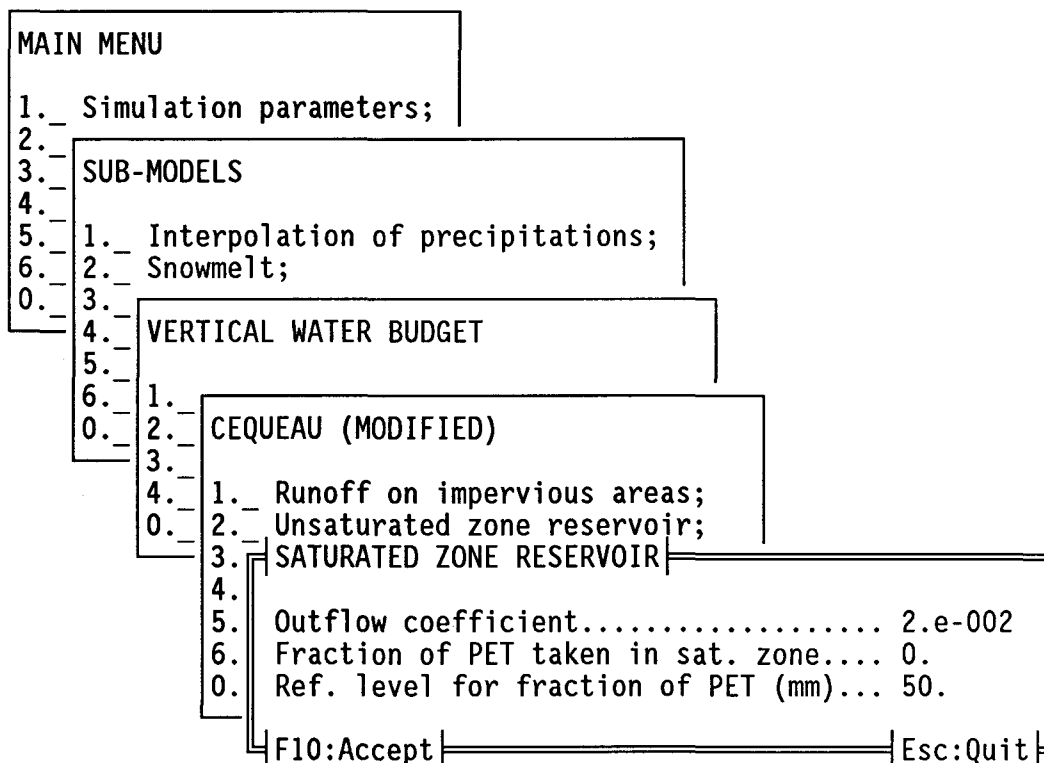


Figure 2.42 Sub-menu #3.4.1.3: saturated zone reservoir.

- Threshold for outflow (mm): type the threshold level (millimeters) water must reach before any runoff occurs from lakes and marshes.
- Outflow coefficient: type the outflow coefficient.

When this is done, leave the sub-menu by pressing "F10" (accept and save the new values) or "ESC" (no change to previously stored values).

2.3.5.4.1.5 Sub-menu #3.4.1.5: initial levels in reservoirs (figure 2.44)

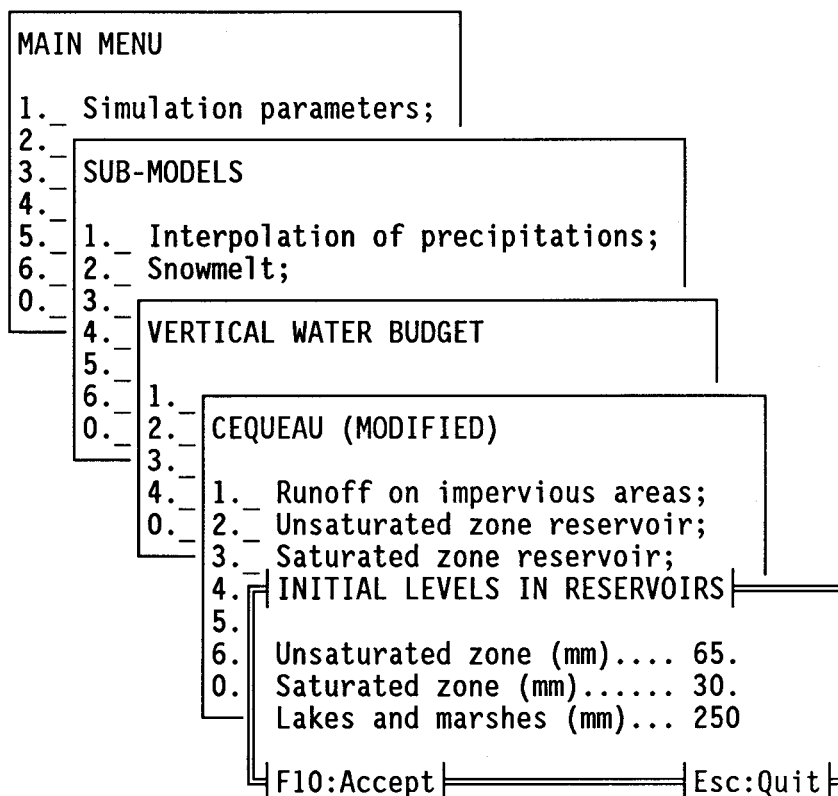


Figure 2.44 Sub-menu #3.4.1.5: initial levels in reservoirs.

- Unsaturated zone (mm): type the initial level of water (in millimeters) in the unsaturated zone reservoir.
- Saturated zone (mm): type the initial level of water (in millimeters) in the saturated zone reservoir.
- Lakes and marshes (mm): type the initial level of water (in millimeters) in the saturated zone reservoir.

When this is done, leave the sub-menu by pressing "F10" (accept and save the new values) or "ESC" (no change to previously stored values).

Note that identical values are given to each square, whereas individual values can be given to each square, if the appropriate file name is given in sub-menu 2.1.2 and option 1 is selected in sub-menu 2.3.2.

2.3.5.4.1.6 Sub-menu #3.4.1.6: land-use groups (figure 2.45)

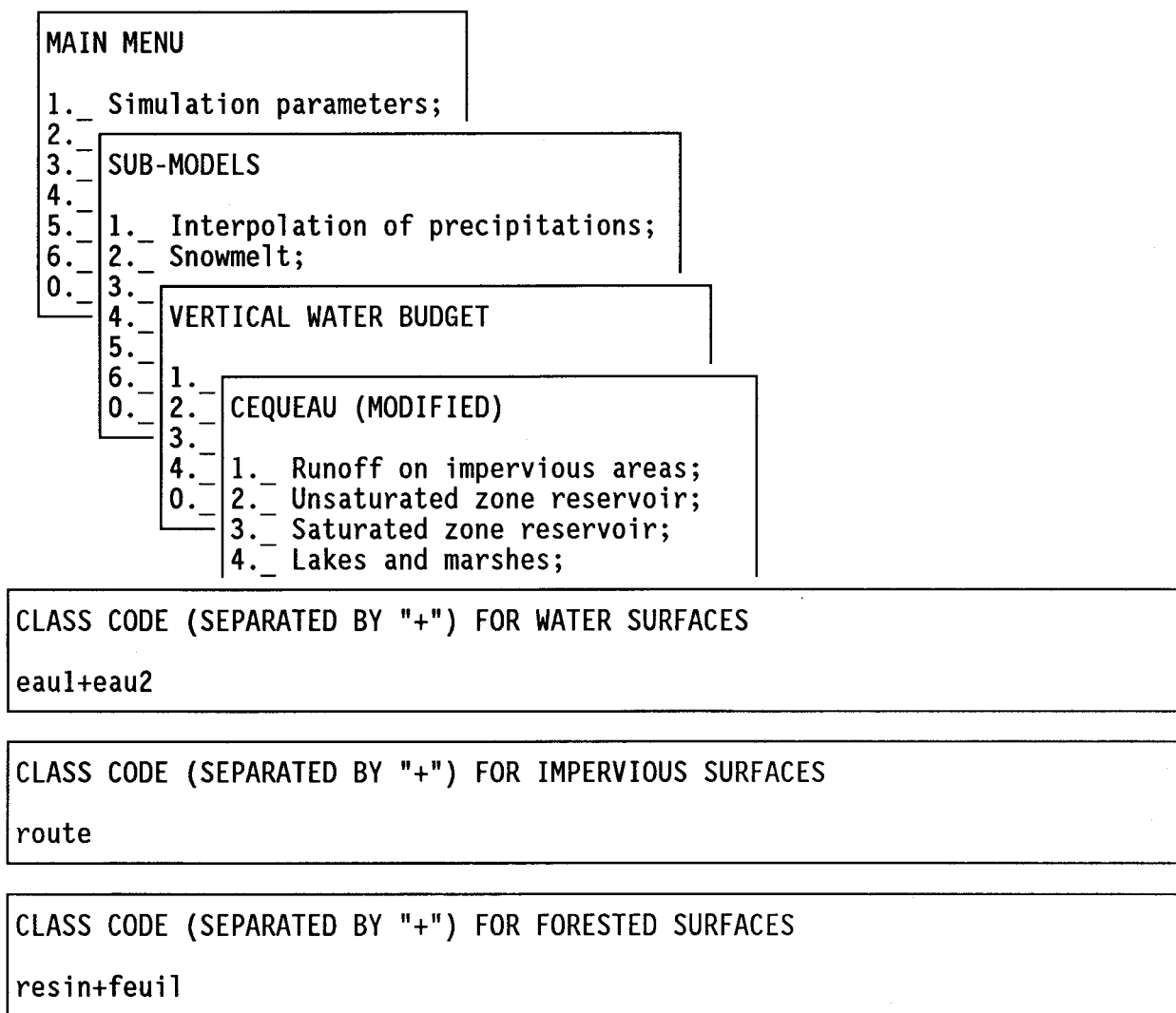


Figure 2.45 Sub-menu #3.4.1.6: land-use groups.

Land-use groups corresponding to the types of land-uses needed in the CEQUEAU vertical budget sub-model are defined in sub-menu 3.4.1.6. Four land-use groups are considered, namely water surfaces (including swamps and marshes), impervious areas, forested areas, all other areas.

As required in the menu, type the class code(s) of the land-use class(es) corresponding to water surfaces and swamp areas in the first rotating window, with a "+" sign between codes. Then, press "ENTER" to proceed to the next groups. The original land-use classes that have not been assigned to the first three groups will be assigned automatically to "all other areas".

2.3.5.4.2 Sub-menu #3.4.2: BV3C (figure 2.46)

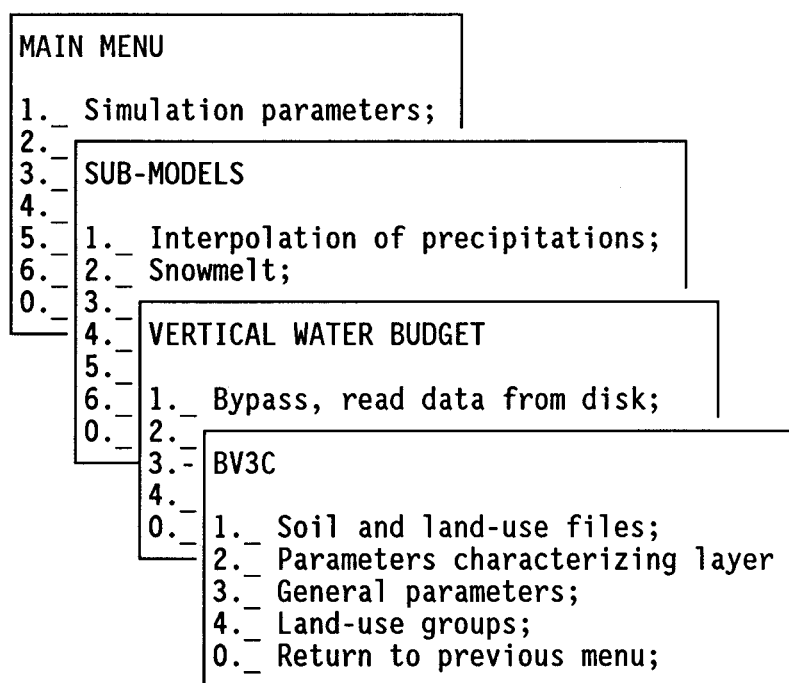


Figure 2.46 Sub-menu #3.4.2: BV3C.

See section 3.5.2 for more informations.

Most input data necessary for BV3C are contained in files, so that few supplementary values are needed. Select each one of the options in sub-menu 3.4.2 to complete input of all necessary informations.

2.3.5.4.2.1 Sub-menu #3.4.2.1: soil and land-use files

```

MAIN MENU
1. _ Simulation parameters;
2. _
3. _ SUB-MODELS
4. _
5. _ 1. _ Interpolation of precipitations;
6. _ 2. _ Snowmelt;
0. _ 3. _
4. _ VERTICAL WATER BUDGET
5. _
6. _ 1. _ Bypass, read data from disk;
0. _ 2. _
3. _ BV3C
4. _
0. _ 1. _ SOIL AND LAND-USE FILES
2. _
3. _ Characteristics of the root system...: clifton.clu
4. _ Leaf area index on day D.....: ind_fol.73
0. _ Root depth on day D.....: pro_rac.73
Hydraulic properties of soil types...: clifton.sol
Spatial distribution of soil types...: clifton.tso
F10:Accept Esc:Quit
  
```

The diagram illustrates the nested menu structure for sub-menu #3.4.2.1. It shows four overlapping boxes representing the hierarchy: MAIN MENU, SUB-MODELS, VERTICAL WATER BUDGET, and BV3C. The SOIL AND LAND-USE FILES box is the innermost, containing file names for root system characteristics, leaf area index, root depth, hydraulic properties, and spatial distribution of soil types. Navigation keys F10:Accept and Esc:Quit are shown at the bottom of the innermost box.

Figure 2.47 Sub-menu #3.4.2.1: soil and land-use files.

Informations from five soil or land-use files are needed for BV3C. Enter the proper filename for:

- characteristics of the root system,
- leaf-area index on day D,

- root depth on day D,
- hydraulic properties of soil types,
- spatial distribution of soil types.

See section 2.2.3 for file structures and contents.

2.3.5.4.2.2 Sub-menu #3.4.2.2: parameters characterizing layers (figure 2.48)

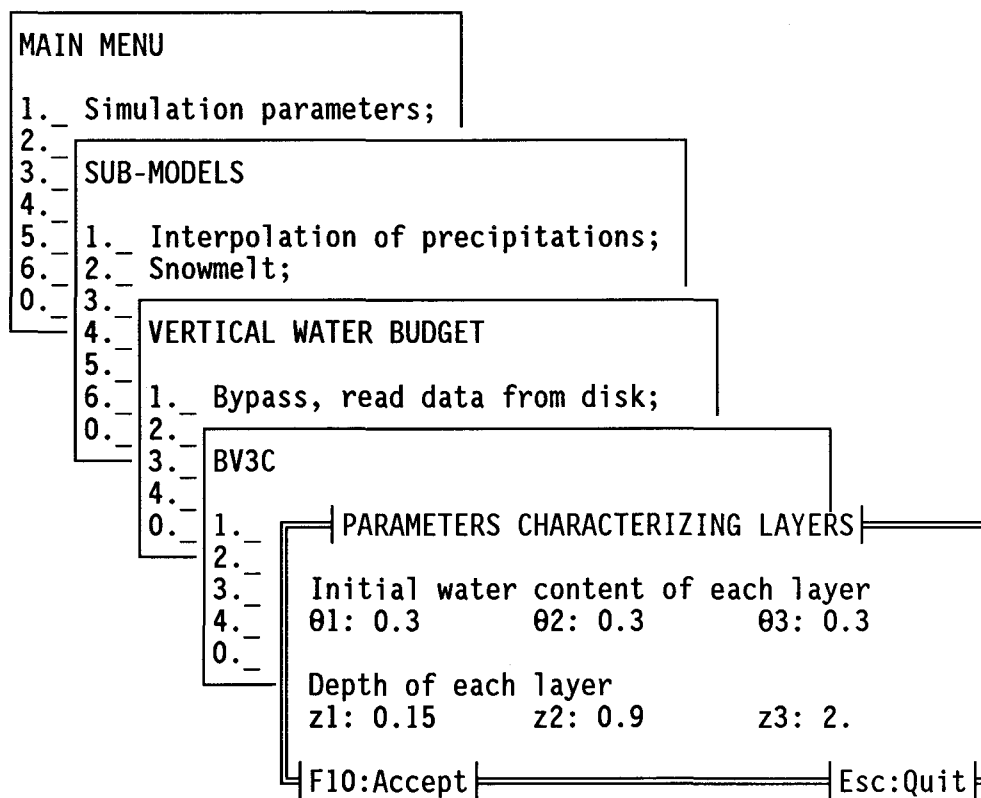


Figure 2.48 Sub-menu #3.4.2.2: parameters characterizing layers.

The initial water content and depth of each layers, should be given in sub-menu 3.4.2.2.

- Initial water content of each layer
01: 02: 03:

Enter water content values (m^3/m^3) of each layer, noting that $\theta_i \leq \theta_s$.

- Depth of each layer (m)

Z1: Z2: Z3:

Enter the depth (m) of the bottom of each layer.

Press "F10" to confirm the values and leave the menu.

2.3.5.4.2.3 Sub-menu #3.4.2.3: general parameters (figure 2.49)

```

MAIN MENU
1. _ Simulation parameters;
2. _
3. _ SUB-MODELS
4. _
5. _ 1. _ Interpolation of precipitations;
6. _ 2. _ Snowmelt;
0. _ 3. _
4. _ VERTICAL WATER BUDGET
5. _
6. _ 1. _ Bypass, read data from disk;
0. _ 2. _
3. _ BV3C
4. _
0. _ 1. _ Soil and land-use files;
      2. _ Characterizing layers parameters;
      3. _ GENERAL PARAMETERS
      4. _
      0. _ Extinction coefficient DES.....: 0.6
            Recession coefficient.....: 2.e-003
            F10:Accept | Esc:Quit
  
```

The diagram illustrates the nested menu structure for general parameters. It starts with the MAIN MENU, which includes options for simulation parameters, sub-models, and vertical water budget. The sub-models menu is selected, leading to the VERTICAL WATER BUDGET menu. From there, the BV3C option is chosen, which leads to the GENERAL PARAMETERS menu. The GENERAL PARAMETERS menu displays the extinction coefficient (DES.....: 0.6) and the recession coefficient (.....: 2.e-003). At the bottom of the GENERAL PARAMETERS menu, there are two options: F10:Accept and Esc:Quit.

Figure 2.49 Sub-menu #3.4.2.3: general parameters.

The values of two coefficients are entered in that menu.

- Extinction coefficient DES: enter the proper coefficient value for extinction of radiation at the ground surface with increasing leaf area index.
- Recession coefficient: enter the proper coefficient value for recession flow.

Press "F10" to confirm the values and leave the menu.

2.3.5.4.2.4 Sub-menu #3.4.2.4: land-use groups (figure 2.50)

MAIN MENU	
1._	Simulation parameters;
2._	
3._	SUB-MODELS
4._	
5._	1._ Interpolation of precipitations;
6._	2._ Snowmelt;
0._	3._
	4._ VERTICAL WATER BUDGET
	5._
	6._ 1._ Bypass, read data from disk;
	0._ 2._
	3._ BV3C
	4._
	0._ 1._ Files' names;
	2._ 3 couches parameters;

CLASS CODE (SEPARATED BY "+") FOR IMPERVIOUS SURFACES
route

CLASS CODE (SEPARATED BY "+") FOR WATER SURFACES
eau1+eau2

Figure 2.50 Sub-menu #3.4.2.4: land-use groups.

Three groups of land-use classes are considered in BV3C, namely: impervious areas, water surfaces and all other areas.

As required in the menu, type the class code(s) of the original land-use class(es) corresponding to "impervious areas", separated by a "+" sign. Then, press "ENTER" to proceed to the next group "water surfaces" and do as before. The original land-use classes that have not been assigned yet are automatically assigned to "other areas".

2.3.5.5 Sub-menu #3.5: surface and sub-surface runoff (figure 2.51)

MAIN MENU	
1._	Simulation parameters;
2._	
3._	SUB-MODELS
4._	
5._	1._ Interpolation of precipitations;
6._	2._ Snowmelt;
0._	3._ Evapotranspiration;
4._	
5._	SURFACE AND SUB-SURFACE RUNOFF;
6._	
0._	1._ Bypass, read data from disk;
	2._ Kinematic wave equation; ✓
	3._ User's defined runoff function;
	0._ Return to previous menu.

Figure 2.51 Sub-menu #3.5: surface and sub-surface runoff.

See section 3.6 for more information.

Three options are currently available for the simulation of surface and sub-surface runoff (figure 2.51). Select one and press "ENTER".

Option 1 allows the user to bypass the surface runoff sub-model by reading instead "runoff" values from a previous run or computed elsewhere. Values are read from the file specified in sub-menu 2.1.3 (intermediate data). It will be also possible for the user to write its own vertical water budget, following the instructions given in this user's guide.

Initial values of water in transit can be obtained from the file whose name appears in sub-menu 2.1.2 if option 2 is selected in sub-menu 2.3.2.

Otherwise, initial runoff values are initialized to "zero". Return to sub-menu 3.5 by selecting option "0" and pressing "ENTER".

2.3.5.5.1 Sub-menu #3.5.1: land-use groups

MAIN MENU	
1._	Simulation parameters;
2._	
3._	SUB-MODELS
4._	
5._	1._ Interpolation of precipitations;
6._	2._ Snowmelt;
0._	3._ Evapotranspiration;
	4._
	5._ SURFACE AND SUB-SURFACE RUNOFF;
	6._

CLASS CODE (SEPARATED BY "+") FOR FOREST
resin+feuil

Figure 2.52 land-use groups for surface and sub-surface runoff.

When option 2, kinematic wave equation, is chosen, sub-menu 3.5.1 appears. Only two overland classes are considered, forested areas and open areas. As required, type the class code (s) of the original land-use class(es) corresponding to "forested areas". Those include both coniferous and deciduous forests. Then press "ENTER" to confirm your entries and leave the menu. All other land-use classes are grouped together.

2.3.5.6 Sub-menu #3.6: channel routing

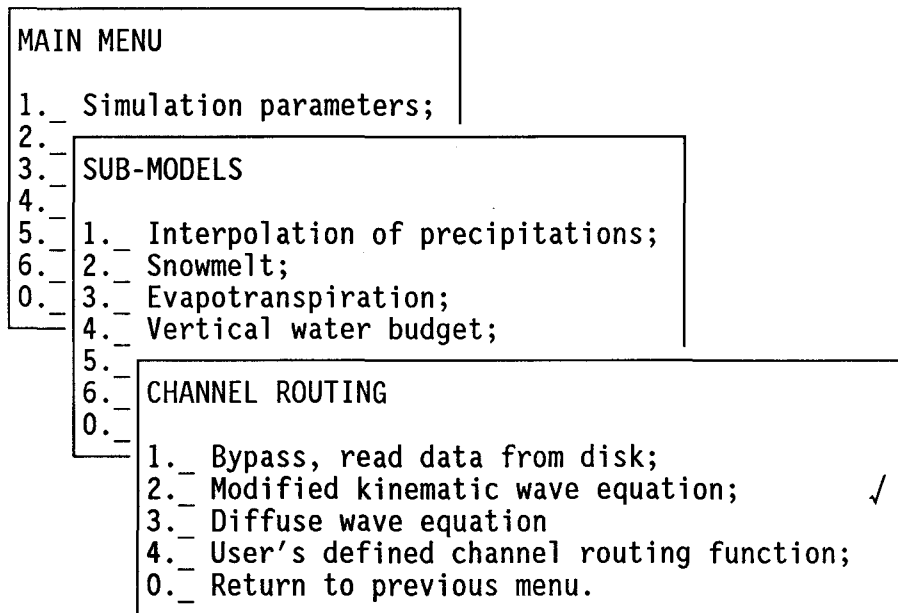


Figure 2.53 Sub-menu #3.6: channel routing.

See section 3.7 for more information.

Four options are currently available for the simulation of channel routing (figure 2.53).

Option 1 allows the user to bypass the channel routing sub-model by reading instead "streamflow" values from a previous run or computed elsewhere. Values are read from the file specified in sub-menu 2.1.3 (intermediate data). It will be also possible for the user to write his own model, following the instructions given in this user's guide.

Two sub-models, are programmed in HYDROTEL 2.0 as options 2 and 3, namely: a modified kinematic wave equation and a diffusive wave equation.

Select any of the options and press "ENTER" to confirm your choice.

Initial values of water levels in the reaches can be obtained from the file whose name appears in sub-menu 2.1.2, if option 3 is selected in sub-menu 2.3.2. Otherwise, initial runoff values are initialized to "zero". If option 3, the diffusive wave equation, is chosen it is necessary to have "initial values of water levels" different from zero. One way is to do a first run with option 2 and save the values as mentioned above.

Return to sub-menu 3.6 by selecting option "0" and pressing "ENTER".

2.3.6 Sub-menu #4.0: data output

Sub-menu #4.0 (figure 2.54) leads to windows in which informations needed to output data will be given. The following menus are similar to those related to sub-menus #2.0.

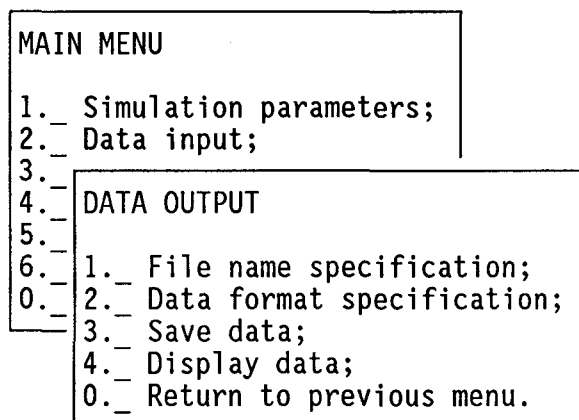


Figure 2.54 Sub-menu #4.0: data output.

2.3.6.1 Sub-menu #4.1: file name specification

Sub-menu #4.1 (figure 2.55) leads to two sub-menus in which the file names for intermediate results or final settings of the state variables, will be given. Note that default file names are given, but may be modified if needed.

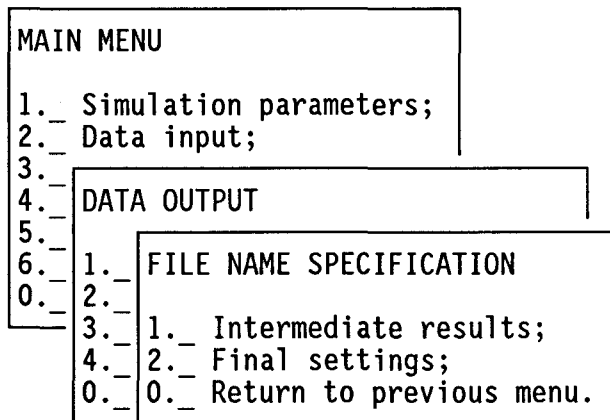


Figure 2.55 Sub-menu #4.1: file name specification.

2.3.6.1.1 Sub-menu #4.1.1: intermediate results

File names for files containing intermediate results can be given here (figure 2.56).

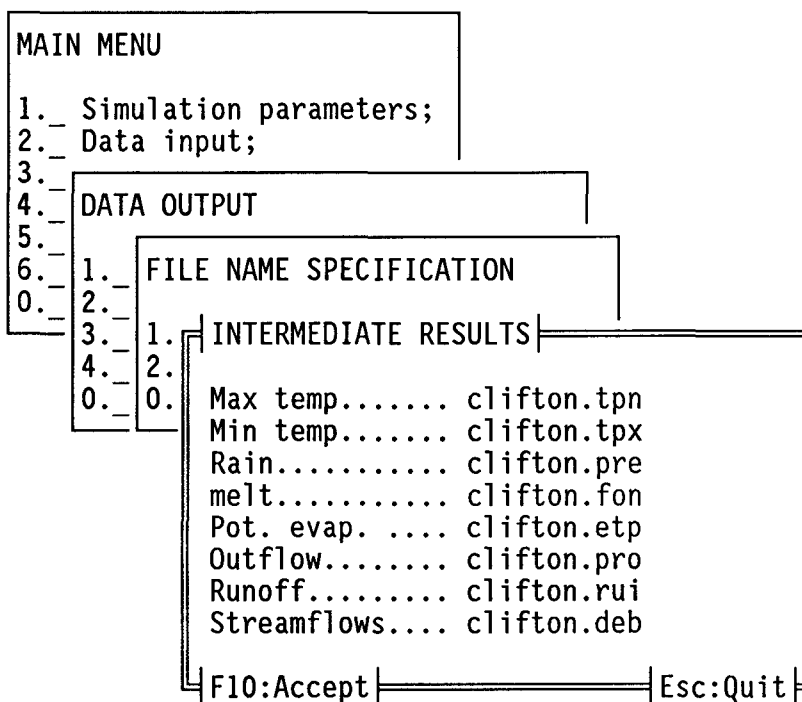


Figure 2.56 Sub-menu #4.1.1: intermediate results.

2.3.6.1.2 Sub-menu #4.1.2: final settings

File names for values of state variables that will be used in a later run as initial values are given here (figure 2.57). The initialization procedure is explained at the end of Part 2.

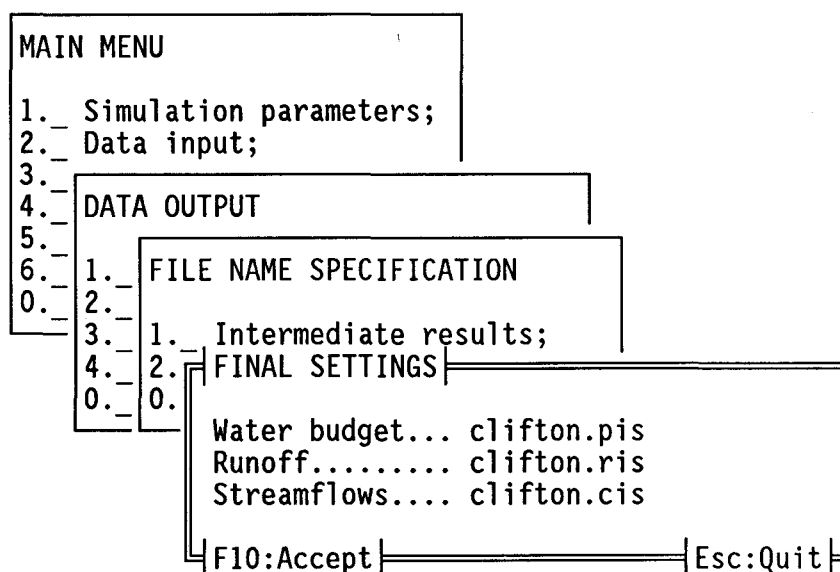


Figure 2.57 Sub-menu #4.1.2: final settings.

2.3.6.2 Sub-menu #4.2: data format specification

Data format in which the output files will be written are chosen in the sub-menus accessed from this sub-menu (figure 2.58).

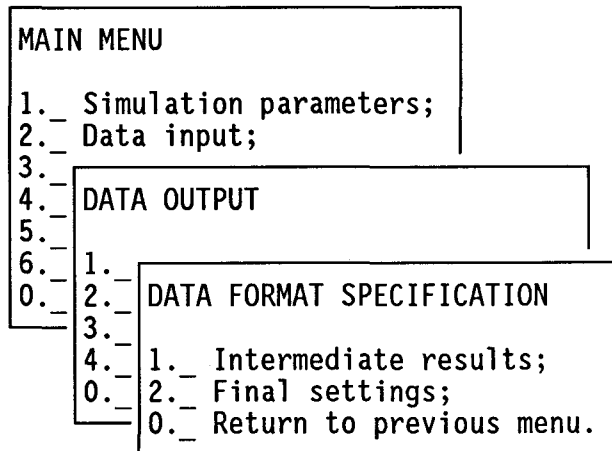


Figure 2.58 Sub-menu #4.2: data format specification.

2.3.6.2.1 Sub-menu #4.2.1: intermediate results

Only INRS ASCII text file format is available with HYDROTEL 2.0 (figure 2.59).

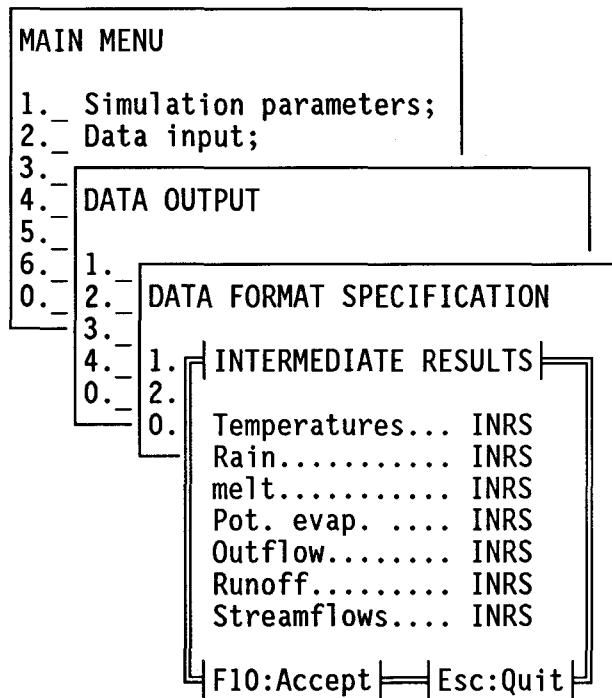


Figure 2.59 Sub-menu #4.2.1: intermediate results.

2.3.6.2.2 Sub-menu #4.2.2: final settings

Only INRS ASCII text file format is available with HYDROTEL 2.0 (figure 2.60).

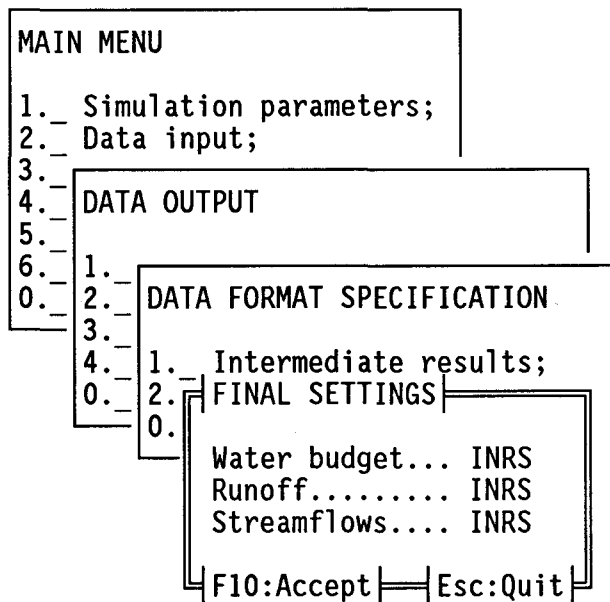


Figure 2.60 Sub-menu #4.2.2: final settings.

2.3.6.3 Sub-menu #4.3: save data

To be used in other runs of HYDROTEL or otherwise, data have to be saved (figure 2.61). Figure 2.62 shows an example of the matrices saved for a particular time. Intermediate results or final settings of state variables may be saved.

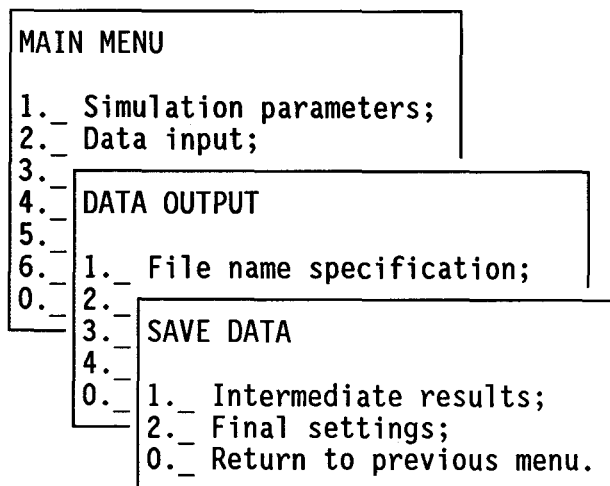


Figure 2.61 Sub-menu #4.3: save data

[illegible]

Figure 2.62 Available water from rain and/or melt.

2.3.6.3.1 Sub-menu #4.3.1: intermediate results

Any of the variables appearing in sub-menu 4.3.1 (figure 2.63) can be saved if it is selected.

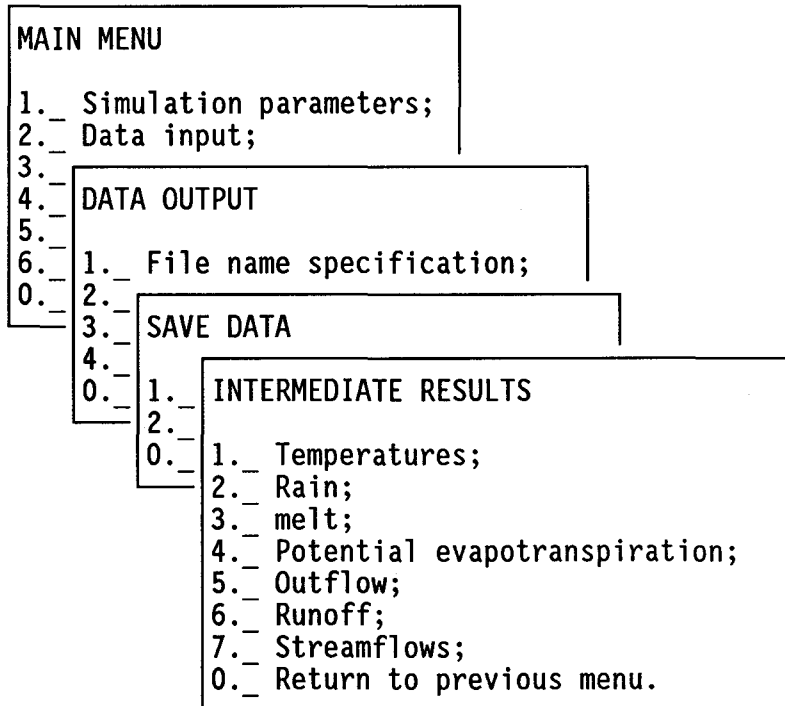


Figure 2.63 Sub-menu #4.3.1: intermediate results.

2.3.6.3.2 Sub-menu #4.3.2: final settings

The final values of any of the state variables appearing in sub-menu 4.3.2 (figure 2.64) can be saved if it is selected.

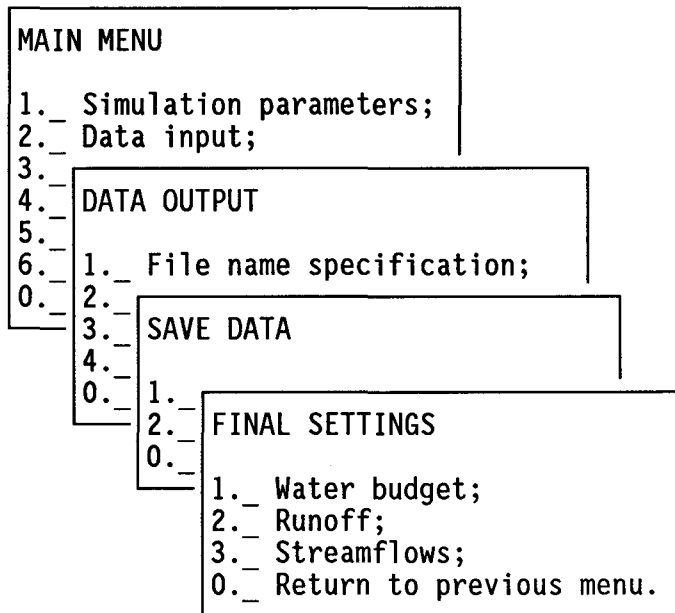


Figure 2.64 Sub-menu #4.3.2: final settings.

2.3.6.4 Sub-menu #4.4: display data

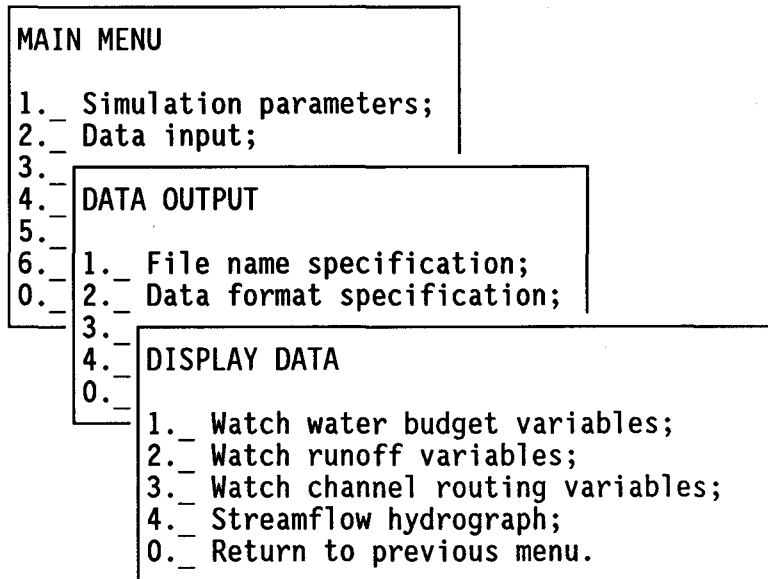


Figure 2.65 Sub-menu #4.4: display data.

Sub-menu 4.4 contains four options (figure 2.65). The first three options allow the user to monitor selected variables both in time and space during the simulation. They are mutually exclusive. In other words, only one of them may be active for a particular simulation.

The fourth option allows display of the simulated hydrograph together with related variables.

It is necessary to select those options before the simulation, if one wishes either to look at variables during the simulation or display the simulated hydrograph automatically after the simulation.

When this is done, return to "main menu" by selecting option "0" and pressing "ENTER".

If one of the first three options is chosen, a discretized map of the basin appears in the left portion of the screen (figures 2.66 to 2.69). A rectangular cursor is "on" and can be moved from square to square or reach to reach, by the "arrows" on the keyboard. To the right of the map, tabular information is given relative to square, reaches and vertical water budget, depending on the option. If the vertical water budget is chosen the information is related to the sub-model chosen in sub-menu 3.4 (either CEQUEAU or BV3C).

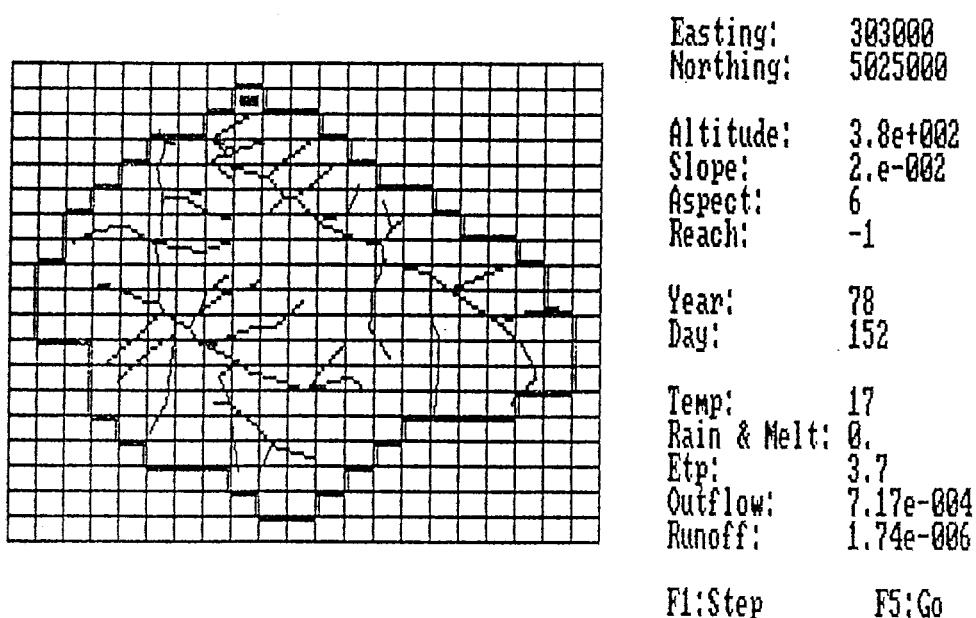
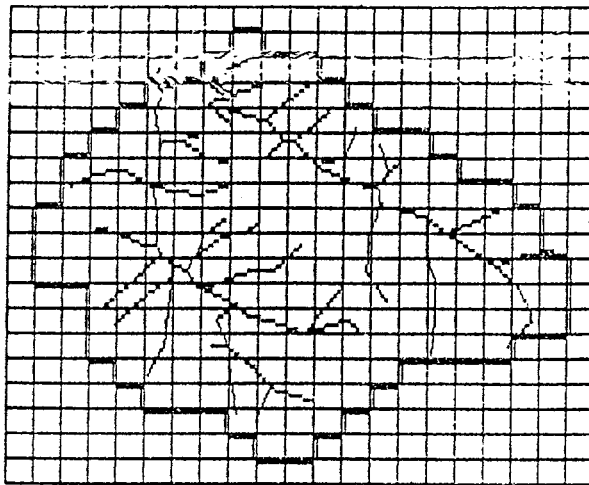
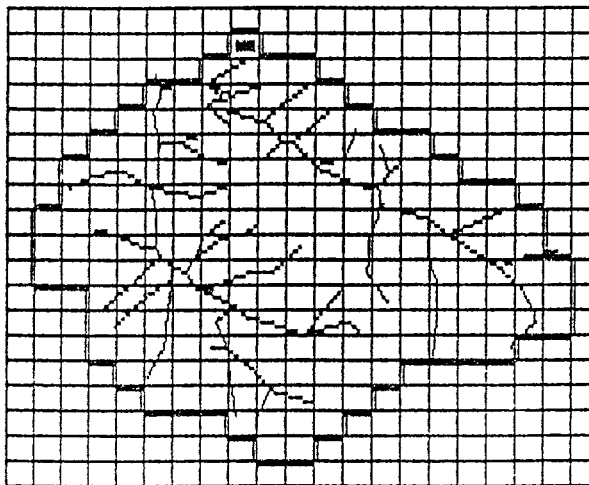


Figure 2.66 Tabular informations on variables related to squares.



Id: 0
 Upstream: 300600
 5023200
 Downstream: 300350
 5023200
 Length: 4.72e+002
 Width: 17
 Slope: 2.12e-003
 Lower reach: -1
 Year: 78
 Day: 152
 Strmflw (up): 1.42e-003
 Strmflw (dwn): 2.45e-010
 Lat. inflow: 0.
 F1:Step F5:Go

Figure 2.67 Tabular informations on variables related to reaches.



Easting: 303000
 Northing: 5025000
 Year: 78
 Day: 152
 Temp: 17
 Prec: 0.
 Etp: 3.7
 hs: 60
 hn: 30
 hm: 2.47e+002
 Outflow: 7.17e-004
 F1:Step F5:Go

Figure 2.68 Tabular informations on variables related to CEQUEAU water budget.

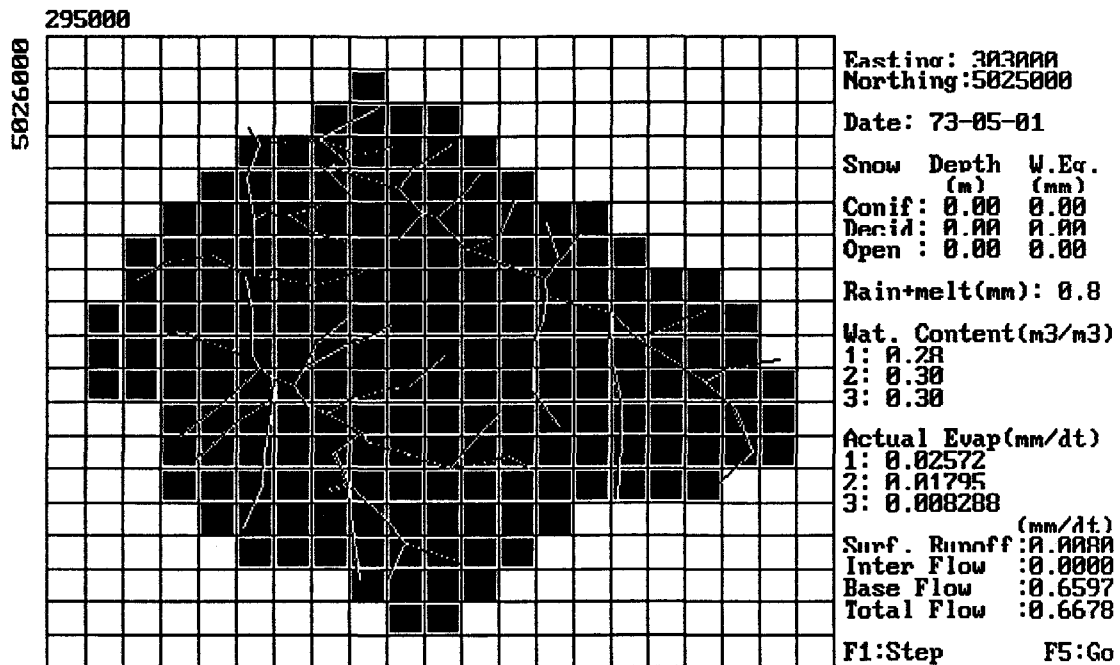


Figure 2.69 Tabular informations on variables related to BV3C water budget.

It is possible to "watch" the simulation step by step by pressing "F1". After the simulation is done for a particular step, moving the cursor will change accordingly the values of the variables and parameters appearing on the right. By doing this it is possible to "watch" both the temporal and the spatial variation of particular variables.

It is also possible to choose a continuous simulation by pressing "F5". Then, the values, in the right part of the screen, change continuously. As those values are determined by the position of the cursor, it is recommended to position the cursor at the right place, before starting the continuous simulation. Typing F1 when in continuous mode returns control to step by step simulation.

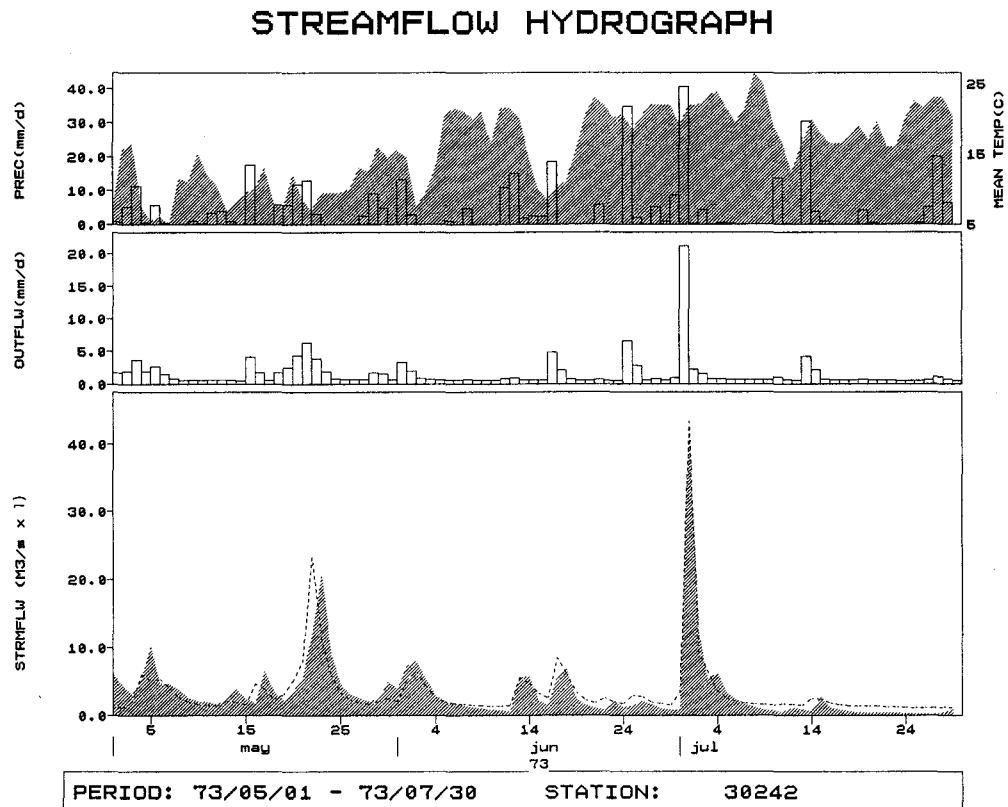


Figure 2.70 Streamflow hydrograph.

As mentioned previously, if option 5 is selected, the simulated hydrograph is displayed automatically at the end of the simulation. The display is divided into four windows (figure 2.70). The vertical window on the right permits interactive modification of the other windows. Representative values of daily rain, melt and mean temperature for the basin are displayed in the upper window, whereas the same is done for outflow resulting from the daily vertical water budget. In the lower window, measured streamflows are displayed (light color against a dark background) together with simulated streamflow (dashed line).

In the upper part of the right window, the first and the last day of the simulation are displayed.

When a simulation is done for more than 365 days, only the first 365 days are displayed initially. It is possible to display other parts of the simulation in two ways: direct modification of the first and/or last day displayed or window modification. By doing that it is also possible to "zoom" on a particular period.

- Direct modification of starting and ending dates in the display window

1. Move the cursor to the day(s) or year(s) to be modified.
2. Strike the "enter" key. The local interactive window becomes active.
3. Modify the day or year. (The local window is desactivated automatically).
4. Move the cursor to "Display new window".
5. Strike the "enter" key. The new window is then displayed.

- Modification of the position or size of the display window

1. Move the cursor to "window" and strike the "enter" key to activate this mode.
2. Using the arrows "or "" it is possible to displace the display window towards the beginning (or end () of the simulation period. Striking the "+" key will increase the display window (max: 365 values), whereas striking the "-" key will decrease the display window.

Note that the displayed dates above will change as the window is modified.

3. When satisfied with the displayed dates, strike the "enter" key again.
4. Move the cursor to "display new window" and strike the "enter" key. The window is then displayed.

The identification number of the streamflow station corresponding to the outlet of the basin is displayed in the lower part of the interactive window.

It is now possible to print the graphs appearing in all three windows. To do that move the cursor to "PRINT" and press "ENTER". Remember that the proper printer driver must be installed.

Note that there is a time delay before printing starts.

It is possible to go out from the display by moving the cursor to "EXIT" and striking the "enter" key.

2.4 Calibration of model parameters and initialization of state variables

The following section has been prepared in order to give only a few hints on the subjective calibration of model parameters and initialization of state variables. However, it should help to obtain better results more rapidly. An objective technique should be included with the next version of HYDROTEL, together with physical, mathematical or empirical limits for the variation of parameters.

2.4.1 Calibration of model parameters

Calibration is the operation by which one tries to give the best possible values to model parameters. Of course, the more parameters, the more difficult it is to really find the best values. The process can be done subjectively or objectively, with the help of criteria, in either cases.

2.4.1.1 Control criteria

With the current version of HYDROTEL, the visual comparison of simulated and measured streamflows will be used to help in the calibration of model parameters. However, as both simulated and measured streamflows will be available on files, the user will have the possibility of using its own criteria to help finding the best parameter values. More objective criteria will be available in future versions.

2.4.1.2 Pre-calibration sensitivity analysis

Before an effective calibration process is undertaken, it is suggested to become acquainted with the effect of changing the value of anyone parameter on the simulated streamflows. Remember that some parameters affect the volume of the flood, while others affect its shape, or the distribution between base flow, interflow and direct runoff.

2.4.1.3 Subjective calibration

In order to simplify the calibration process, it is suggested to calibrate first the model parameters, excluding snowmelt. This means that summer periods representative enough of the flow regime on the river should be used. Periods (one to four months in length) should be used to calibrate the parameters and others (at least one) to verify the calibration.

Try first to obtain similar total volumes of simulated and measured streamflows. Then, look at the distribution between base flow and interflow and runoff. After that, it will be easier to make the final adjustment for the shape of the hydrographs.

Remember that the calibration process is one of trials and errors. So, be patient and systematic.

Once you consider that you have a good set of parameters for the model itself, go for a full year including snow cover simulation and melt and calibrate the remaining parameters. Don't be surprised if you feel that model parameters could be changed to obtained better results. Do so.

2.4.2 Initialization of state variables

When a long period of time (at least one year) is used for calibration purposes, initial values of state variables (levels in reservoirs simulating the vertical water profile and water in transit to the outlet of the basin) are not that important. Only the first 5 to 15 days may be affected, depending how far the actual values given to state variables are from the values that should have been given. If relatively short periods are used for calibration purpose, more careful consideration should be given to initial values.

2.4.2.1 Vertical water profile

Let us look first at the vertical water profile. Whatever model is used it is easier to start the simulation when only base flow is contributing, that is one or two day after the last rainfall.

Two sub-models are available with HYDROTEL 2.0.

2.4.2.1.1 CEQUEAU (modified)

If the vertical water budget is simulated as in the CEQUEAU model, three state variables need be initialized.

A few days after the last rainfall, the actual water level in the unsaturated reservoir should be below the threshold level for sub-surface runoff. Moreover, if the threshold level for percolation to the saturated zone reservoir is identical to that for sub-surface runoff, then the water level in that reservoir is equal to these thresholds at the end of the flood and decreases only by evapotranspiration. It is then only necessary to estimated total evapotranspiration since the actual level dropped to the threshold levels and subtract that value from the threshold value to obtain the estimated value for the water level in the unsaturated zone reservoir. It should be noted that this initial value will be given to the unsaturated zone reservoirs of all squares.

The initial water level in the saturated zone reservoir should be related to streamflow. The lower the streamflow value the lower the water level. A first approximation of the initial value in the reservoir can be obtained from the following equation:

$$H = \frac{86.4 Q_o}{A \cdot C} \quad (2.1)$$

where:

H = water level in saturated zone reservoir (mm)

Q_o = measured streamflow (m³s⁻¹)

- 86.4 = constant (conversion of units)
 A = basin area (km²)
 C = outflow coefficient from the saturated zone reservoir.

More information on how to obtain an initial value for that level will be given in the next section.

The third state variable for which an initial value has to be given is the level in the LAKES and MARSHES reservoir of each square. Unless lakes and marshes occupy a large proportion of the basin, this variable may be given a value close to the threshold level in that reservoir. This will be accurate enough. Further subjective adjustments may be necessary if the fraction of the basin occupied by lakes and marshes is important and it is felt by comparison of simulated and measured streamflows that changing the initial value would help. It is suggested to test the sensitivity of changes in that reservoir.

2.4.2.1.2 BV3C

If the vertical water budget is simulated by BV3C, three state variables need be initialized, namely the water contents θ_i of all three layers.

In the surface layer, layer no 1, θ_1 should be close to θ_{cc} , the water content at field capacity, maybe a little below.

In layer 2, θ_2 should also be close to θ_{cc} . It should be remembered here that interflow tends to become insignificant when θ_2 drops from θ_s (water content at saturation) to θ_{cc} .

The value of θ_3 should be determined with relation to streamflow, as for the saturated zone reservoir of the CEQUEAU model, knowing that the product $Z_{33}\theta_3$ in equation 3.22 is equivalent to H in equation 2.1. A first approximative to θ_3 would be θ_{cc} as in the upper layers. More informations will be given in the next version of HYDROTEL.

2.4.2.2 Water in transit

At any time, water is in transit to the outlet of the basin, from square to square or reach to reach. This also has to be initialized.

2.4.2.2.1 First simulation on a new basin

It applies primarily when the CEQUEAU vertical budget is selected. As the saturated zone reservoir in CEQUEAU and layer 3 in BV3C have similar behaviour, the method can be used to obtain initial values of water in transit from both sub-models. A more specific adapted method will be described with the next version of HYDROTEL.

The following method is suggested.

Estimation of water level in the saturated zone reservoir for base flow simulation

With equation (2.1), obtain a first estimate H of the water level (equal for all square) in the saturated zone reservoir corresponding to the measured streamflow Q_o .

Then, estimate the level in the reservoir at time $(t-n)$ from the following equation:

$$H_{t-n} = \frac{H_t}{(1 - C)^n} \quad (2.2)$$

where:

H_{t-n} and H = water level in saturated zone reservoir at time $(t-n)$ and time t , respectively

n = number of days (10 to 20)

C = outflow coefficient from the saturated zone reservoir.

Parameter values for base flow simulation

You can start your simulation any day of any year, but make sure that water is made available to the drainage network only from the saturated zone reservoir. To stop water from going out of other reservoirs, utilize the following values or similar ones:

- Sub-menu 1.2:
 - number of days: 30 (or more);
- Sub-menu 3.4.1.1:
 - depth threshold for surface runoff (mm): 100;
- Sub-menu 3.4.1.2:
 - capacity of the reservoir (mm): 500;
 - runoff coefficient: 0.0;
 - percolation coefficient: 0.0;

Leave other parameters with default values.

- Sub-menu 3.4.1.3:
 - type your own values or use default values. Remember that the outflow coefficient is used in equations (2.1) and (2.2) (below);
- Sub-menu 3.4.1.4:
 - outflow coefficient: 0.0;

Leave the other parameter with its default value.

- Sub-menu 3.4.1.5:
 - saturated zone (mm): value as estimated above by equation (2.2).

First initialization simulation

Make a first initialization simulation. As there is no water in transit at the beginning of the simulation, the streamflows will first increase during the first time steps (up to 10 days or more) and then decrease regularly. Look at that part of the hydrograph and note the day at which a streamflow value close to that measured is simulated.

Second initialization simulation

Keep the same values as before but change the number of days in the simulation so that the day at which a streamflow value close to that measured has been simulated is now the last day of the simulation. Run the program and save the values of water in transit from square to square and from reach to reach for later use.

2.4.2.2.2 All further simulations on a basin for which initialization files do exist

Once you have obtained initialization files for water in transit from square to square or reach to reach, on a particular basin, they can be used for later simulations, provided the initial streamflow is relatively close to that corresponding to data on the files.

It is always possible to create new initialization files using the procedure described above. Do not forget to change back the values of the parameters afterward.

2.5 Integration of user's developed sub-models

HYDROTEL 2.0 has been developed to facilitate integration of user's defined sub-models, both in "C" and "FORTRAN". A guide is added in appendix A.

PART 3

MAIN SIMULATION EQUATIONS AND FLOW CHARTS

PART 3 MAIN SIMULATION EQUATIONS AND FLOW CHARTS

3.1 Introduction

A description of the main simulation equations used in the model is given in part 3. Such a description should help the user to understand the model and make better choices between available options. Of course, it will be assumed that the reader is already familiar with hydrological simulation and forecasting.

3.2 Spatial distribution of precipitation

Three methods are currently available to assign precipitation values to each of the squares representing the watershed. At each time step, before applying the chosen method, station values are first checked for missing data.

If this is effectively the case at a particular station, the precipitation value reported at the station closest to that station is used as a substitute for the missing data.

It should also be noticed that whatever interpolation method is used, it is possible to make a correction to the value interpolated to each square, in order to take into account the increase of precipitation with altitude. The correction is based on the vertical gradient of precipitation and the difference in altitude between a particular square and the altitudes of the stations used in the interpolation process.

3.2.1 Thiessen polygons

If the Thiessen method for the spatial distribution of station data is chosen, the precipitation value observed at the station closest to a particular square is assigned to that square.

3.2.2 Weighted mean of nearest three stations

In this method, the values observed at the nearest three stations are weighted according to the distance from a particular square. The weights are inversely proportional to the distance and their sum must equal one.

3.2.3 Arithmetic mean of nearest three stations

This method is similar to the previous one except that the weights are equal (1/3). The previous method is preferred, but this method could be applied, particularly if the station network is regular and dense.

3.3 **Snow cover simulation and melting**

Only a modified degree-day method is available with HYDROTEL 2.0. However, simulation of snowpack processes using an energy budget method will be added in version 2.1 of the model.

3.3.1 Transformation of rainfall into snowfall

At temperatures around 0°C, precipitation may fall as snow or rain. Assuming that the information available is air temperature (°C), rainfall (mm) and snowfall (cm) at the stations, the problem is to estimate what happens on each square, depending on its altitude.

The air temperature observed at the stations is first interpolated to each square, with one of the methods used for precipitations. A threshold temperature STRNE closed to 0°C or a little over 0°C, is also chosen.

If $[T_a - (\text{STRNE} + 2) \geq 0]$: all precipitation is considered to be liquid.

If $[T_a - (\text{STRNE} - 2) \geq 0]$: all precipitation is considered to be solid.

If $[(\text{STRNE} - 2) < T_a < (\text{STRNE} + 2)]$: a linear distribution between rainfall and snowfall is assumed.

The transformation of rainfall (mm) into snowfall (cm) takes into account the density of new snow as a function of air temperature. The relation used is experimental and ρ_s varies from 50 kg m⁻³ at $T_a = -17^\circ\text{C}$ to 151 kg m⁻³ at $T_a = 0^\circ\text{C}$.

$$\rho_s = 151 + 10.63 T_a + 0.2767 T_a^2 \quad (3.1)$$

3.3.2 Simulation of snowpack transformation and melt

As mentioned above the simulation of snowpack transformation and melt is based on a modified degree-day method. The melt equation at the air-snow interface is essentially that developed by Riley *et al.* (1972):

$$M_s = C_f \frac{R_s}{R_h} (T_a - T_s) (1 - A) + 0.0125 R T_a \quad (3.2)$$

where:

M_s = melt at the snow-air interface (mm d⁻¹);

C_f = melt factor depending on land-use (mm °C⁻¹ d⁻¹);

R_s = radiation index for a sloping surface;

R_h = radiation index for a horizontal surface;

T_a = air temperature (°C);

T_s = threshold temperature (assumed to be 0°C by Riley *et al.* (1972));

A = albedo of snow;

R = rainfall (mm).

A low constant melt is further assumed at the snow-ground interface.

It should be that mentionned that the program takes into account the daily variation of radiation on horizontal and sloping surfaces, as well as that of albedo since the last snowfall.

The day-to-day variation of snow depth, water equivalent and density resulting from precipitation and melting is simulated, with settlement of the pack taken into account for computing daily values of snow depth (Riley, 1969). The cold content and liquid water content of the pack are also simulated, which, together with the water budget variables mentioned above, allow a simulation of snowpack processes closer to that possible with an energy budget approach. The equations used for that purpose are similar to those suggested by Raudkivi (1979), Obled and Rossé (1977), Paré (1979) and Leconte (1984).

Three land-use classes are considered separately for snow processes, namely coniferous forest, deciduous forest and open areas. Melt water from those three classes is weighted according to the area covered by each class in a particular square, to obtain the mean water depth available for infiltration on that square.

3.3.3 Input variables

Values of input variables are assumed to be identical for each square representing the basin.

Information on land-use and topography is used in the snowpack submodel, but will not be discussed here as it is common to other parts of the model.

The following variables apply to the snowpack submodel exclusively:

- COMPAC: settlement constant. This constant is applied to the difference between the actual snow depth at density ρ_t corresponding to a particular water equivalent and the snow depth that would be observed at maximum density DSNGX. A value around 0.1 is suggested;
- CFR, CFF, CDF ($\text{mm d}^{-1} \text{ } ^\circ\text{C}^{-1}$): melt factors for coniferous forests, deciduous forests and open areas respectively. Effective cover should be taken into account when choosing a particular value. The smallest value should be given to CFR and the greatest to CDF. Actual values usually range between 2 and 5 $\text{mm d}^{-1} \text{ } ^\circ\text{C}^{-1}$;
- DSNGX (kg m^{-3}): maximum density of snowpack (usually at the end of the season). A value of DSNGX ranging approximately from 450 to 600 kg m^{-3} could be assumed. It is suggested to look at past snowcover records in the region under study to decide upon a value;
- FONSFOL (mm d^{-1}): melt rate at the snow-ground interface. That value should be relatively low, taking into account the actual ground condition in the basin. For instance, Riley *et al.* (1972) assumes 0.5 mm d^{-1} . It is suggested to define such a value with an equation based on the average thermal gradient in the upper layer of the ground. Other values cited in the literature are close to that used by Riley *et al.* (1972);
- TS ($^\circ\text{C}$): threshold temperature for melt. This temperature is assumed to be 0°C by Riley *et al.* (1972). Standard degree-day equations use values of TS different for forested and open areas in order to take into account the radiation effect. In the current model, the value of TS is assumed to be identical for all three land-use classes, the radiation effect being taken into account by both the melt factors and the radiation indices.

3.4 Evapotranspiration

3.4.1 Potential evapotranspiration

In order to allow estimation of potential evapotranspiration from available data, various equations are offered as options so that the user can select the one that answers his needs best, given a particular set of data. Specific PET values are computed for each square, from interpolation of data measured at climatological stations.

3.4.1.1 Thornthwaite potential evapotranspiration

3.4.1.1.1 The equation

Thornthwaite equation is well known and has been applied in many studies in the past. Every one knows that it is not the best equation to use, but in many basins it is almost the only one applicable, because of lack of data permitting to use precise equations of the Penman type.

The equation is:

$$E_{th} = \frac{16.2}{30.4} \frac{10 T_a}{X_1} X_2 C_1 * 10^{-3} \quad (3.3)$$

where:

E_{th} = Thornthwaite potential evapotranspiration (m d⁻¹);

T_a = mean daily air temperature (°C);

X_1 = Thornthwaite's thermal index;

X_2 = exponent derived from X_1 ;

C_1 = adjustment factor for latitude and day length.

Since there is no way to distinguish between land-use classes, E_{th} is identical for all land-use classes.

3.4.1.1.2 Input data

Values for X_2 and C_1 are estimated in the program. Aside from station temperatures interpolated to each square, the following variables are considered as input:

- X_1 : an initial value for X_1 can be obtained from the following formula:

$$X_1 = \sum_{i=1}^{12} \left(\frac{T_{m_i}}{5} \right)^{1.5}. \text{ The variable } T_{m_i} \text{ is the mean interannual monthly temperature for a particular month } i;$$

- L_a : mean latitude of the basin (degrees and hundredth of a degree);
- J_{sol} : temporal shift parameter for the estimation of C_1 . Usually, J_{sol} should be set to 80, to obtained the maximum day length at the end of June.

3.4.1.2 Linacre potential evapotranspiration

3.4.1.2.1 The equation

Considering the fact that availability of data was limiting considerably the use of equations as that of Penman, Linacre (1977) writes that "it seems useful to develop an approximation to the Penman formula, based solely on temperature measurements". He adds that "the outcome may resemble yet another empirical formula both in appearance and in simplicity of use, but should have much of the generality of the basic formula of Penman, with sufficient accuracy for many practical problems and unusually modest demands as regards input data".

The equation is:

$$E_{lin(I)} = \frac{\Delta}{\Delta + \gamma} \left[\frac{24.41 (0.75 - A) T_M}{100 - L_a} + 0.3807 (T_a - T_d) \right] * 10^{-3} \quad (3.4)$$

where:

$E_{lin(I)}$ = Linacre potential evapotranspiration for land-use classe I (md^{-1})

Δ = slope of saturation vapor pressure at temperature T_a ($\text{mb } ^\circ\text{C}^{-1}$)

γ = psychrometric constant ($\text{mb } ^\circ\text{C}^{-1}$)

A = albedo of land-use class I

T_a = mean daily air temperature ($^\circ\text{C}$)

T_M = sea-level equivalent of the measured mean temperature T_a

$$T_M = T_a + 0.006 h_a$$

T_d = dew point temperature

h_a = altitude (m)

L_a = mean latitude of the basin (degrees and hundredth of a degree)

The ratio $\Delta/(\Delta + \gamma)$ increases very slowly between 0° and 40°C , ranging approximately from 0.4 to 0.9. So, a linear approximation to $\Delta/(\Delta + \gamma)$ appropriate for a given range of T_a , may be given by:

$$\frac{\Delta}{\Delta + \gamma} = C + D T_a \quad (3.5)$$

where:

C = intersect for $T_a = 0^\circ\text{C}$

D = slope ($^\circ\text{C}^{-1}$)

It is suggested to the user to compute his own graph of $\Delta/(\Delta + \gamma)$ against T_a to select proper values for C and D.

Also, if dew point temperatures are not available, an approximation to $(T_a - T_d)$ may be obtained from the following empirical relation:

$$T_a - T_d = 0.0023 h_a + 0.37 T_a + 0.53 (T_{JX} - T_{JN}) + 0.35 (T_{MX} - T_{MN}) - 10.9 \quad (3.6)$$

where:

T_{JX} and T_{JN} = maximum and minimum daily air temperatures ($^\circ\text{C}$)

T_{MX} and T_{MN} = mean air temperature of the warmest and coldest months, respectively ($^\circ\text{C}$).

3.4.1.2.2 Input data

Daily maximum, mean and minimum air temperatures as well as altitudes for each square are assumed available as they are read elsewhere in the model. Albedo values as a function of time for each land-use class should also be available from PHYSITEL, as one of the parameters characterizing each land-use class. These values can be modified and updated in HYDROTEL.

Input data more specific to Linacre's potential evapotranspiration include:

- T_d = dew point temperature at climatological stations
- L_a = mean latitude of the basin (degrees and hundredths of a degree)

- C and D = the constants for the linear approximation to $\Delta/(\Delta + \gamma)$
- Also, if T_d values are not available, then proper values for the following variables should be read:

T_{MX} = mean air temperature of warmest month (°C)

T_{MN} = mean air temperature of coldest month (°C)

3.4.1.3 Monteith - Penman potential evapotranspiration

3.4.1.3.1 The equation

Two formulations of the original Penman equation are available.

The first one is that modified by Monteith (1965). It applies to saturated surfaces, and the essential difference with Penman original equation is in the wind function. It is a special case of the more general equation developed by Monteith, including both aerodynamic and stomatal resistances to transpiration, which may be used to compute actual evapotranspiration. As data for ground heat flux are seldom available, this term of the energy budget is not considered. When all needed data are available this equation is usually preferred to others.

The second one keeps Penman's empirical wind function.

The general formulation of the equation is:

$$E_p = \left[\frac{\Delta R_n + \gamma E_a}{\Delta + \gamma} \right] \frac{10^{-3}}{L_e} \quad (3.7)$$

with, in either case:

$$R_n = (1 - A(I)) R_g - \sigma T_a^4 (0.56 - 0.08 \sqrt{h_r e_s}) (0.1 + 0.9 h/H) \quad (3.8)$$

If R_g is not measured then:

$$R_g = I g_a (A + B h/H) \quad (3.9)$$

and for option 1: (more theoretical wind function)

$$E_a = \frac{86400 \rho C_p k^2 u_1 (1-h_r) e_s}{\ln \left[\frac{Z_1 - d(I)}{Z_o(I)} \right] \ln \left[\frac{Z_1 - d(I)}{Z_{ov}(I)} \right]} \quad (3.10)$$

for option 2 (Penman's empirical wind function):

$$E_a = \gamma L_e E_{ap} = \gamma L_e [0.26 (1+0.54 u_1) (1-h_r) e_s] \quad (3.11)$$

where:

E_p = Penman potential evapotranspiration ($m d^{-1}$)

Δ = slope of the saturation vapor pressure at temperature T_a ($mb k^{-1}$)

R_n = net solar radiation ($J m^{-2} d^{-1}$)

E_a = term representing the "drying power of the air" ($J m^{-2} d^{-1} mb k^{-1}$)

γ = psychrometric constant ($0.6638 mb k^{-1}$)

L_e = latent heat of vaporization ($2.466 \times 10^6 J kg^{-1}$)

$A(I)$ = albedo of land-use class I on day d

R_g = global daily solar radiation ($J m^{-2} d^{-1}$)

σ = Stefan-Boltzman constant ($4.8986 \times 10^{-3} \text{ Jm}^{-2} \text{ K}^{-1} \text{ d}^{-1}$)

T_a = mean daily air temperature (K)

h_r = relative humidity (%)

e_s = saturation vapor pressure for water at temperature T_a (mb)

h = hours of bright sunshine on day d (h)

H = day length on day d (h)

ρ = air density (1.2923 kg m^{-3})

c_p = specific heat of air ($1005 \text{ J kg}^{-1} \text{ K}^{-1}$)

k = von Karman constant (0.4)

u_1 = wind speed at height Z_1 (ms^{-1})

Z_1 = height at which wind measurements are taken (m)

$d(l)$ = zero plane displacement height ($0.7 h_{\text{veg}}$) (m)

$h_{\text{veg}}(l)$ = height of vegetation land-use classe l on day d (m)

$Z_o(l)$ = roughness length for momentum transport ($0.13 (h_{\text{veg}}(l) - d(l))$) (m)

$Z_{ov}(l)$ = roughness length for water vapor transport ($Z_o(l)/5$) (m)

Ig_a = daily extraterrestrial solar radiation ($\text{Jm}^{-2} \text{ d}^{-1}$)

A and B = constants

3.4.1.3.2 Input data

Mean air temperature T_a , as well as extraterrestrial solar radiation Ig_a and day length H are considered available, as they are read or computed elsewhere in the model.

Albedo values and heights as a function of time, for each land-use class should also be available from PHYSITEL, as parameters characterizing each land-use class. The values can be modified and updated in HYDROTEL. It should be noted here that for the purpose of computing evaporation, water surfaces corresponding to lakes and large rivers are considered as a "land-use" class. Proper albedo and heights values should be given to that particular class. A number of land-use classes significantly different from an hydrological point-of-view can be processed by the model and their characteristics can vary in time. However, if such detailed informations are not available, fewer classes with time invariant main characteristics may also be used.

The following files are specific to Penman's equation and should be available and read if that equation is chosen:

- R_g daily global solar radiation ($J\ m^{-2}\ d^{-1}$)
or
 h , daily hours of bright sunshine (h)
- u_1 , wind speed at height Z_1 (m)
- h_r , relative humidity (%)

If R_g is not available, the users must give proper values for the constants A and B. The default values are $A = 0.20$ and $B = 0.55$.

As seen from equation 3.11, Penman's empirical wind function does not make allowance directly for vegetation height. However, a wind speed correction is done for vegetation height assuming neutral conditions and a logarithmic profile. It should apply over a larger number of surfaces.

If the first option (equation 3.10) is chosen, evaporation values over forested areas might be overestimated. This option is interesting, because it permits better differentiation between various types of vegetation, but should be used with care.

3.4.1.4 Priestley-Taylor potential evapotranspiration

3.4.1.4.1 The equation

The following equation is derived from that of Penman. As mentioned by Brutsaert (1984), "when the air has been in contact with a wet surface over a very long fetch, it may tend to become vapor saturated, so that E_a (in the Penman equation) should tend to zero". Then, the first term of Penman's equation can be seen as representing a lower limit to evaporation from a moist surface, which Slatyer and McIlroy (1961) refer to as "equilibrium evaporation" E_e .

Using the same notation as for the Penman equation, E_e can be estimated by:

$$E_e = \frac{10^{-3}}{Le} \left[\frac{\Delta}{\Delta + \gamma} R_n \right] \quad (3.12)$$

where E_e is in m d^{-1} and all other terms have the same meaning as in equations 3.7 to 3.9.

Later on, the concept of equilibrium evaporation lead to an empirical relation by Priestley and Taylor (1972) giving evaporation E_{pt} from a wet surface under conditions of minimal advection.

$$E_{pt} = \alpha E_e \quad (3.13)$$

As seen above E_{pt} is considered to be proportional to E_e . The constant of proportionality α is equal to 1.26, as estimated by Priestley and Taylor (1972). A number of authors have found values close to that estimated by Priestley and Taylor (1972), but others found values closer to 1 or higher that 1.26 to 1.28.

If that equation is used, a value around 1.26 is suggested.

3.4.1.4.2 Input data

Mean air temperature T_a , as well as extraterrestrial solar radiation Ig_a and day length H are considered available, as they are read or computed else where in the model.

Albedo values, as a function of time, for each land-use class should also be available from PHYSITEL, as parameters characterizing each land-use class. These values can be modified and updated in HYDROTEL.

The following files are specific to Priestley and Taylor equation and should be available and read, if that equation is chosen:

- R_g = daily global solar radiation ($Jm^{-2} d^{-1}$)
or
 h = daily hours of bright sunshine (h)
- h_r = relative humidity (%)

If R_g is not available, the users must give proper values for the constants A and B. The default values are $A = 0.20$ and $B = 0.55$.

3.5 Vertical water budget

The terrestrial part of the hydrologic cycle, as applied to a basin, can be divided into three main processes: vertical distribution of incoming water at the ground surface from either rain or melt, surface and sub-surface runoff and channel flow. The "functions" explained in this section are concerned with the first of these processes, namely the vertical distribution of the incoming water.

3.5.1 CEQUEAU (modified)

3.5.1.1 Description of the function

In the CEQUEAU model (Morin et al., 1981) the vertical water budget on each of the square is simulated with the help of three reservoirs (figure 3.1). The water budget on the fraction of the square not covered by either lakes (water surfaces) or marshes is simulated by two reservoirs in series, representing respectively processes in the unsaturated and saturated zones, whereas that on the fraction covered by either lakes or marshes is simulated by one reservoir. Two outlets have been taken off from the original model because they were seldom, if not never, used. The first one was at the bottom of upper land reservoir and the second one was in the ground water reservoir, at a position similar to the one kept for the upper reservoir. The water available for routing on each square, at each time step is computed as the weighted average of the water coming out of the reservoirs in the land portion and in the lakes and marshes portion of the square.

For the land portion, at each time step, a percentage corresponding to the fraction of the square occupied by impervious areas is taken out from the available water from rain and melt, before it can infiltrate into the ground. A water budget is then made for both reservoirs. For the reservoir representing processes in the unsaturated zone, the water level HS fluctuates between 0 and HSOL, a level over with the reservoir is considered full and surface runoff occurs. HS increases with infiltration from rain and melt water and decreases with evapotranspiration, percolation to the saturated zone and sub-surface runoff. There is no percolation if $HS < HINF$. The percolation or sub-surface runoff is proportional to the difference between HS and the thresholds HINT and HINF, respectively. In the same way, the water level HN in the reservoir representing the saturated zone, increases with percolation from the unsaturated zone and decreases by evapotranspiration and ground water outflow, the latter being proportional to HN.

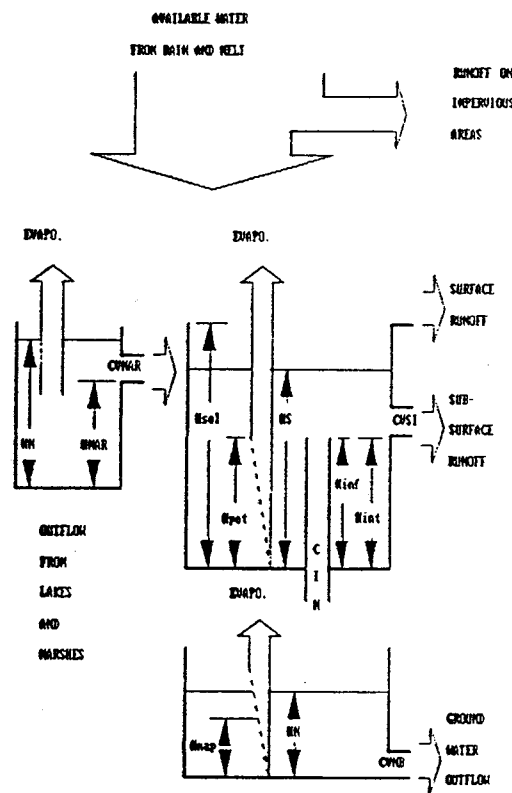


Figure 3.1 Vertical water budget adapted from the CEQUEAU model.

Evapotranspiration is satisfied using both reservoirs. A fraction of potential evapotranspiration is first taken out from the saturated zone reservoir. This fraction varies with H_N , being greater if $H_N > H_{NAP}$ and smaller if $H_N < H_{NAP}$. The remaining portion of the potential evapotranspiration, usually the greatest part of it, is taken from the unsaturated zone reservoir, at potential rate, if $H_S > H_{POT}$ and at a reduced rate if $H_S < H_{POT}$.

The water budget in the lakes and marshes reservoir is estimated in the same way as with the previous reservoirs.

So, at each time step, water becomes available on each square as runoff from impervious areas, surface runoff, sub-surface runoff and ground water outflow from the land portion, and as outflow from lakes (water surfaces) and marshes.

3.5.1.2 Input data

Values of variables are assumed to be identical for each individual square. Initial values given to them for a particular basin could be derived from those given for the test data set. The variables are grouped according to the reservoir to which they apply.

. **Runoff on impervious areas:**

- **HRIMP (mm):** threshold over which surface runoff begins from impervious areas. It is suggested to ignore that variable by putting it equal to zero.

. **Unsaturated zone reservoir:**

- **HSOL (mm):** maximum depth of water which can be stored in the reservoir (capacity of the reservoir). This value corresponds to saturated conditions. It can be determined with reference to porosity and the mean thickness of the unsaturated zone in the basin;
- **HINT (mm):** threshold level for sub-surface runoff. This value, as that of HINF and HPOT below, should be estimated with reference to the field capacity of the unsaturated zone in the basin. It is suggested to give identical or nearly identical values to HINT, HINF and HPOT;
- **CVSI:** runoff coefficient. This parameter should be adjusted by looking at the volume of the flood and the shape of the recession part of the hydrograph, assuming simulation of channel flow is good;
- **HINF (mm):** threshold level for percolation from the unsaturated zone to the saturated zone;
- **CIN:** percolation coefficient. This parameter partly controls the distribution of infiltrated water between the unsaturated and saturated zone and thus between the volume of the floods and the base flow;

- X_{infma} (mm d⁻¹): maximum amount of percolation water at each time step;
- HPOT (mm): threshold level for evapotranspiration to occur at potential rate.

. Saturated zone reservoir:

- CVNB: outflow coefficient. The value of CVNB should be adjusted so that simulated streamflow decreases at the same rate as measured streamflow in low flow periods;
- EVNAP: reference fraction of evapotranspiration satisfied from water in the saturated zone. It is suggested to give a relatively low value to EVNAP (.10 for instance), unless the water table is usually high in the basin and water is effectively taken from the saturated zone by the roots;
- HNAP (mm): reference level over which the effective fraction of evapotranspiration taken from the reservoir is greater than EVNAP and under which it is smaller. The variation is linear.

. Lakes and marshes:

- HMAR (mm): threshold level for outflow from the reservoir;
- CVMAR: outflow coefficient.

. Initial levels in the reservoirs:

- HS (mm): initial water level in the unsaturated zone reservoir. It should be noticed that HS decreases only by evapotranspiration below HINT HPOT and HINF, and is close to HINT at the end of a flood;
- HN (mm): initial water level in the saturated reservoir. The value of HN can be estimated with reference to base flow, when the value of CVNB is already optimized;

- HM (mm): initial water level in the lakes and marshes reservoir. The difference between HM and HMAR is more important than the absolute value of either variables, provided that these value are large enough to satisfy evapotranspiration in general conditions. Of course, if shallow lakes and marshes may dry in a particular basin, this should be taken into account in deciding on a given value.

3.5.2 BV3C

3.5.2.1 Description of the function

For the simulation of the vertical water budget, a new model capable of making good use of remotely sensed data has been developed for HYDROTEL. The variables and fluxes have been defined so as to represent as much as possible physical processus taking place during water redistribution in the soil column. They are by no means an exact representation of the much more complex reality of water movements and storage in the soil. Nevertheless they should represent what happens in the average.

For modeling purposes, the soil column is divided into three layers (figure 3.2).

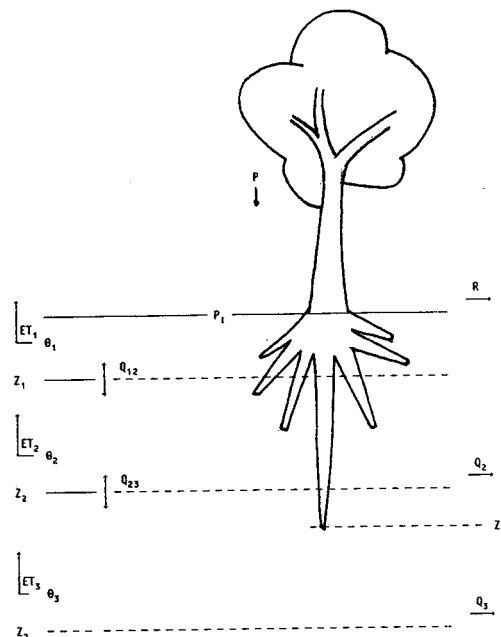


Figure 3.2 Vertical water budget in BV3C

The surface layer, from $Z = 0$ to $Z = Z_1$, is relatively shallow (10 to 20 cm). The reasons for this lie in the fact that evaporation from bare soils is taking place only in the upper 15 to 20 cm of the soil column, and that estimation of soil humidity by remote sensing is restricted to the same layer, at most. In other words, evaporation from bare soils will take place only from layer 1 and updating of soil moisture by remote sensing will, in practice, be done only for layer 1.

Layer 2, is to be considered as a transition layer between the surface layer and layer 3. Usually it should be unsaturated. It could be related to interflow. The value Z_2 taken by its maximum depth is not critical, since the model is not taking care of the variation of hydraulic characteristics on the vertical.

Layer 3, the deepest layer generating streamflow, can be considered as the one responsible for base flow. It should remain normally more saturated than the first two layers.

The relative values of Z_2 and Z_3 can be chosen so as to take care of usually higher humidity gradients closer to the surface and provide a good simulation of both interflow and base flow. For instance, if $Z_1 = 0.2$ m and $Z_3 = 2.5$ m, Z_2 can be set to 1.0 m, giving a thickness of .80 m for layer 2 and 1.5 m for layer 3.

All these values Z_1 , Z_2 and Z_3 , are assumed identical for all squares within a particular basin.

Other variables characterizing the soil type are allowed to vary from square to square, but not on the vertical. Those are the hydraulic conductivity at saturation K_s , the matrix potential at "saturation" ψ_s , the water content at saturation (θ_s), at field capacity (θ_{cc}) and at the permanent wilting point (θ_{pf}).

The state variables are the water contents θ_1 , θ_2 and θ_3 of each layer at time t .

The following computations are done for each square at each time step.

It should be mentioned here that, a given time step Δt is further divided into shorter time step Δt_c whenever computation accuracy for a numerical integration on time needs so.

At the beginning of each time step, infiltration P_i of available water P from rain and/or melt occurs on pervious areas, at a maximum rate limited by the value of the hydraulic conductivity at saturation K_s , whenever the surface layer is not saturated. The fraction of available water that does not penetrate into the soil column becomes surface runoff R .

The hydraulic conductivities $K(\theta_j)$ for all three layers are estimated from the following equation suggested by Campbell (1974).

$$K(\theta_j) = K_s \left[\frac{\theta_j}{\theta_s} \right]^{2b+3} \quad (3.14)$$

where:

$K(\theta_j)$ = hydraulic conductivity at water content θ_j in layer j ($m\ h^{-1}$)

K_s = hydraulic conductivity at saturation for soil type k ($m\ h^{-1}$)

θ_s = water content at saturation for soil type k

b = $1/\lambda$, λ being the pore size distribution for soil type k

Next, the matrix potentials $\psi(\theta_j)$ are computed from an equation suggested by Clapp and Hornberger (1978) as a modification to Campbell's equation for $\psi(\theta)$:

$$\psi(\theta_j) = \psi_s \left[\frac{\theta_j}{\theta_s} \right]^{-b} \quad \text{for} \quad 0 < \theta_j \leq \theta_* \quad (3.15)$$

$$\psi(\theta_j) = -m \left[\frac{\theta_j}{\theta_s} - n \right] \left[\frac{\theta_j}{\theta_s} - 1 \right] \quad \text{for} \quad 0^* < \theta_j \leq \theta_s \quad (3.16)$$

with:

$$\theta^* = \theta_s \frac{1 + 2b}{2 + 2b}$$

$$\psi^* = \psi_s \left(\frac{\theta^*}{\theta_s} \right)^{-b}$$

$$\omega^* = \frac{\theta^*}{\theta_s}$$

$$m = \frac{\psi^*}{(1-\omega^*)^2} - \frac{\psi^* b}{\omega^* (1-\omega^*)}$$

$$n = 2\omega^* - \frac{\psi^* b}{m\omega^*} - 1$$

Matrix
potential
 $\psi(\theta_i)$

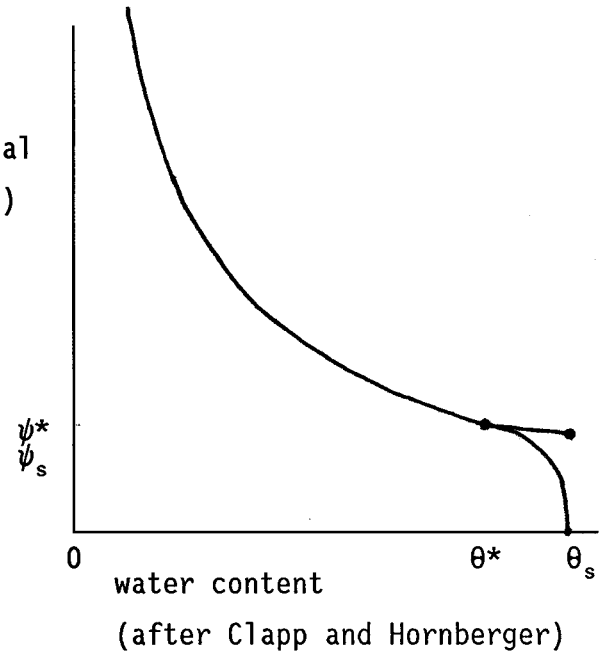


Figure 3.3 Variation of the matrix potential with θ

where:

$\psi(\theta_i)$ = matrix potential at water content θ_i (m)

ψ_s = matrix potential at θ_s (m)

and all other variables are defined above.

The Clapp and Hornberger (1978) modification to Campbell's equation is used because there would be a discontinuity close to θ_s otherwise, as can be seen from figure 3.3.

The vertical hydraulic conductivities between adjacent layers are then:

$$K_{12} = \frac{Z_{11} K(\theta_1) + Z_{22} K(\theta_2)}{Z_{11} + Z_{22}} \quad (3.17)$$

and:

$$K_{23} = \frac{Z_{22} K(\theta_2) + Z_{33} K(\theta_3)}{Z_{22} + Z_{33}} \quad (3.18)$$

where:

K_{12} and K_{23} : vertical hydraulic conductivity (downward or upward) between layer 1 and layer 2, and layer 2 and layer 3, respectively (mh^{-1}).

Z_{11} , Z_{22} and Z_{33} = thickness of layers 1, 2 and 3, respectively (m).

The flows out of and between the layers are computed next.

The vertical flow Q_{12} (either upward or downward) between layer 1 and layer 2 is:

$$Q_{12} = K_{12} \left[2 \frac{\psi(\theta_2) - \psi(\theta_1)}{Z_{11} + Z_{22}} + 1 \right] \quad (3.19)$$

and that (Q_{23}) between layer 2 and layer 3 is:

$$Q_{23} = K_{23} \left[2 \frac{\psi(\theta_3) - \psi(\theta_2)}{Z_{22} + Z_{33}} + 1 \right] \quad (3.20)$$

The flow Q_2 out of layer 2 is:

$$Q_2 = (K(\theta_2) \sin (\arctan (S (m,n))) Z_{22})/D_x \quad (3.21)$$

where:

$S (m,n)$ = slope of square m,n (m/m)

D_x = grid size (m)

Finally, the outflow Q_3 from layer 3 is:

$$Q_3 = K_r Z_{33} \theta_3 \quad (3.22)$$

where:

K_r = recession constant (h^{-1})

After determination (explained in detail below) of actual evapotranspiration from potential evapotranspiration, water content in all three layers and vegetation type, the vertical water budget is computed, by the following equations:

$$\theta_1 = \theta_1 + (\Delta t_c / Z_{11}) (P_1 - Q_{12} - ETR_1) \quad (3.23)$$

$$\theta_2 = \theta_2 + (\Delta t_c / Z_{22}) (Q_{12} - Q_{23} - ETR_2 - Q_2) \quad (3.24)$$

$$\theta_3 = \theta_3 + (\Delta t_c / Z_{33}) (Q_{23} - Q_3 - ETR_3) \quad (3.25)$$

where:

Δt_c = actual time step used in the compulation (h)

ETR_1 , ETR_2 and ETR_3 = actual evapotranspiration from layers 1, 2 and 3 respectively.

In practice, the whole process, from the estimation of $K(\theta_j)$ to that of θ_j , is done twice for each Δt_c , in order to modify θ_j from its value at the beginning of the time step to its value at the end of the time step by successive approximations.

Finally, all three values of θ_j are checked to verify if $\theta_j > \theta_s$ or $\theta_j < 0$. In either case a redistribution of water content is done if possible. There is surface runoff if the surface layer is saturated. On the other hand, if all three θ_j are negative, these values are put equal to zero and a message is issued asking whether to stop or continue. This situation should be very rare.

Let us now come back to the computation of actual evapotranspiration for all "land use" classes over land. This excludes evaporation from water surface classes. Also, evaporation from impervious areas is set equal to zero.

For all other land-use classes, evaporation from the soil column and transpiration from vegetation is derived from potential evapotranspiration values as follows.

Evaporation E_s from bare soil is first estimated by:

$$E_s = \left[E_p(I) e^{-(D \cdot LAI(I,t))} \right] \left[\Delta t / 24 \right] \quad (3.26)$$

where:

E_p = potential evapotranspiration ($m \cdot d^{-1}$)

D = extinction coefficient

$LAI(I,t)$ = leaf area index for land-use classe I at time t

Δt = time step (h)

Next, the relative water content in each layer θ_{rj} is estimated from the following relation:

$$\theta_{rj} = \frac{\theta_j - \theta_{pf}(k)}{\theta_{cc}(k) - \theta_{pf}(k)} \quad (3.27)$$

If $(\theta_j - \theta_{pf}(k)) < 0$, then $\theta_{rj} = 0$.

Also, θ_{rj} cannot be greater than 1.

Knowing the relative water content, it is possible to compute the dryness coefficient C_s , for evaporation from bare soil.

$$C_s = \frac{1 - e^{-\alpha(k)\theta_{r1}}}{1 - 2e^{-2\alpha(k)} + e^{-\alpha(k)\theta_{r1}}} \quad (3.28)$$

where:

$\alpha(k)$ = coefficient depending on soil type k

θ_{r1} = relative water content in the surface layer.

In order to compute C_t , the dryness coefficient for transpiration from vegetation, it is first necessary to compute Fu_i , the relative water content effectively available to vegetation, given the type and stage of vegetation:

$$Fu_i = \min (\theta_{ij}, C_o(I) * R_j(I,t)) \quad (3.29)$$

where:

min = minimum value between the two compared values.

$C_o(I)$ = maximum fraction of the relative water content at field capacity ($\theta_j = \theta_{cc}$) useful for land-use classe I .

$R_j(I,t)$ = fraction of $C_o(I)$ effectively useful for land-use class I , as a function of root depth at time t , for each soil layer j (the estimation of $R_j(I,t)$ is explained in section 3.9).

Then the weighted mean available water content effectively available to land-use classe I , F_u , for a given root profile is:

$$F_u = \frac{Fu_1 + Fu_2 + Fu_3}{C_o(I) * (R_1(I,t) + R_2(I,t) + R_3(I,t))} \quad (3.30)$$

And the dryness coefficient C_t , for transpiration from land-use class I, is:

$$C_t = \frac{1 - e^{-\alpha(k) F_u}}{1 + 2e^{-\alpha(k) F_u} + e^{-\alpha F_u}} \quad (3.31)$$

The actual bare soil evaporation is then:

$$E_r = C_s E_s \quad (3.32)$$

And, the actual transpiration is:

$$T_r = C_t \left[(E_p - E_s) \left(\beta + (1-\beta) \frac{E_r}{E_s} \right) \right] \quad (3.33)$$

where:

β = coefficient representing the effect of surface drying on potential transpiration
($\beta = 1.1$).

Finally, for the surface layer:

$$ETR_1 = \sum_I P_A(I) \left[\frac{F_{u1} T_r}{C_o(I) (R_1(I,t) + R_2(I,t) + R_3(I,t))} + E_r \right] \quad (3.34)$$

And for the other two layers:

$$ETR_j = \sum_I P_A(I) \left[\frac{F_{uj} T_r}{C_o(I) (R_1(I,t) + R_2(I,t) + R_3(I,t))} \right] \quad (3.35)$$

where:

$P_A(I)$ is the percentage of area devoted to land-use class I.

3.5.2.2 Input variables

Most input variables in BV3C are variables for which values can be given from a normal knowledge of the mean characteristics of the soil and vegetation types within the basin. See sections 3.8 and 3.9 for more details.

First, characteristics of land-use classes have to be available. A first group of four variables considered constant in time, is related to characteristics of the root system of each land-use class.

Those are:

- $C_o(I)$: the maximum fraction of the relative water content at field capacity ($\theta_f = \theta_{cc}$) useful for land-use class I. Values smaller than one (1) are usually given to $C_o(I)$, but, as a first guess, a value of one can be given.
- $Z_s(I)$: maximum depth at which vegetation of land-use class I can pump water at a rate equal to $C_o(I)$.

For a number of crops, a good value for ZS is .30 m. It is related to soil compaction due to agricultural practices.

- $ZV(I)$: depth reached by the roots when the root system is fully developed at the surface. ZV can be seen as a growing constant. In the model, we must have the condition $ZV < ZP - ZS$.
- $ZP(I)$: maximum depth of the root system at maturity for land-use class I. We must have $ZP < Z_3$, the maximum depth of soil layer 3.

Other land-use characteristics one allowed to vary in time, if the information is available.

Those are:

LAI: leaf area index. The LAI varie from 0 for bare soil to values greater than 8 or 10 for very dense vegetation. However, as can be seen from equation 3.26, assuming an extinction coefficient $D = 0.6$, LAI values around 5 are sufficient to eliminate most of evaporation from bare soil, when they are reached during crop development.

- $Z(l,t)$: actual depth reached by the root system of land-use class l , at time t .

In order to characterize each soil type k , values of θ_s , θ_{cc} , θ_{pf} , K_s , ψ_s , λ and α have also to be available. Values suggested by Rawls and Brakensiek (1989) (with the exception of α) are used as default values in the model. If the user has better values, he may change the default values. Values for α are taken from Patoine (1988) and vary from 10 for sand to 0.5 for clay.

The last needed file is that giving the spatial distribution of soil types within the basin. Only one soil type is permitted per grid square.

A few more parameters, constant throughout the basin, complete the set of needed informations for BV3C. Those are:

- Z_1 , Z_2 and Z_3 : the respective maximum depth of layer 1, 2 and 3.
- D : the extinction coefficient in equation 3.6, representing the extinction of energy available for evaporation from bare soil with crop development (as expressed by LAI).
- K_r : the recession constant, characterizing base flow.

Finally, the initial water content of all three layers, θ_1 , θ_2 and θ_3 have to be given.

3.5.2.3 Interaction of the root system with the soil layers

In the order to understand more fully how the root system interacts with the soil layers to redistribute actual evapotranspiration on the vertical more details are added here.

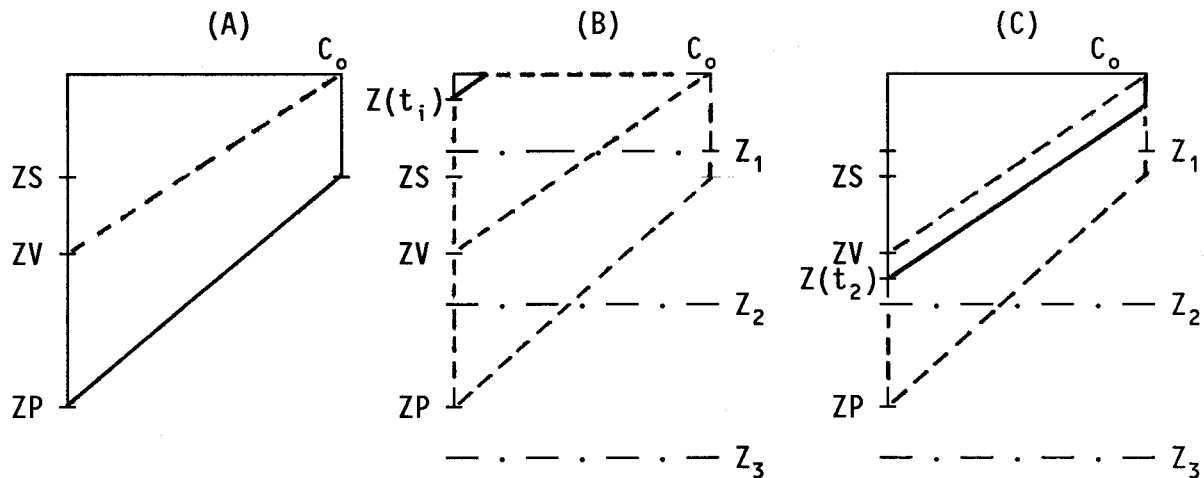


Figure 3.4 Interaction of the root system with the soil layers

The vertical distribution of root density at plant maturity is presented in figure 3.4 A. Here, the root density should be seen as the vertical distribution of the capacity of the root system to pump soil humidity at a given depth. Down to ZS, this capacity is constant and equal to C_0 . Below ZS it decreases linearly to zero at the maximum depth ZP (Brisson, 1989).

The development of the vegetation in the early stage is shown in figure 3.4 B. Here the actual depth $Z(t_1)$ has not reached Z_1 , and, by reasoning on similar triangles, the fraction $R_j(l, t)$ effectively useful for land-use class I, as a function of time for each soil layer j is given by:

$$R_1(l, t_1) = .5 (Z(t_1)/ZV)$$

$$R_2(l, t_1) = R_3(l, t_1) = 0$$

Later on, in the growing season, at time t_2 for instance, the root system reaches a depth $Z(t_2)$ (figure 3.4 C). It can be seen that full development is reached at the surface, so that part of the root system is able to have access to the maximum amount of water available at maturity, down to a depth $(Z(t_2) - ZV)$. Below that depth the root system has not reached full development.

It can also be seen that the root system has not reached full development neither in layer

1 nor in layer 2. More over $Z(t_2) < Z_2$, so that the root system is restricted to the first two layers. For the case shown in figure 3.4 C the respective values of $R_i(I,t)$ are:

$$R_1(I, t_2) = \left[\frac{Z(t_2) - ZV}{Z_1} \right] + \left[1 - \frac{Z(t_2) - ZV}{Z_1} \right] \left[.5 \left[1 + \frac{Z(t_2) - Z_1}{ZV} \right] \right]$$

$$R_2(I, t_2) = .5 \left[\frac{Z(t_2) - Z_1}{ZV} \right]$$

$$R_3(I, t_2) = 0$$

Only two of the many cases representing the interaction of the root system with the 3 soil layers used in the model are presented here. The reasoning is the same for all other cases. The constraints accepted for the model are $ZV < ZP - ZS$ and $Z1 < ZS$.

3.6 Surface and sub-surface runoff

Once water becomes available for transfer to the outlet of the basin, it finds its way downward, first through drainage paths in sub-surface layers or at the surface of the ground, to the nearest stream. Surface runoff occurs effectively in a multitude of very thin to thin streams of various dimensions at the surface of the ground. As we go downstream, the dimensions of the streams become bigger and bigger until the dimensions are large enough to constitute the first river reach considered for the simulation of channel flow.

In the model, water available for runoff is first transferred from square to square as surface and sub-surface runoff until a square containing a river reach is found out (figure 3.5). The upstream flow is then transferred to the channel reach crossing that square as channel inflow. The path from square to square to that first river reach is defined by the main drainage network obtained from topography (relative height, slope and aspect of contiguous squares).

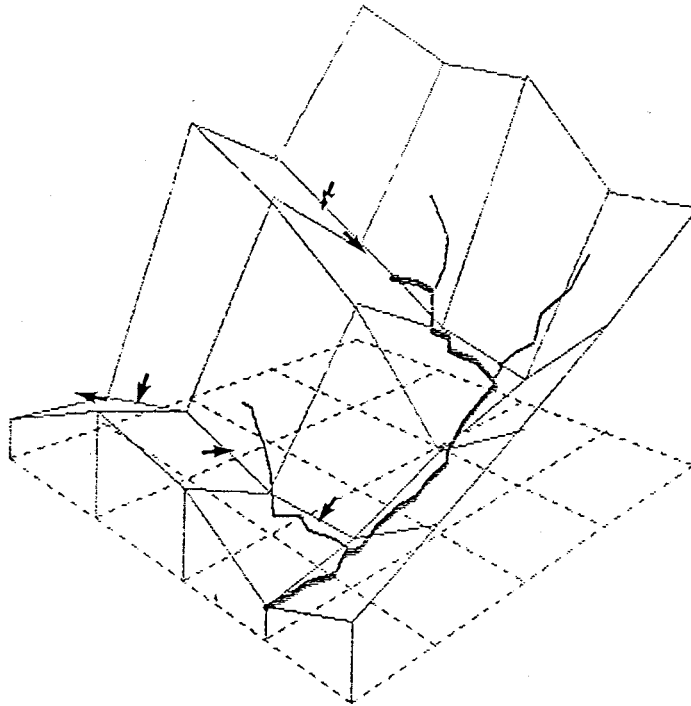


Figure 3.5 Surface and sub-surface runoff and channel flow.

Only one method of transfer is currently available.

3.6.1 Kinematic wave equations

The kinematic wave equations may be used to simulate surface runoff, if a large roughness coefficient is used to take into account the fact that the flow is not made out of a continuous thin layer of water flowing down a relatively uniform sloping surface, but rather water trying to find its way downward through a very complex network of thin streams. The basic equations applied to each square are the following:

(continuity equation)

$$\frac{\partial R}{\partial x} + \frac{\partial h}{\partial t} = i \quad (3.36)$$

(kinematic equation)

$$h = cR^d \quad (3.37)$$

where:

R = surface runoff ($\text{m}^2 \text{s}^{-1}$);

h = flow depth (m);

i = water available for runoff from the vertical water budget function (m s^{-1});

$$c = \left(\frac{n}{1.49 \sqrt{S_0}} \right)^{3/5};$$

d = coefficient ($d = 0.6$);

n = Manning's roughness coefficient estimated from land-use classes;

S_0 = slope of the surface of the square;

x = side of each square (m);

t = time (s).

3.6.2 Input data

All input data necessary for the application of the kinematic wave equations for the simulation of flow on each particular square, come from mean topographic data and land-use classes estimated for that square. That is:

- altitude (m): mean altitude of each square;
- basin mask: binary matrix identifying squares within ("one") or outside ("zero") the basin;

- slope (m m^{-1}): determined from the difference in altitude between contiguous squares;
- aspect: determined to eight directions from the difference in altitude between contiguous squares, by a steepest descent algorithm. Slope and aspect for each square are interrelated;
- land-use: information on land-use is used to determine values of the Manning's roughness coefficient n .

The actual values given to n are presented in Table 3.1.

Table 3.1 Values of Manning's roughness coefficient n for flow over squares, as a function of land-use classes.

n	land-use class
.3	open areas
.4	forested areas

In later versions of HYDROTEL, for those having the complementary software program PHYSITEL, only the mean altitude of each square and the land-use classes will be needed, all other variables being derived from the altitude matrix.

Initial values for water in transit as surface and sub-surface runoff have also to be estimated, as explained in section 2.4.2.2.

3.7 Channel routing

Channel routing can be simulated in a large number of ways. Among those we have chosen to use methods which can take advantage of informations obtained from remote sensing and elevation models.

One may then think of applying the complete set of St. Venant equations. However, it is not necessary to apply those as, in most cases, the diffusive wave equations give similar results, with much less mathematical complexity and computing time. It will thus be programmed for the next version of HYDROTEL. For channel routing the kinematic wave approximation is sufficient for mountain streams, but is less accurate when the slope is smaller and the neglected terms can no longer be neglected. In the current version, a modified set of kinematic wave equations is used, permitting a larger range of applications.

3.7.1 Modified kinematic wave equations

3.7.1.1 Theory

The set of kinematic wave equations used in HYDROTEL has been modified to include the secondary (or surface) slope. This modification allows correction of the friction slope. The following equations are used in the model:

- continuity equation

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q \quad (3.38)$$

- dynamic equation

$$\frac{\partial h}{\partial x} = S_o - S_f \quad (3.39)$$

This system of equations can be solved with the help of the following equations:

- cross-section-discharge relationship

$$A = \alpha Q^{\beta} S_f^{-\beta/2} \quad (3.40)$$

- depth-discharge relationship

$$h = rQ^s \quad (3.41)$$

where:

Q = stream flow ($\text{m}^3 \text{s}^{-1}$);

A = flow cross section (m^2);

q = lateral inflow ($\text{m}^2 \text{s}^{-1}$);

x = reach length (m);

t = time (s);

h = flow depth (m);

S_o = channel bottom slope (m/m);

S_f = friction slope (m/m);

α = coefficient . $\alpha^* = \left(\frac{n}{1.49} B^{2/3} \right)^{0.6}$;

β = coefficient . $\beta^* = 0.6$;

r = coefficient . $r^* = \alpha S_o^{-8/2}$;

s = coefficient . $s^* = \beta$;

B = channel width (m).

* For a rectangular cross-section.

3.7.1.2 Input data

The following informations must be input for channel routing, using the modified kinematic wave equations.

For each reach end:

- identification number;
- UTM coordinates (m);
- altitude (m);
- channel width (m).

For each reach:

- identification number for lower end;
- identification number for higher end;
- Manning's roughness coefficient n.

Initial values for water in transit in each have also to be estimated, as explained in section 2.4.2.2.

3.7.2 Diffusive wave equation

3.7.2.1 Theory

If higher order derivatives are neglected, the diffusive wave equation can be written:

$$\frac{\partial Q}{\partial t} = -C \frac{\partial Q}{\partial x} + \frac{\sigma}{C^2} \frac{\partial^2 Q}{\partial t^2} + \frac{2\sigma^2}{C^3} \frac{\partial^3 Q}{\partial x \partial t^2} \quad (3.42)$$

where:

Q = streamflow (m^3s^{-1})

C = celerity (ms^{-1})

σ = diffusion (m^2s^{-1})

t = time (s)

x = distance (m)

If partial derivatives are converted to a centered finite difference scheme (figure 3.5), it is possible to write for node (j,i) :

$$\begin{aligned} p^1 Q(j-1, i-1) + q^1 Q(j-1, i) + r^1 Q(j-1, i+1) \\ = pQ(j, i-1) + qQ(j, i) + rQ(j, i+1) \end{aligned} \quad (3.43)$$

with:

$$p^1 = -\frac{h}{4} + \frac{g}{2} - \frac{2}{h^2} \frac{g^2}{h^2}$$

$$q^1 = 1 - g + \frac{4}{h^2} \frac{g^2}{h^2}$$

$$r^1 = -\frac{h}{4} + \frac{g}{2} - \frac{2}{h^2} \frac{g^2}{h^2}$$

$$p = \frac{h}{4} - \frac{g}{2} - \frac{2}{h^2} \frac{g^2}{h^2}$$

$$q = 1 + g + \frac{4}{h^2} \frac{g^2}{h^2}$$

$$f = \frac{h}{4} - \frac{g}{2} - \frac{2}{h^2} \frac{g^2}{h^2}$$

and:

$$h = \frac{\Delta x}{C \Delta t}$$

$$g = \frac{\sigma \Delta x}{C^3 \Delta t^2}$$

There are as many equations as interior nodes. The problem is solved by inversion of a tri-diagonal matrix. The Goudounov algorithm, which is easy to use and leads to a minimal truncature error is use for that.

The chosen method is well adapted to propagation of waves along a complex river network (reaches in series and parallel), allows use of C (Q) and σ (Ce) laws, as well as any distribution in space and time of lateral inflow.

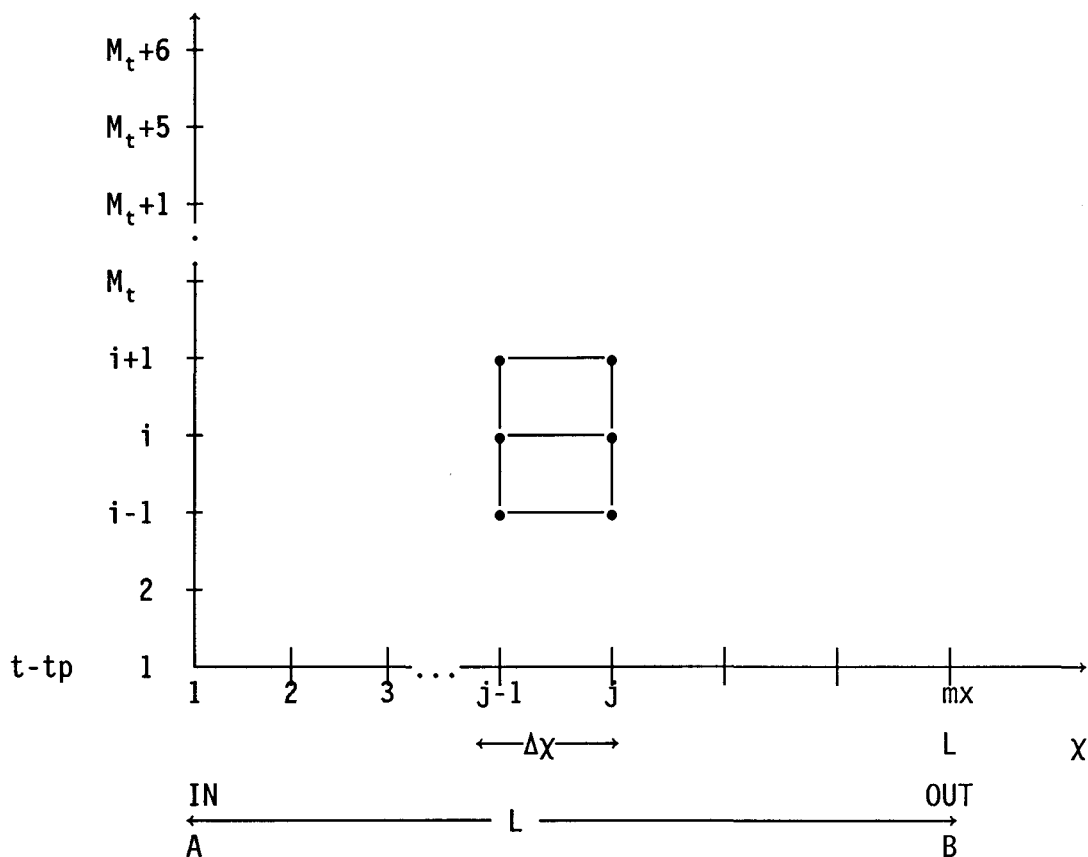


Figure 3.6 Finite difference scheme for the solution of the diffusive wave equation

3.7.2.2 Input data

The following informations must be input for channel routing, using the diffusive wave equation.

For each reach end:

- identification number;
- UTM coordinates (m);
- altitude (m);
- channel width (m).

For each reach:

- identification number for lower end;
- identification number for higher end;
- Manning's roughness coefficient n .

Initial values for water in transit in each have also to be estimated, as explained in section 2.4.2.2.

3.8 Land-use classification

Before defining classes, one has to remember the particular application in which those classes will be used. For instance, someone working in forestry may want to differentiate forest species and may eventually classify all non forested areas as one large class or in a few large ones (urban areas, agricultural areas, water surfaces). The same will apply to agriculture, where crops will have to be differentiated.

In hydrology, the same approach is taken. Classes are defined as a function of their hydrological significance. More over, in hydrological modeling another restriction is added. It concerns the link between the various equations used in the model and the land-use classes. More specifically, if a particular class cannot be used by any of the

equations of the model, it has to be either integrated to another one or eventually ignored.

At the present stage of development of the HYDROTEL model the following classes are suggested:

1. bare fields;
2. crops and pasture 1;
3. crops and pasture 2;
4. extractive areas (gravel, sand pits, ...);
5. forested areas 1 (coniferous);
6. forested areas 2 (deciduous);
7. highways and other impervious areas;
8. surface waters 1 (large streams, rivers and lakes);
9. surface waters 2 (narrow streams);
10. urban areas;
11. waste lands and bushes;
12. wetlands, marshes.

These classes should be considered as preliminary. More meaningful and appropriate classes should be obtained from the first applications to particular basins and new simulation equations. One has probably noted that the general classes "crops and pasture", "forested areas" and "surface waters" are already divided into two sub-classes. The idea is to facilitate classification and, at the same time, be ready as much as possible for the introduction of new equations without changing the whole classification. At the same time, one could decide what he is going to put in those classes. For instance, we are suggesting "coniferous" and "deciduous" to qualify "forested areas 1" and "forested areas 2". In a basin covered by coniferous forests only, only "forested areas 1" could be used, or both classes could be used, if hydrologically different forested areas do exist. An example of this would be given by dense coniferous forests in parts of the watershed and much less dense coniferous forests in other parts.

Again, crops which, from an hydrological point-of-view, have the same effect should be integrated in the same class, specially if the available equations cannot distinguish between them.

For computation purposes, each land-use class is characterized by the variables:

- albedo,
- leaf area index,
- height,
- maximum root depth,
- maximum fraction c_o of useful reserve effectively available to the vegetation because of plant physiology
- maximum depth down to which c_o remains constant
- depth reached by the root system when it is fully developed at the surface,
- actual depth of the root system on day d .

The first three variables (namely albedo, LAI and height) characterize the land-use class above the surface. They are allowed to vary in time. More specifically, in order to suit informations coming from satellite data or any other source, values can be given any day of the year. The model will interpolate linearly in time between dates. This procedure allows updating of the values taken by the variables. If no such information is available and a constant value throughout a particular year is acceptable, then the same value is given for two dates outside or coinciding with the beginning and end of the simulation period.

The next five variables describe the root system. They are considered constant in time, except the last one which can vary in the same way as the over ground variables.

Default values for all those variables are given in the files accompanying this program. It is important to repeat that the 13 land-use classes listed above are not absolutely necessary to run the model. As a matter of facts, for various historic reasons, most models do not differentiate between land-use classes, or use only a few broad classes, namely forested areas, agricultural areas, urban areas, (sometimes assimilated to impervious areas), and water surfaces.

If the user is satisfied with those four classes he is free to use only those and assign representative values for the variables characterizing the land-use class. Moreover, all variables are not used by all sub models. For instance, Thornthwaite potential evapotranspiration does not use any of them and the CEQUEAU vertical water budget does not need informations on the root system.

In short, if informations are available, the model can make use of them, if not, representative values and broad land-use classes may be used as well.

3.9 Soil types and hydraulic characteristics

Hydrologic processes differ from soil type to soil type. In a number of conceptual models assimilating vertical water storage and flow to a series of reservoirs on top of one another, soil type is taken into account by calibration of coefficient and parameter values. Usually the coefficients and parameters used in those models are not easily related to specific hydrologic processes so that it is difficult to give them initial values, based on a certain knowledge of soil properties.

Variables representing hydraulic properties of soil types are used in BV3C, one of the available options for the simulation of the vertical water budget. The values appearing in table 3.1 come from Rawls and Brakensied (1989) with the exception of α which comes from Patoine (1988).

Those values should be seen as initial values that can be given to the variables, which can be changed by the user. The actual values for a particular soil type and basin may differ, but at least, the values in table 3.1 should represent, in the average, good initial values.

The proportions of sand, silt and clay appearing for each soil type are not used in the model. They are included in table 3.1 only to help the user to select a soil type, if such information is available.

If BV3C is used, it is possible to vary the soil type from square to square within the basin. This possibility can be interesting if soil types of quite different hydraulic characteristics exist in various parts of the basin.

Of course, it may happen that no information on soil types is available for a particular basin. In that case, it is suggested to select a soil type in the middle of the list for a first run of the program. Other soil types can be selected next depending on the results.

Texture				Effective porosity θ_s (m ³ /m ³)	Water retained at -0.33 bar tension θ_{cc} (m ³ /m ³)	Water retained at -15 bar tension θ_{pf} (m ³ /m ³)	Saturated Hydraulic Conductivity ↓ K_s (mh ⁻¹)	Matrix potential at "saturation" ψ_s (m)	Pore size distribution (λ)	Coefficient in eq. 3.28 and 3.31 α
Class	percentage									
	Sand S	Clay C	Silt Si							
Sand	>85	Si+1.5C<15		0.417	0.091	0.033	0.2100	0.1598	0.694	10.0
Loamy sand	70-90	15<Si+1.5C and Si+2C<30		0.401	0.125	0.055	0.0611	0.2058	0.553	6.0
Sandy loam	43-52	<7	<50	0.412	0.207	0.095	0.0259	0.3020	0.378	4.5
Loam	<52	7-27	28-50	0.434	0.270	0.117	0.0132	0.4012	0.252	3.5
Silt loam		12-27 <12	>50 50-80	0.486	0.330	0.133	0.0068	0.5087	0.234	3.0
Sandy clay loam	<45	20-35	>20	0.330	0.255	0.148	0.0043	0.5941	0.319	3.5
Clay loam	20-45	27-40		0.390	0.318	0.197	0.0023	0.5643	0.242	2.0
Silty clay leam	<20	27-40		0.432	0.366	0.208	0.0015	0.7033	0.177	1.5
Sandy clay	>45	>35		0.321	0.339	0.239	0.0012	0.7948	0.223	1.0
Silty clay		>40	>40	0.423	0.387	0.250	0.0009	0.7654	0.150	0.8
Clay	<45	>40	<40	0.385	0.396	0.272	0.0006	0.8560	0.165	0.5

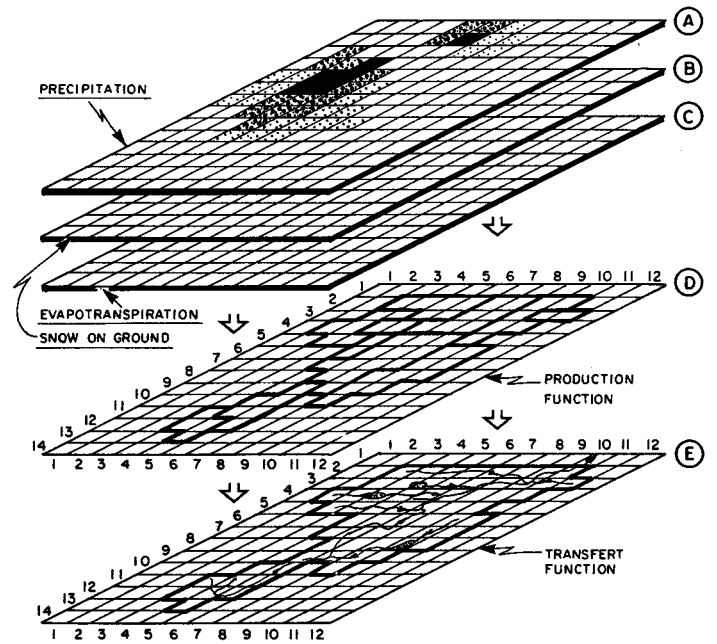
Table 3.1 Soil hydraulic properties classified by soil texture

REFERENCES

REFERENCES

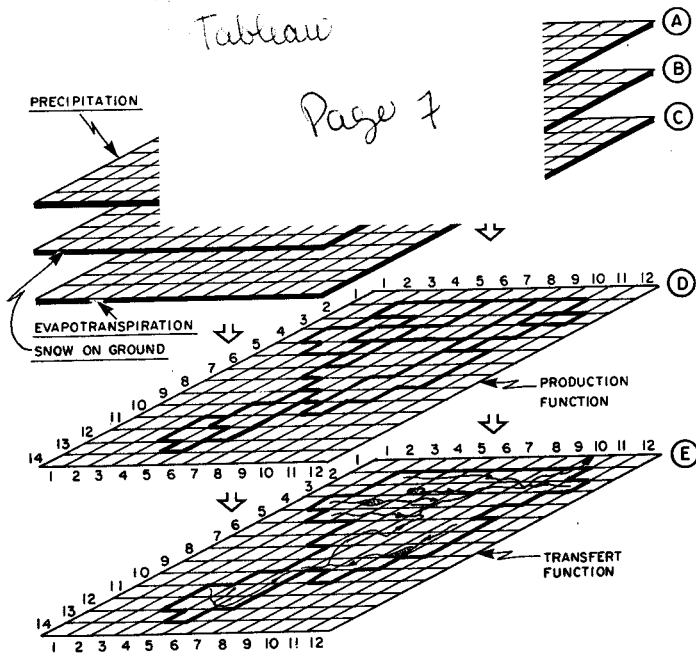
- LECONTE, R. (1984). Modélisation du régime hydrologique d'un grand bassin versant situé en région subarctique. Mémoire de maîtrise ès sciences appliquées, spécialité: génie chimique. Université de Sherbrooke, Québec, 320 p.
- MORIN, G., J.P. FORTIN, J.P. LARDEAU, W. SOCHANSKA et S. PAQUETTE (1981). Modèle CEQUEAU: manuel d'utilisation. INRS-Eau, rapport scientifique No 93, 449 p.
- OBLED, C.H. and B. ROSSÉ (1977). Mathematical models of a melting snowpack at an index plot. Journal of Hydrology, 32: 139-163.
- PARÉ, A. (1979). Modèle d'hydrologie appliqué aux régions subarctiques: application au bassin versant de la rivière Desaulniers. Mémoire de maîtrise ès sciences appliquées, spécialité: génie chimique. Université de Sherbrooke, Québec, 231 p.
- PECK, E.L., T.N. KEEPER and E.R. JOHNSON (1981). Strategies for using remotely sensed data in hydrologic models. NASA-CR-666729, 77 p.
- RANGO, A. (1985). Assessment of remote sensing input to hydrologic models. Water Resources Bulletin, 21(3): 423-432.
- RAUDKIVI, A.J. (1979). An advanced introduction to hydrological processes and modelling. University of Auckland, New Zealand, Pergamon Press, 479 p.
- RILEY, J.P., E.K. ISRAELSEN and K.O. EGGLESTON (1972). Some approaches to snowmelt prediction. Actes du Colloque de Banff sur le rôle de la neige et de la glace en hydrologie. AISH Pub., Vol. 2, No 107, p. 956-971.
- PRIESTLEY, C.H.B. and R.J. TAYLOR (1972). On the assesment of surface heat flux and evaporation using large scale parameters. Monthy Weather Review, 100: 81-92.

- SLATYER, R.O. and I.C. ILROY (1961). Practical Microclimatology, CSIRO, Australia. UNESCO.
- LINACRE, E.T. (1977). A simple formula for estimating evaporation rates in various climates, using temperature data alone. *Agricultural Meteorology*, 18: 409-424.
- PATOINE, M. (1988). Mise au point d'un modèle informatisé de gestion de l'irrigation. Mémoire de maîtrise. INRS-Eau, U. du Q., 277 p.
- BRISSE, N. (1989). Modèle de simulation de la culture du soja et de son fonctionnement hydrique: estimation agrométéorologique des potentialités de production. Thèse de doctorat de l'Institut national agronomique. Paris-Grignon, 180 p. + 11 annexes.
- MONTEITH, J.L. (1965). Evaporation and environment. *Symp. Soc. expl. Biol*, 19: 205-234.
- RAWLS, W.J. and D.L. BRAKENSIEK (1989). Estimation of soil water retention and hydraulic properties, in: *Unsaturated flow in hydrologic modeling, Theory and practice*, H.J. Morel-Seytoux (ed). Kluwer Academic Pub. p. 275-300.
- CAMBELL, G.S. (1974). A simple method for determining unsaturated conductivity from moisture retention data. *Soil Sci.* 117: 311-314.
- CLAPP, R.B. and G.M. HORNBERGER (1978). Empirical equations for some hydraulic properties. *W.R.R.* 14-4: 601-604.



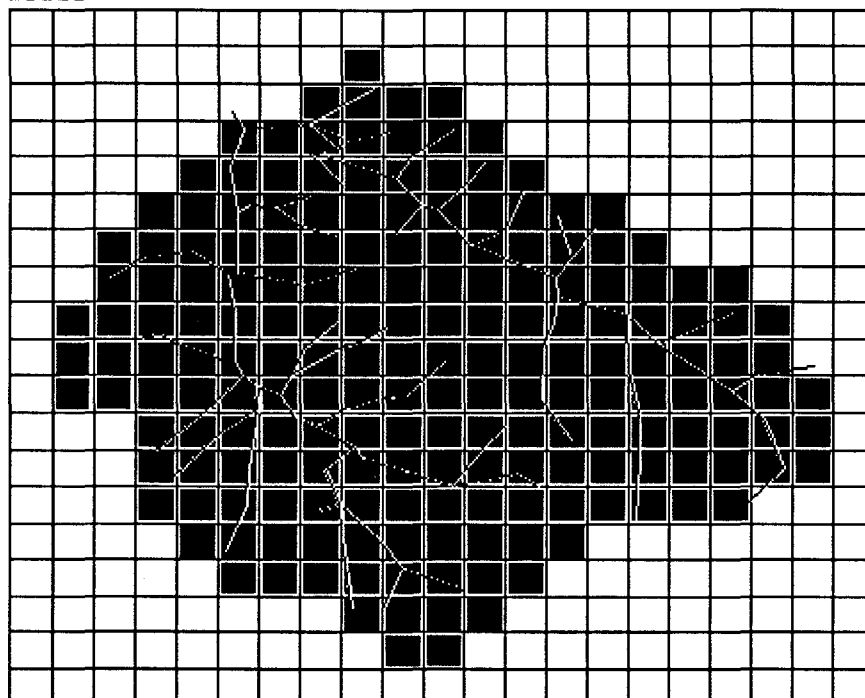
Tableau

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295000

5026000



Easting: 303000
Northing: 5025000

Date: 73-05-01

Snow Depth W.Eq.
(m) (mm)
Conif: 0.00 0.00
Decid: 0.00 0.00
Open : 0.00 0.00

Rain+melt(mm): 0.8

Wat. Content(m3/m3)
1: 0.28
2: 0.30
3: 0.30

Actual Evap(mm/dt)
1: 0.02572
2: 0.01795
3: 0.008288

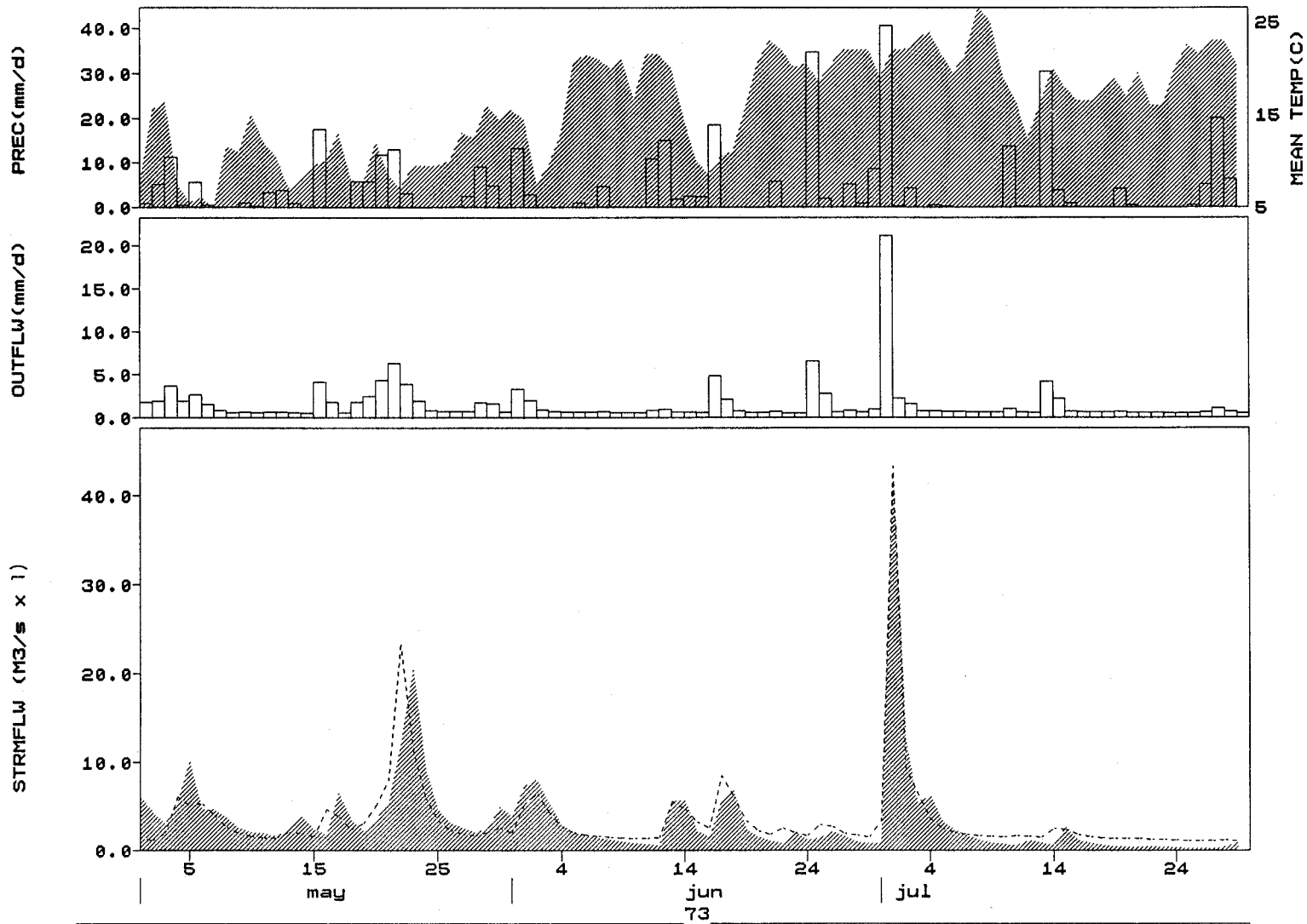
(mm/dt)
Surf. Runoff: 0.0000
Inter Flow : 0.0000
Base Flow : 0.6597
Total Flow : 0.6678

F1:Step F5:Go

Tubtanc

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STREAMFLOW HYDROGRAPH



PERIOD: 73/05/01 - 73/07/30

STATION:

30242

Tableau

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