HYDROTEL 1.1

USER'S GUIDE

by

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GENERAL INFORMATION

PART 1 GENERAL INFORMATION

1.1 Software main characteristics and hardware requirements

Name: HYDROTEL 1.1

Objective: Simulation of streamflows using ground and remotely sensed data.

Programming languages: "C". It will be possible to link users defined subprograms written in MS FORTRAN starting with HYDROTEL 2.0 next fall.

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.

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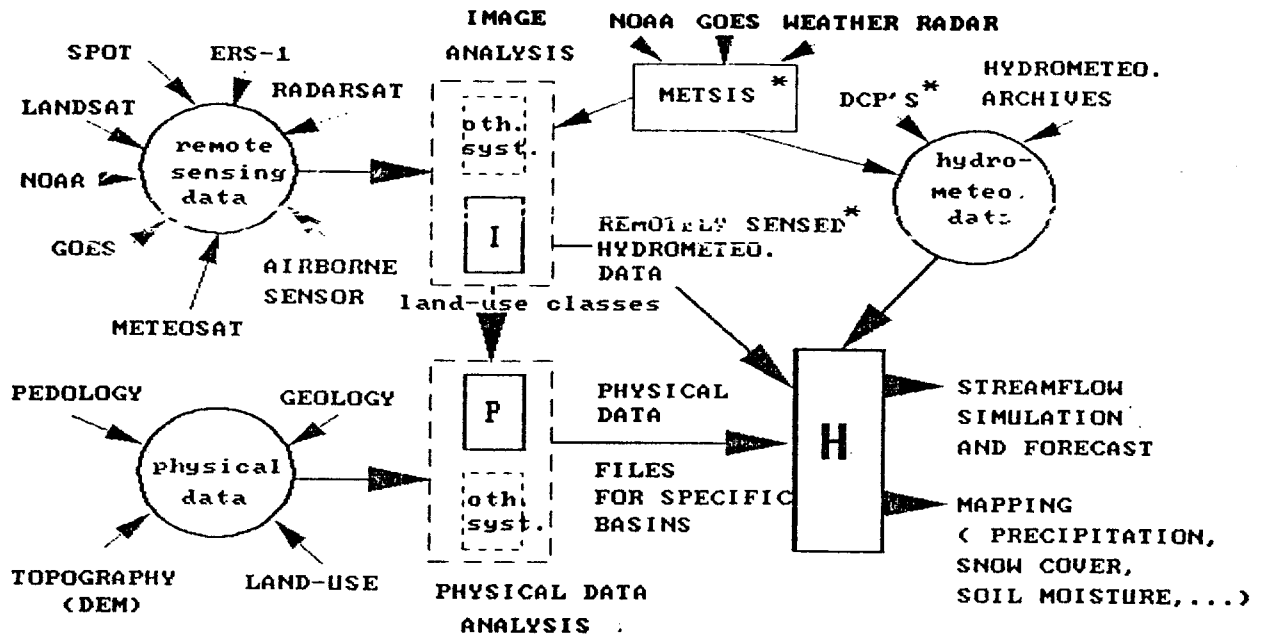
Figure 1.1 Integrated analysis of physical, remotely sensed and meteorological data for steamflow simulation and forecasting by PHYSITEL, IMATEL and HYDROTEL.

As seen by INRS-Eau the status of the current HYDROTEL version (V 1.1) is the following:

- HYDROTEL 1.1 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 1.1 should be regarded as only a step in the development of the model originally conceived.

- HYDROTEL 1.1, 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 1.1 is presented with better data displays.

- HYDROTEL 1.1 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 1.1.

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 1.1 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 (1.1) 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.

For informations, contact:

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PART 2

THE HYDROTEL PROGRAM (1.1)

PART 2 THE HYDROTEL PROGRAM (1.1)

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.
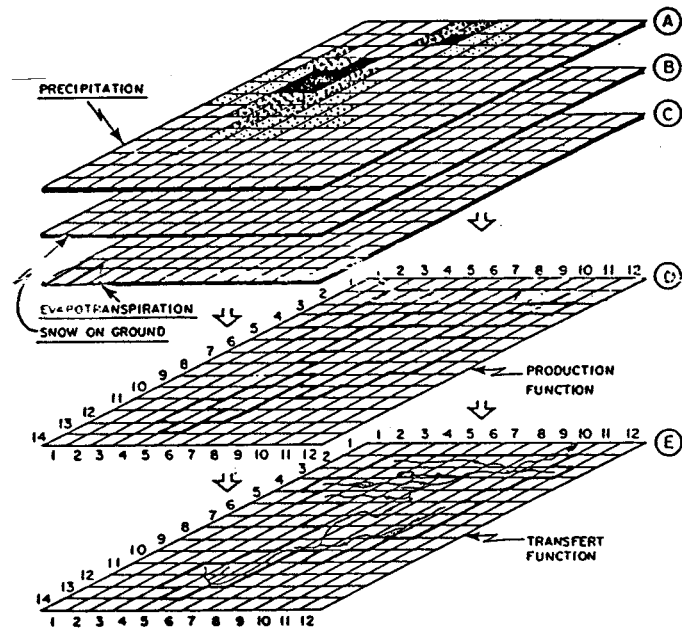
Figure 2.1   Spatial structure of the model.

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 drivers disk.

Adage/Lexidata PG90 Model 30	ADAGE30.SYS
AT&T 6300/6310 - 640 x 400 Monochrome	CGI6300B.SYS
AT&T 6300/6310 - 640 x 400 Color	CGI6300C.SYS
Compaq Portable III Display	COMPAQ3.SYS
DGIS High Performance Displays	CGIDGIS.SYS
Hercules InColor Display	HERCINCO.SYS
Hercules Monochrome Graphics Adapter	HERCBW.SYS
High Resolution EGA Displays	HIRESEGA.SYS
IBM 8514/a 1024 x 768 Display	IBMAFH.SYS
IBM 8514/a 640 x 480 Display	IBMAFL.SYS
IBM Color Graphics Adapter - High Res. Mono.	IBMBW.SYS
IBM Color Graphics Adapter - Med. Res. Color	IBMCO.SYS
IBM Enhanced Graphics Adaptor - 4 modes	IBMEGA.SYS
IBM Personal System/2 - Mode 11	IBMVGA11.SYS
IBM Personal System/2 - Mode 12	IBMVGA12.SYS
IBM Personal System/2 - Mode 13	IBMVGA13.SYS
Toshiba 3100 Lap Top Display	T3100.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.PTE	M7023312.73	M7024624.74
CLIFTON.CLA	CLIFTON.STN	M7023312.74	M7027802.73
CLIFTON.ICR	CLIFTON.TRO	M7027372.73	M7027802.74
CLIFTON.IRO	M7020885.73	M7027372.74	M7028124.73
CLIFTON.MSK	M7020885.74	M7027520.73	M7028124.74
CLIFTON.NDS	M7022280.73	M7027520.74	M7028906.73
CLIFTON.ORI	M7022280.74	M7024263.73	M7028906.74
CLIFTON.PCP	M7022306.73	M7024263.74	H0030242.73
	M7022306.74	M7024624.73	H0030242.74

2.2.2 Installing HYDROTEL 1.1

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=\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 1.1, 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: <u>sub-basin of the Eaton river upstream of streamgauge station</u> 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.
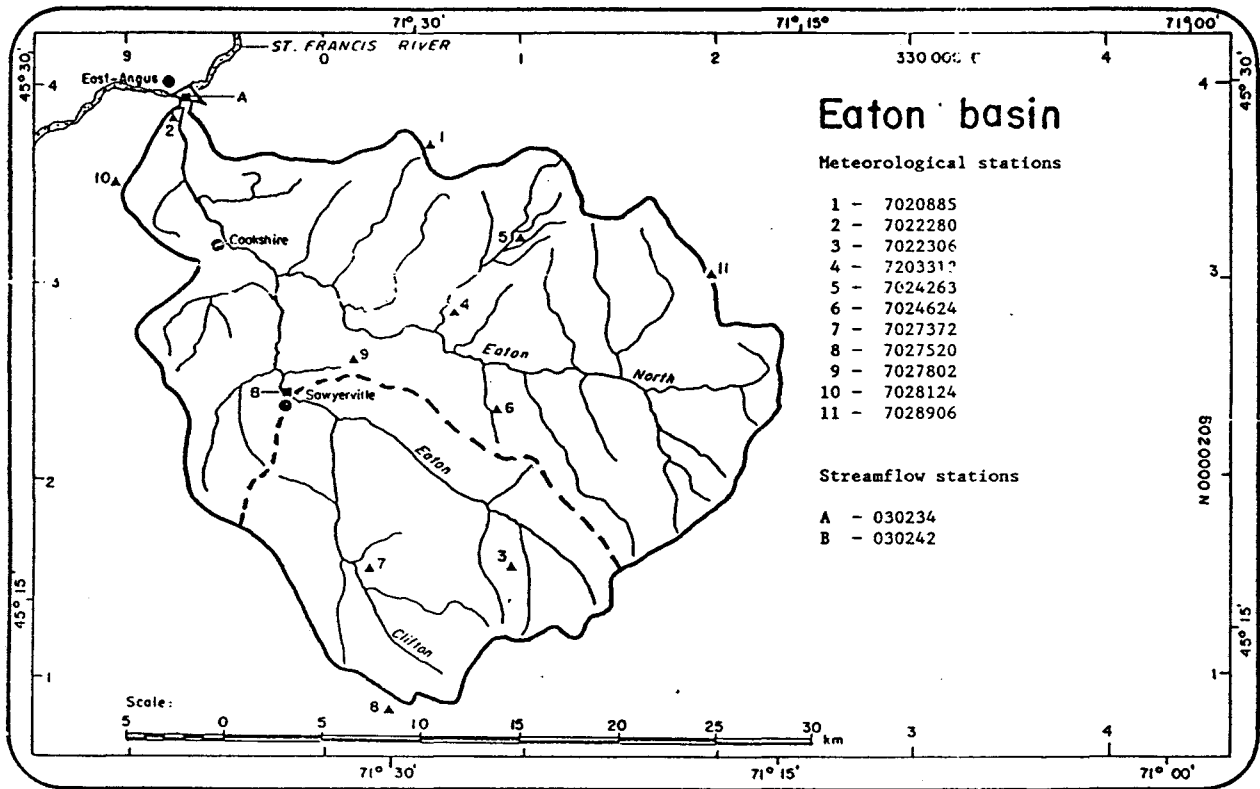
Figure 2.2   Streamflow and climatological stations on the Eaton basin.

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 colums;
  - 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, Northing, 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 for each square:

- file name: Clifton.CLA;
- file structure:
    - 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.

- 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).

. 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;

. 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.

. INRS data formats

- streamflow data (ms^{-1}) 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 colums lines.

General format for each line:

Colum'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; colums 75-78 are not
  used; the number of days in the month, e.g. "30" for November, is typed in
  colums 79-80.

- The second line contains 10 days from day 11 to 20; colums 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).

Each monthly record containing daily values is 232 characters long.

Colum(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)

Comments:

The following elements are read and used in HYDROTEL 1.1
- Daily maximum temperature: 001 (.1°c)
- Daily minimum temperature: 002 (.1°c)
- Total precipitation: 012 (.1mm)

. Intermediate results

- Format for values ou squares:

The following variables are concerned:
- temperatures (*.TEM)
- 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 colums 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 colums 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 colums 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)

2.3 Using HYDROTEL (1.1)

2.3.1 Starting HYDROTEL 1.1

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 1.1 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):

```
┌─────────────────────────────────────────┐
│ MAIN MENU                              │ │
│      ┌────────────────────────────────┐ │
│ 1._  │ SIMULATION PARAMETERS        │ │ │
│ 2._  │                              │ │ │
│ 3._  │ 1.┌─┤ PATH TO FILES ├──────────────────────────────┐
│ 4._  │ 2.│                                                │ │
│ 5._  │ 3.│ Path to data files... c:\hydrotel\basins\      │ │
│ 6._  │ 0.│ Basin filename....... clifton                  │ │
│ 0._  └───┤                                                │ │
│          └┤ F10:Accept ├───────────────────┤ Esc:Quit ├──┘
```
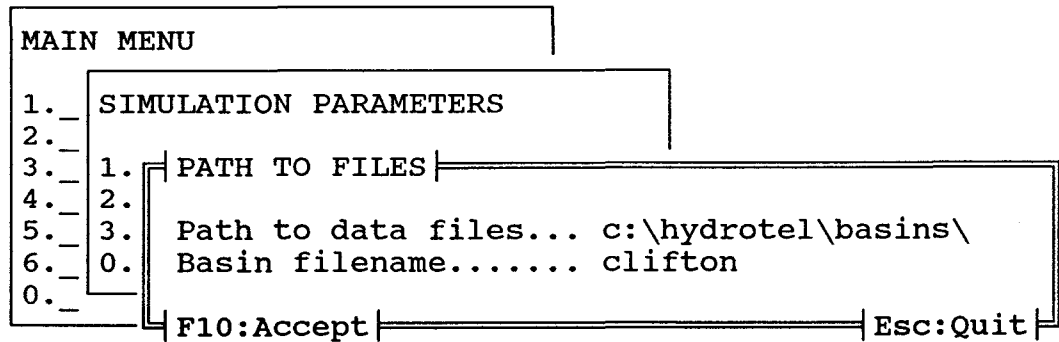
Figure 2.5   Sub-menu #1.1: paths to files.

- 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 (YYDDD): the year (last two digits) and day (1 to 366 (table 2.1)) 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 1.1: <u>1 day</u>.

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".

```
MAIN MENU

1._  SIMULATION PARAMETERS
2._
3._  1._  Path to files;
4._  2._ TEMPORAL PARAMETERS
5._  3.
6._  0.   Start of simulation (YYDDD)... 73   152
0._        Duration (days)................ 10
           Time step (days).............. 1

      F10:Accept                  Esc:Quit
```
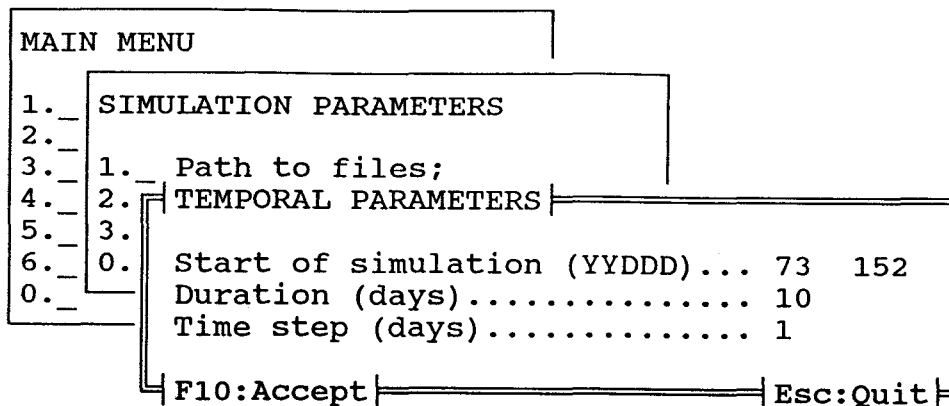
Figure 2.6   Sub-menu #1.2: temporal parameters.

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 changed 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
```
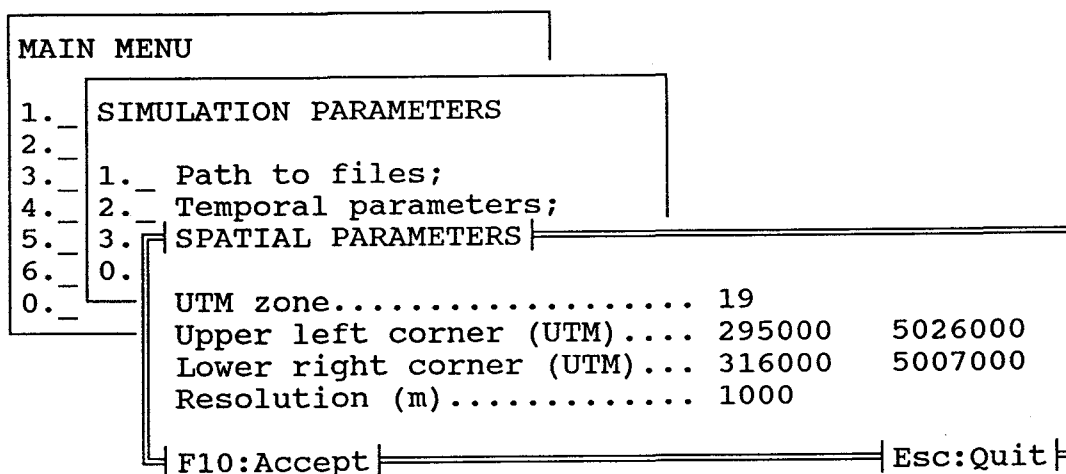
Figure 2.7   Sub-menu #1.3: spatial parameters.

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 S̲u̲b̲-̲m̲e̲n̲u̲ ̲#̲2̲.̲0̲:̲ ̲ ̲d̲a̲t̲a̲_̲i̲n̲p̲u̲t̲

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.

```
 MAIN MENU
 ┌────────────────────────────────────────┐
 │ 1._ ┌──────────────────────────────────┐
 │ 2._ │DATA INPUT
 │ 3._ │
 │ 4._ │1._ File name specification;
 │ 5._ │2._ Data format specification;
 │ 6._ │3._ Read data;
 │ 0._ │4._ Display data;
 └─────│0._ Return to previous menu.
       └──────────────────────────────────┘
```
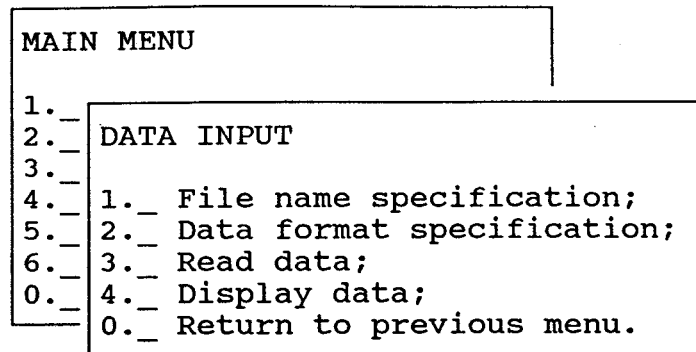
Figure 2.8   Sub-menu #2.0: data input.

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.

```
 MAIN MENU
 ┌───────────────────────────────────────────┐
 │ 1._ ┌───────────────────────────────────────┐
 │ 2._ │DATA INPUT
 │ 3._ │
 │ 4._ │1._ ┌────────────────────────────────────┐
 │ 5._ │2._ │FILE NAME SPECIFICATION
 │ 6._ │3._ │
 │ 0._ │4._ │1._ Basin data;
 └─────│0._ │2._ Initial settings;
       └────│3._ Intermediate data;
            │0._ Return to previous menu.
            └────────────────────────────────────┘
```
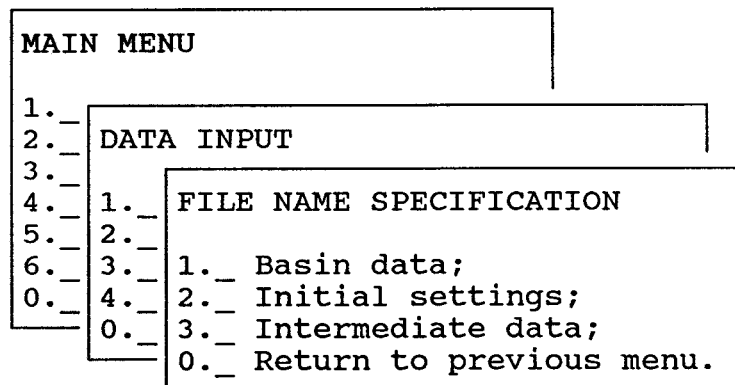
Figure 2.9   Sub-menu #2.1: file name specification.

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.

```
MAIN MENU
1._
2._  DATA INPUT
3._
4._  1._  FILE NAME SPECIFICATION
5._  2._
6._  3._  1.┌ BASIN DATA ├═══════════════════════════
0._  4._  2.│
     0.  3.│  Meteo station id............ clifton.stm
         0.│  Streamflows station id..... clifton.sth
           │  Basin mask................. clifton.msk
           │  Altitude................... clifton.alt
           │  Aspect..................... clifton.ori
           │  Slope...................... clifton.pte
           │  Land-use classes.......... clifton.cla
           │  Reach ends................. clifton.nds
           │  Reaches.................... clifton.tro
           │
           ┤F10:Accept├════════════════════┤Esc:Quit├
```
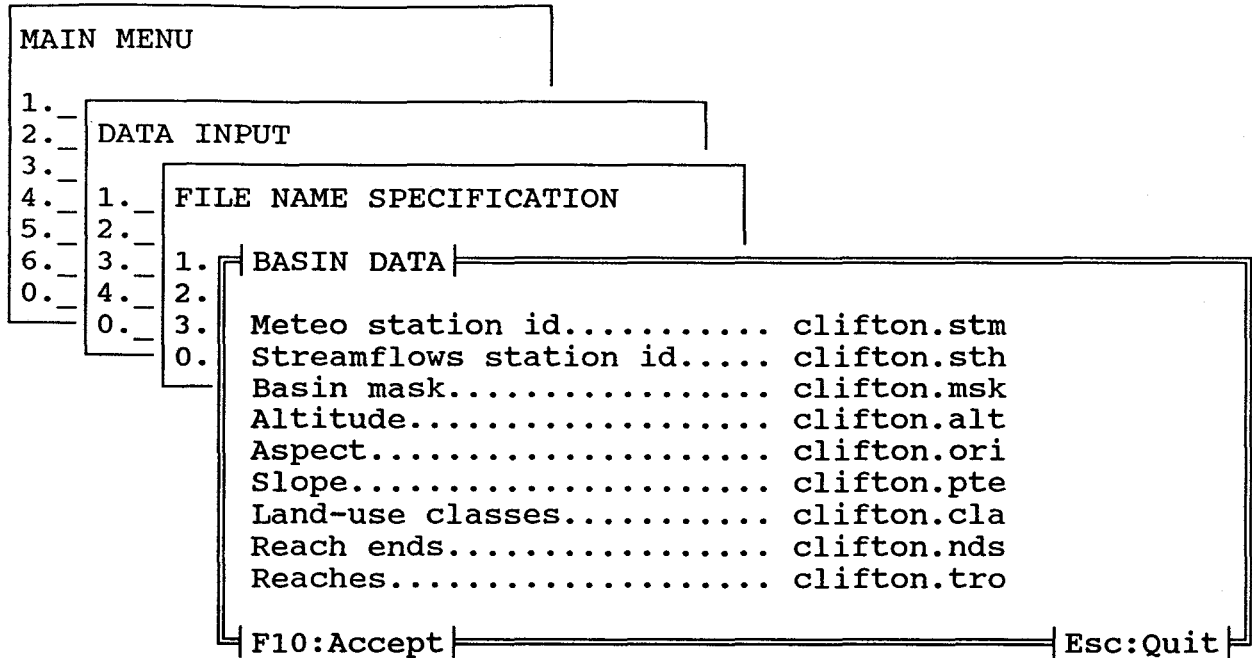
Figure 2.10 Sub-menu #2.1.1: basin data.

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.

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.

```
MAIN MENU

 1._
 2._  DATA INPUT
 3._
 4._  1._
 5._  2._   DATA FORMAT SPECIFICATION
 6._  3._
 0._  4._   1._  Meteo & hydro data;
       0._   2._  Basin data;
              3._  Initial settings;
              4._  Intermediate data;
              0._  Return to previous menu.
```
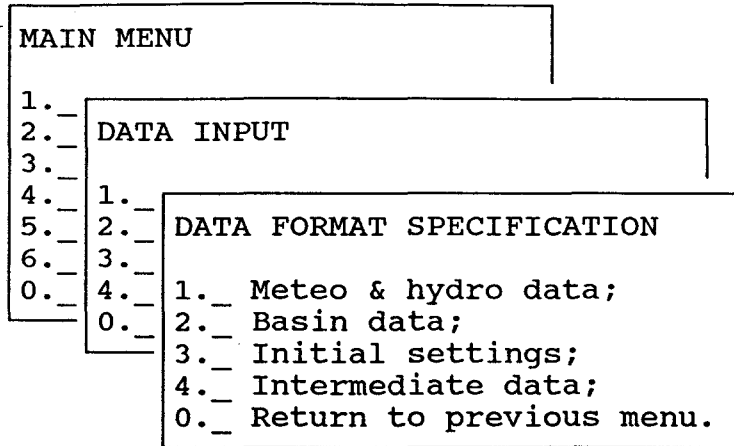
Figure 2.13 Sub-menu #2.2: data format specification.

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.

```
MAIN MENU

 1._
 2._  DATA INPUT
 3._
 4._  1._
 5._  2._   DATA FORMAT SPECIFICATION
 6._  3._
 0._  4._   1._ METEO & HYDRO DATA
       0._   2.
              3.   Meteo data......... INRS
              4.   Streamflow data.... INRS
              0.
                   F10:Accept        Esc:Quit
```
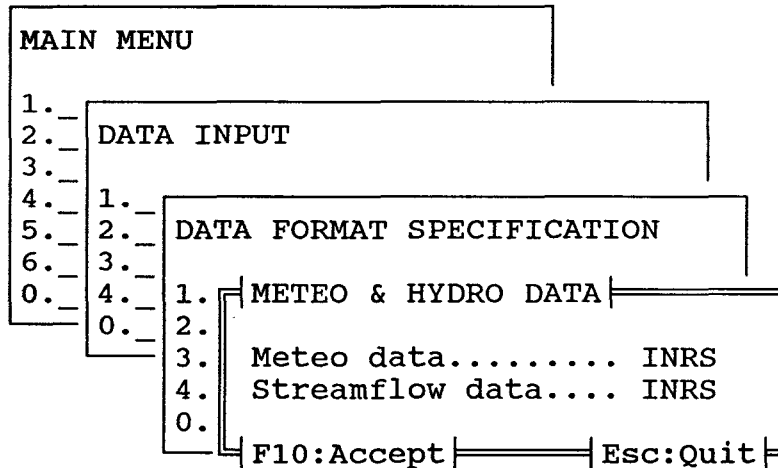
Figure 2.14 Sub-menu #2.2.1: hydrological and meteorological data.

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).

```
┌─────────────────────────────────────────────────┐
│ MAIN MENU                                        │
│                                                  │
│ 1._ ┌─────────────────────────────────────────────┐
│ 2._ │ DATA INPUT                                   │
│ 3._ │                                              │
│ 4._ │ 1._ ┌──────────────────────────────────────────┐
│ 5._ │ 2._ │ DATA FORMAT SPECIFICATION                 │
│ 6._ │ 3._ │                                           │
│ 0._ │ 4._ │ 1._  Meteo & hydro data;                  │
└─────┤ 0._ │ 2.┌┤BASIN DATA├════════════════════════════════┐
      └─────┤ 3. │                                            │
            │ 4. │ Meteo station id............. INRS         │
            │ 0. │ Streamflows station id...... INRS          │
            └────┤ Basin mask.................. INRS          │
                 │ Altitude.................... INRS          │
                 │ Aspect...................... INRS          │
                 │ Slope....................... INRS          │
                 │ Land-use classes............ INRS          │
                 │ Reach ends.................. INRS           │
                 │ Reaches..................... INRS           │
                 │                                            │
                 └┤F10:Accept├═════════════════�┤Esc:Quit├─────┘
```
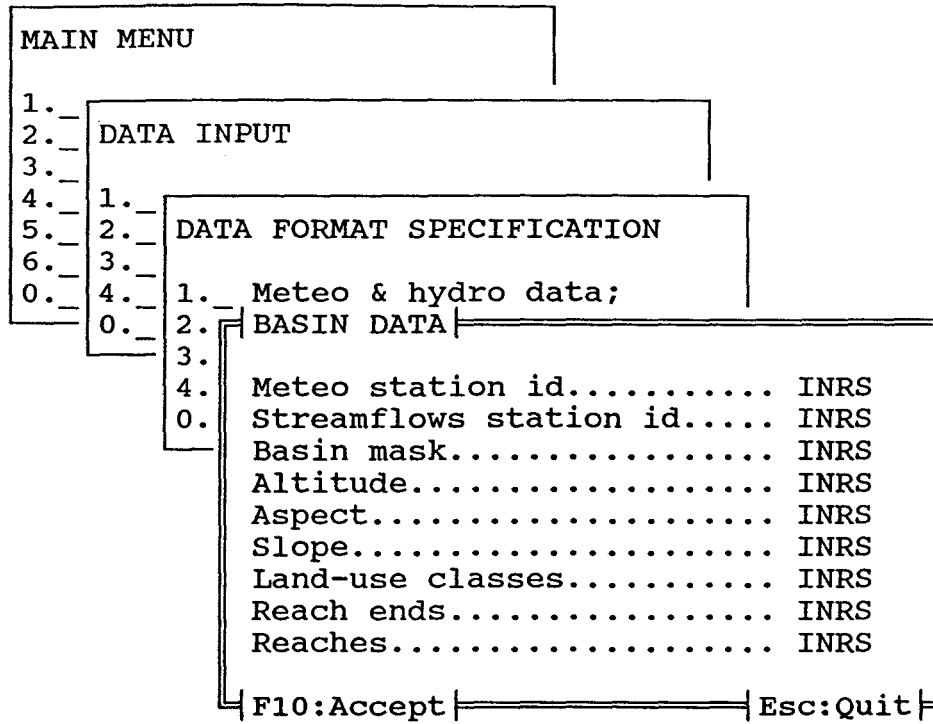
Figure 2.15 Sub-menu #2.2.2: basin data.

2.3.4.2.3 Sub-menu #2.2.3: initial settings

Only INRS ASCII text file format is available with HYDROTEL 1.1 (figure 2.16).

```
MAIN MENU
1._
2._  DATA INPUT
3._
4._  1._
5._  2._  DATA FORMAT SPECIFICATION
6._  3._
0._  4._  1._ Meteo & hydro data;
     0._  2._ Basin data;
          3._INITIAL SETTINGS
          4.
          0.   Water budget.... INRS
               Runoff.......... INRS
               Streamflows..... INRS

               F10:Accept      Esc:Quit
```
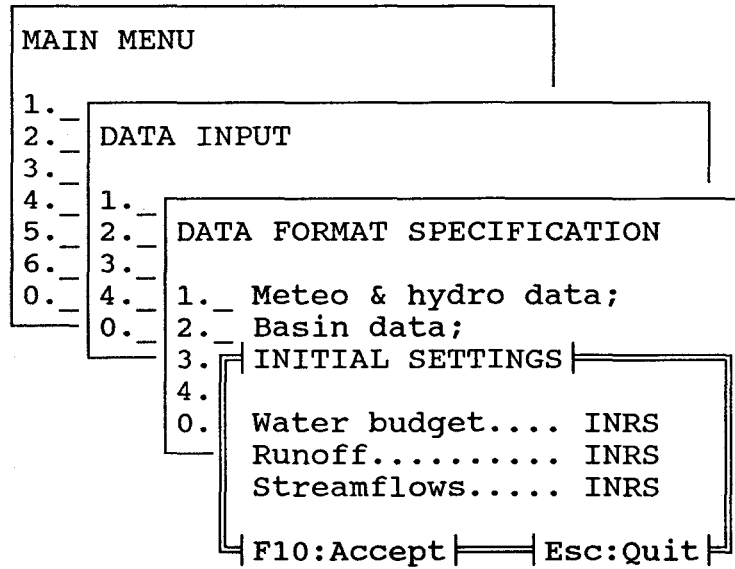
Figure 2.16 Sub-menu #2.2.3: initial settings.

2.3.4.2.4 Sub-menu #2.2.4: intermediate data

Only INRS ASCII text file format is available with HYDROTEL 1.1 (figure 2.17).

```
MAIN MENU
1._
2._  DATA INPUT
3._
4._  1._
5._  2._  DATA FORMAT SPECIFICATION
6._  3._
0._  4._  1._ Meteo & hydro data;
     0._  2._ Basin data;
          3._ Initial settings;
          4._INTERMEDIATE DATA
          0.
               Temperatures... INRS
               Rain........... INRS
               melt........... INRS
               Pot. evap. .... INRS
               Outflow........ INRS
               Runoff......... INRS
               Streamflows.... INRS

               F10:Accept      Esc:Quit
```
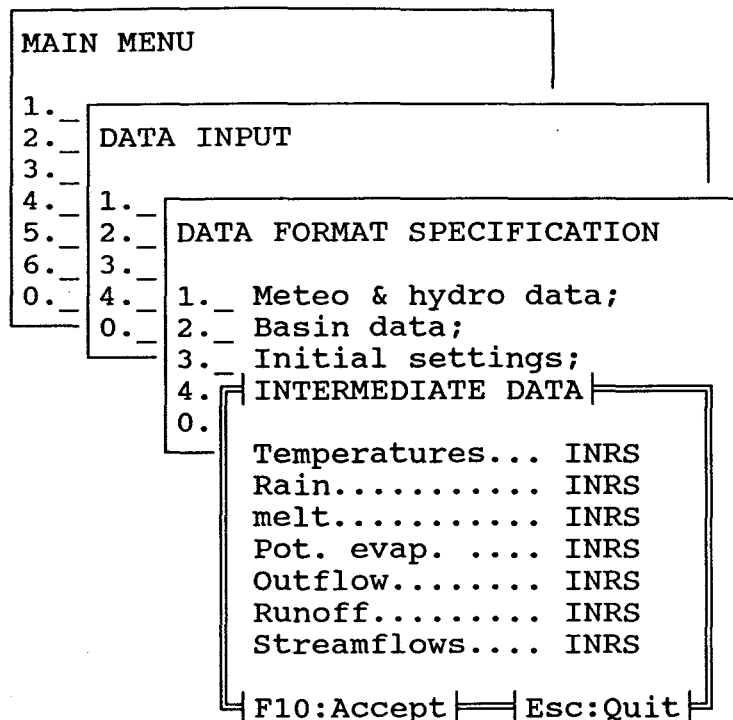
Figure 2.17 Sub-menu #2.2.4: intermediata data.

2.3.4.3 Sub-menu #2.3: read data

With HYDROTEL 1.1, 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.

```
MAIN MENU

1._
2._  DATA INPUT
3._
4._  1._  File name specification;
5._  2._
6._  3._  READ DATA
0._  4._
     0._  1._  Basin data;
          2._  Initial settings;
          0._  Return to previous menu.
```
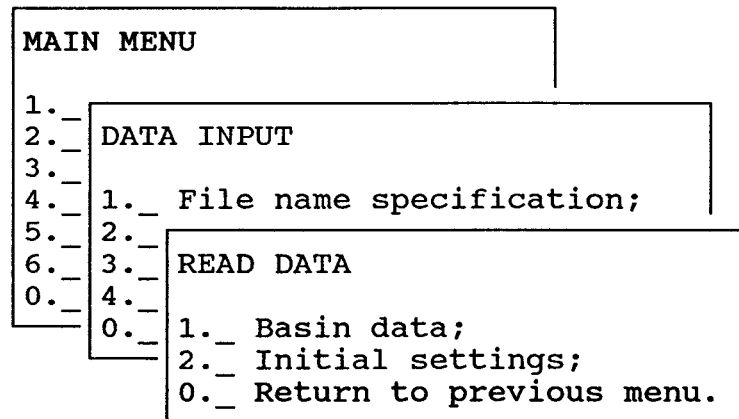
Figure 2.18 Sub-menu #2.3: read data.

2.3.4.3.1 Sub-menu #2.3.1: basin data

With HYDROTEL 1.1, sub-menu 2.3.1 (figure 2.19) is optional. Data will be read
automatically.

```
┌─────────────────────────────────────┐
│ MAIN MENU                           │
│                                     │
│ 1._ ┌───────────────────────────────────┐
│ 2._ │ DATA INPUT                       │
│ 3._ │                                  │
│ 4._ │ 1._ File name specification;     │
│ 5._ │ 2._ ┌──────────────────────────────────┐
│ 6._ │ 3._ │ READ DATA                        │
│ 0._ │ 4._ │                                  │
└─────│ 0._ │ 1._ ┌───────────────────────────────────────┐
      │     │ 2._ │ BASIN DATA                          │
      └─────│ 0._ │                                   ✓ │
            │     │ 1._ Meteo station id;              │
            └─────│ 2._ Streamflows station id;        │
                  │ 3._ Basin mask;                    │
                  │ 4._ Altitude;                      │
                  │ 5._ Aspect;                        │
                  │ 6._ Slope;                         │
                  │ 7._ Land-use classes;              │
                  │ 8._ Reach ends;                    │
                  │ 9._ Reaches;                       │
                  │ 0._ Return to previous menu.       │
                  └────────────────────────────────────┘
```
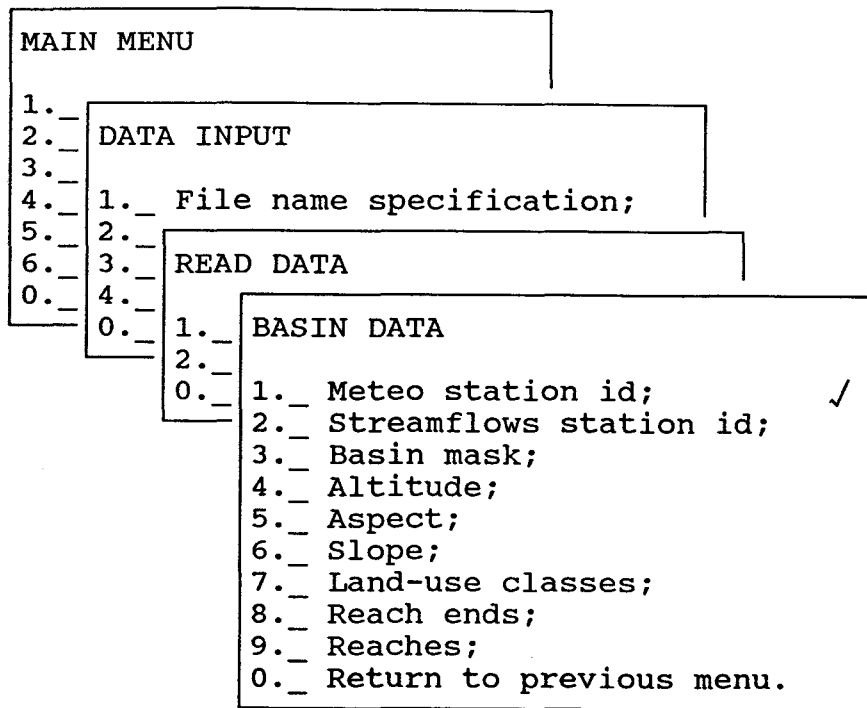
Figure 2.19 Sub-menu #2.3.1: basin data.

2.3.4.3.2 Sub-menu #2.3.2: initial settings

With HYDROTEL 1.1, 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.

```
┌─────────────────────────────────────┐
│ MAIN MENU                           │
│                                     │
│ 1._ ┌───────────────────────────────────┐
│ 2._ │ DATA INPUT                       │
│ 3._ │                                  │
│ 4._ │ 1._ File name specification;     │
│ 5._ │ 2._ ┌──────────────────────────────────┐
│ 6._ │ 3._ │ READ DATA                        │
│ 0._ │ 4._ │                                  │
└─────│ 0._ │ 1._ ┌───────────────────────────────────────┐
      │     │ 2._ │ INITIAL SETTINGS                    │
      └─────│ 0._ │                                     │
                  │ 1._ Water budget;                  │
                  │ 2._ Runoff;                        │
                  │ 3._ Streamflows;                   │
                  │ 0._ Return to previous menu.       │
                  └────────────────────────────────────┘
```
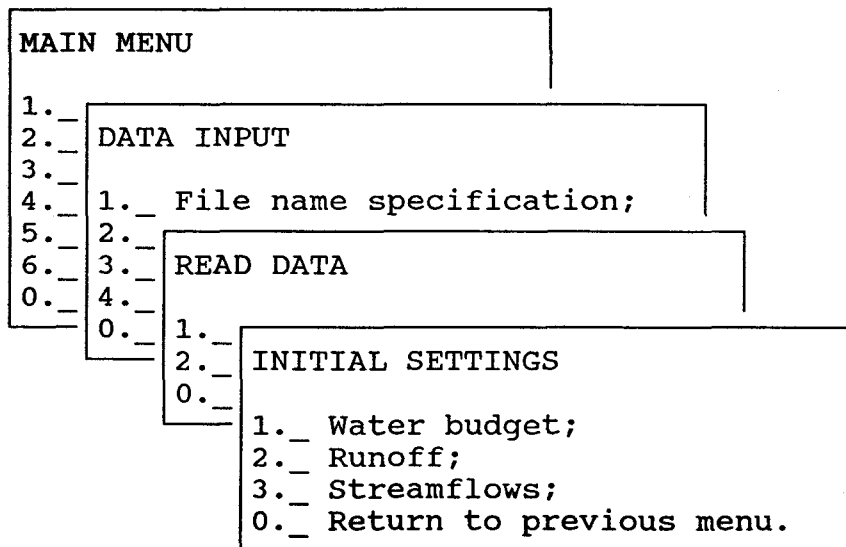
Figure 2.20 Sub-menu #2.3.2: initial settings.

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.

```
MAIN MENU

1._
2._   DATA INPUT
3._
4._   1._  File name specification;
5._   2._  Data format specification;
6._   3._
0._   4._   DISPLAY DATA
      0._
            1._  Basin mask;
            2._  Altitude;
            3._  Aspect;
            4._  Slope;
            5._  Land-use classes;
            6._  Reach ends;
            7._  Reaches;
            0._  Return to previous menu.
```
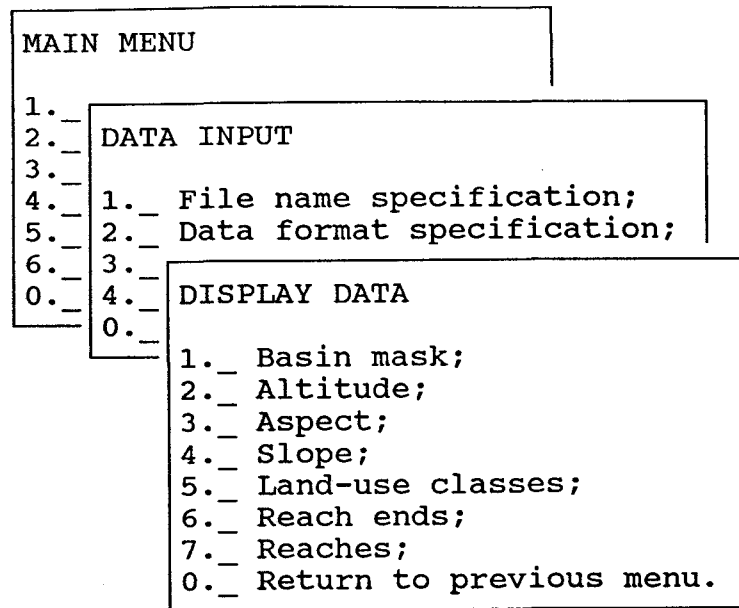
Figure 2.21 Sub-menu #2.4: display data.

2.3.5 Sub-menu #3.0:_ sub-models

```
┌──────────────────────────────────────┐
│MAIN MENU                             │
│                                      │
│1._  Simulation parameters;           │
│2._┌─────────────────────────────────────────┐
│3._│SUB-MODELS                               │
│4._│                                         │
│5._│1._  Interpolation of precipitations;    │
│6._│2._  Snowmelt;                           │
│0._│3._  Evapotranspiration;                 │
│   │4._  Vertical water budget;              │
│   │5._  Surface and sub-surface runoff;     │
│   │6._  Channel routing;                    │
│   │0._  Return to previous menu.            │
│   │                                         │
└───│                                         │
    └─────────────────────────────────────────┘
```

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 1.1, 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.


```
┌─────────────────────────────────┐
│MAIN MENU                        │
│                                 │
│1._  Simulation parameters;      │
│2._┌──────────────────────────────────────────────┐
│3._│SUB-MODELS                                    │
│4._│   ┌──────────────────────────────────────────────────┐
│5._│1._│INTERPOLATION OF PRECIPITATIONS                   │
│6._│2._│                                                  │
│0._│3._│1._  Bypass, read data from disk;           √    │
│   │4._│2._  Thiessen polygons;                           │
│   │5._│3._  Weighted mean of nearest three stations;     │
│   │6._│4._  Arithmetic mean of nearest three stations;   │
│   │0._│5._  User's defined interpolation;                │
│   └───│0._  Return to previous menu.                     │
│       └──────────────────────────────────────────────────┘
```
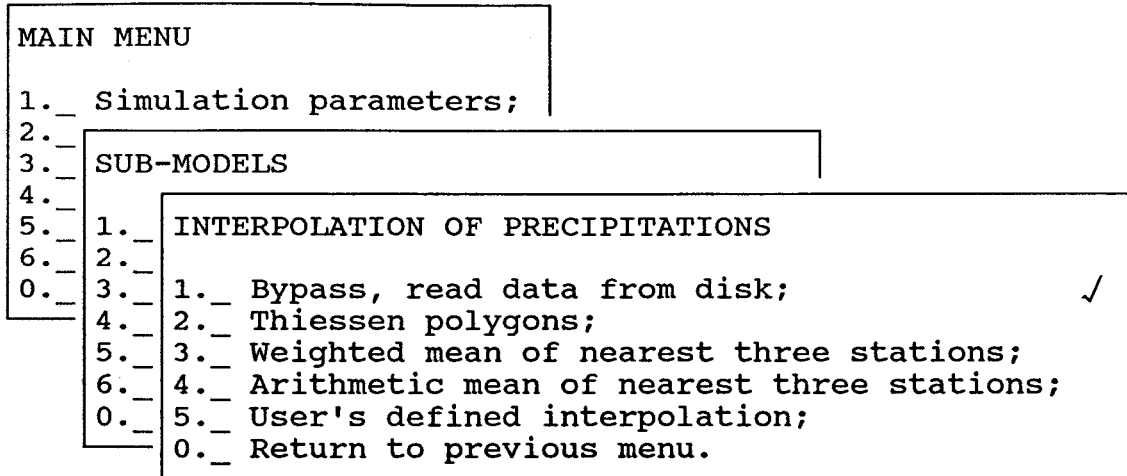
Figure 2.23 Sub-menu #3.1: interpolation of precipitation.

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)

```
┌──────────────────────────────────┐
│MAIN MENU                         │
│                                  │
│1._  Simulation parameters;       │
│2._┌──────────────────────────────────┐
│3._│SUB-MODELS                        │
│4._│                                  │
│5._│1._┌──────────────────────────────────────┐
│6._│2._│INTERPOLATION OF PRECIPITATIONS       │
│0._│3._│                                      │
└───│4._│1._  Bypass, read data from disk;     │
    │5._│2.┌─┤THIESSEN POLYGONS├═══════════════════════════════════════┐
    │6._│3.│                                                          │
    │0._│4.│ Precipitation vert. grad. (%/100m)... 0.                 │
    └───│5.│ Temperature lapse rate (C/100m)...... 0.                 │
        │0.│                                                          │
        └──┤F10:Accept├════════════════════════════════┤Esc:Quit├────┘
```
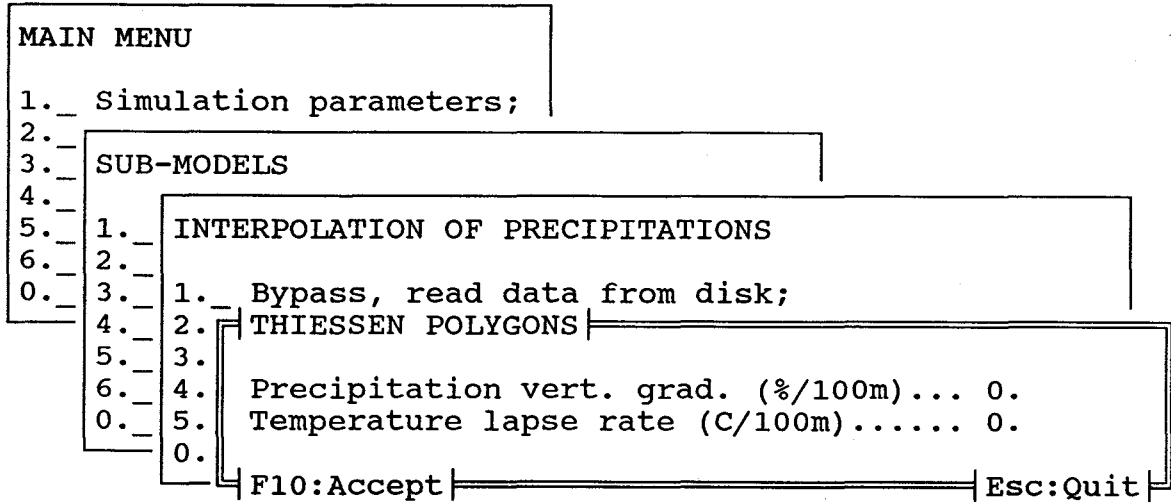
Figure 2.24 Sub-menu #3.1.1: Thiessen polygons.

- 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 ($^\circ$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

```
┌MAIN MENU──────────────────────────┐
│                                    │
│ 1._ Simulation parameters;         │
│ 2._┌─────────────────────────────────────┐
│ 3._│SUB-MODELS                           │
│ 4._│                                     │
│ 5._│1._┌─INTERPOLATION OF PRECIPITATIONS──────────────┐
│ 6._│2._│                                              │
│ 0._│3._│1._ Bypass, read data from disk;              │
└────│4._│2._ Thiessen polygons;                        │
     │5._│3.┌─WEIGHTED MEAN OF NEAREST THREE STATIONS├──────┐
     │6._│4.│                                               │
     │0._│5.│ Precipitation vert. grad. (%/100m)... 0.      │
     └───│0.│ Temperature lapse rate (C/100m)...... 0.      │
         └──┤F10:Accept├════════════════════════════╡Esc:Quit├─┘
```
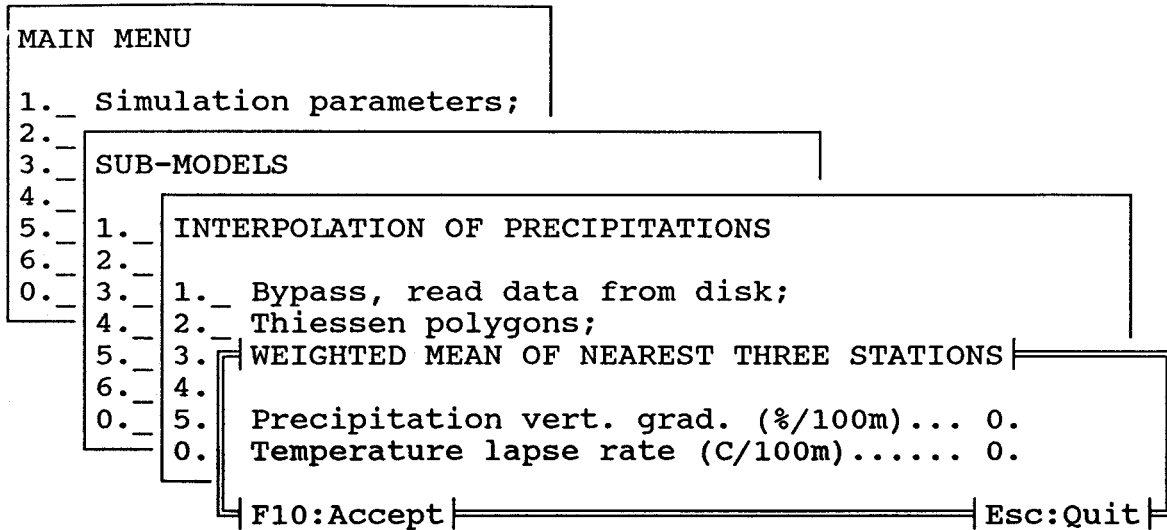
Figure 2.25 Sub-menu #3.1.2: weighted mean of nearest three stations.

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

```
┌MAIN MENU──────────────────────────┐
│                                    │
│ 1._ Simulation parameters;         │
│ 2._┌─────────────────────────────────────┐
│ 3._│SUB-MODELS                           │
│ 4._│                                     │
│ 5._│1._┌─INTERPOLATION OF PRECIPITATIONS───────────────┐
│ 6._│2._│                                               │
│ 0._│3._│1._ Bypass, read data from disk;               │
└────│4._│2._ Thiessen polygons;                         │
     │5._│3._ Weighted mean of nearest three stations;   │
     │6._│4.┌─ARITHMETIC MEAN OF NEAREST THREE STATIONS├──────┐
     │0._│5.│                                                 │
     └───│0.│ Precipitation vert. grad. (%/100m)... 0.        │
         └──│ Temperature lapse rate (C/100m)...... 0.        │
            └┤F10:Accept├════════════════════════════════╡Esc:Quit├─┘
```
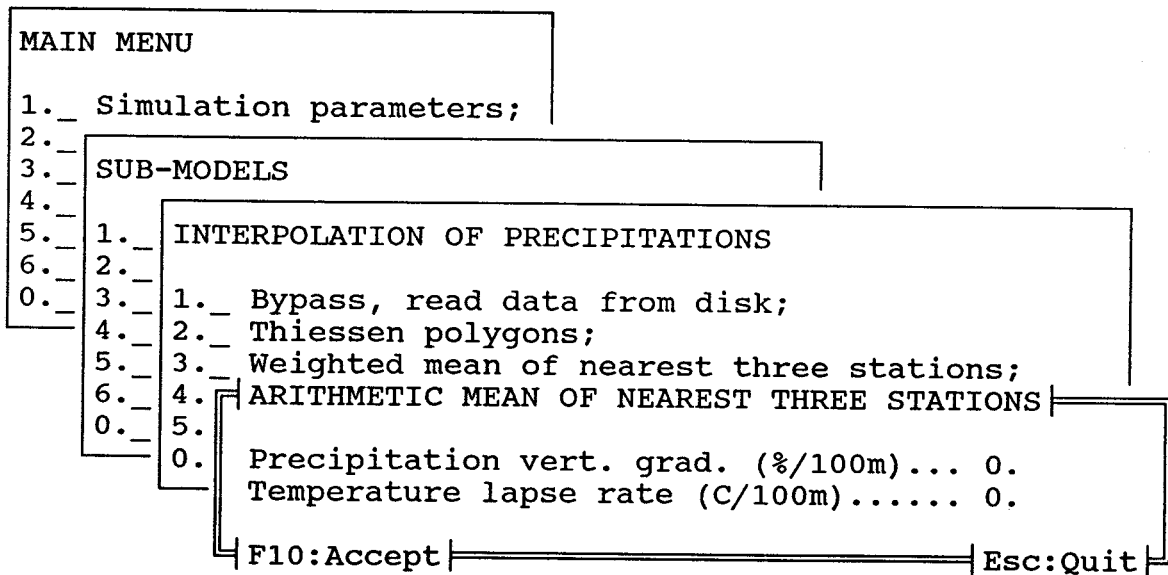
Figure 2.26 Sub-menu #3.1.3: arithmetic mean of nearest three stations.

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


```
┌──────────────────────────────────┐
│ MAIN MENU                        │
│                                  │
│ 1._  Simulation parameters;      │
│ 2._┌──────────────────────────────────┐
│ 3._│ SUB-MODELS                       │
│ 4._│                                  │
│ 5._│ 1._┌──────────────────────────────────┐
│ 6._│ 2._│ SNOWMELT                         │
│ 0._│ 3._│                                  │
└────│ 4._│ 1._  Bypass, read data from disk; │
     │ 5._│ 2._  Modified degree/day method;  √│
     │ 6._│ 3._  User's defined snowmelt;    │
     │ 0._│ 0._  Return to previous menu.    │
     └────└──────────────────────────────────┘
```
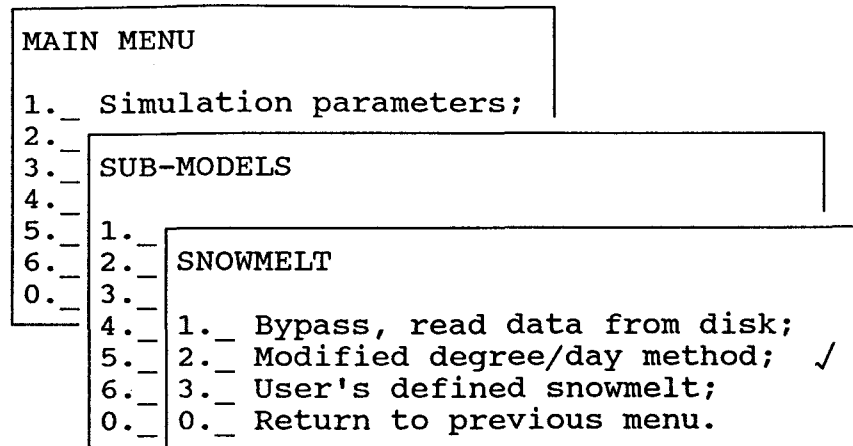
Figure 2.27 Sub-menu #3.2: snowmelt.

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)

```
┌──────────────────────────────────┐
│MAIN MENU                         │
│                                  │
│1._ Simulation parameters;        │
│2._┌─────────────────────────────────┐
│3._│SUB-MODELS                      │
│4._│                               │
│5._│1._┌──────────────────────────────────┐
│6._│2._│SNOWMELT                        │
│0._│3._│                               │
└───│4._│1._ Bypass, read data from disk;  │
    │5._│2.┌┤MODIFIED DEGREE/DAY METHOD├═══════════════════════════════┐
    │6._│3.││                                                         │
    │0._│0.││ Temp. for transf. of rain into snow (°C).... 0.        │
    └───└───│ Melt factor (coniferous forest) (mm/d°C).... 2.       │
            │ Melt factor (deciduous forest) (mm/d°C)..... 3.       │
            │ Melt factor (open areas) (mm/d°C)........... 4.       │
            │ Threshold temp. for melt (°C)............... 0.       │
            │ Melt rate at snow/ground interface (mm/d)... 0.5      │
            │ Maximum density of snowpack (hg/m3)......... 550      │
            │ Settlement constant......................... 0.1      │
            │                                                      │
            └┤F10:Accept├══════════════════════════════┤Esc:Quit├──┘
```

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

See section 3.3 for more informations.

- Temperature for transformation of rain into snow (°C): type the threshold temperature (°C) for the transformation of rain into snow.

- Melt factor (coniferous forest) (mm/d-°C): type melt factor for coniferous forests, in millimeters per day and degree Celcius.

- Melt factor (deciduous forest) (mm/d-°C): type melt factor for deciduous forests;

- Melt factor (open areas) (mm/d-°C): type melt factor for open areas.

- Threshold temperature for melt (°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).

2.3.5.3 Sub-menu #3.3: evapotranspiration

```
MAIN MENU

1._  Simulation parameters;
2._
3._ ┌────────────────────────────────────────────────┐
4._ │ SUB-MODELS                                       │
5._ │                                                  │
6._ │ 1._  Interpolation of precipitations;            │
0._ │ 2._                                              │
    │ 3._ ┌───────────────────────────────────────────────────────┐
    │ 4._ │ EVAPOTRANSPIRATION                                      │
    │ 5._ │                                                         │
    │ 6._ │ 1._  Bypass, read data from disk;                       │
    │ 0._ │ 2._  THORNTHWAITE potential evapotranspiration;     √   │
    │     │ 3._  User's defined potential evapotranspiration;       │
    │     │ 0._  Return to previous menu.                           │
          └───────────────────────────────────────────────────────┘
```

Figure 2.29 Sub-menu #3.3: evapotranspiration.

Three options are currently available for the estimation of potential evapotranspiration (figure 2.29). Select it and press "ENTER".

Option 1 allows the user to bypass the PET sub-program 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). It will be also possible for the user to write its own PET subprogram, following the instructions given in this user's guide.

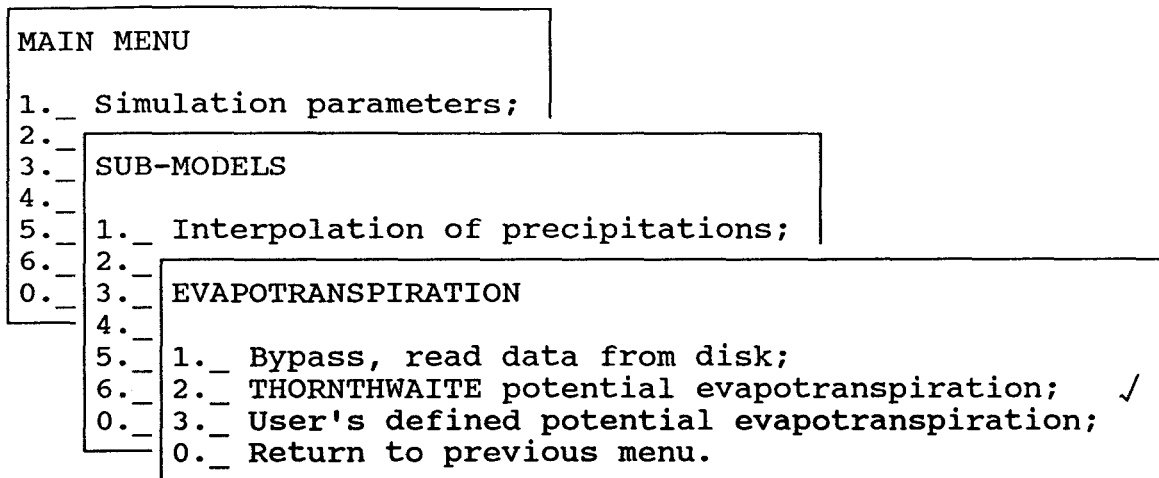2.3.5.3.1 Sub-menu #3.3.1: input data for Thorthwaite PE (figure 2.30)

```
┌─────────────────────────────────────────┐
│MAIN MENU                                 │
│                                          │
│1._  Simulation parameters;               │
│2._┌──────────────────────────────────────────┐
│3._│SUB-MODELS                                 │
│4._│                                           │
│5._│1._  Interpolation of precipitations;     │
│6._│2._┌──────────────────────────────────────────────────────┐
│0._│3._│EVAPOTRANSPIRATION                                     │
└───│4._│                                                       │
    │5._│1._  Bypass, read data from disk;                     │
    │6._│2.┌─THORNTHWAITE POTENTIAL EVAPOTRANSPIRATION├═══════┐
    │0._│3.│                                                    ║
    └───│0.│ Thornthwaite thermal index............. 30.       ║
        └──│ Mean latitude of the basin (degrees)... 45.25     ║
           │ Temporal shift parameter................ 80        ║
           │                                                    ║
           └┤F10:Accept├══════════════════════════┤Esc:Quit├──╝
```
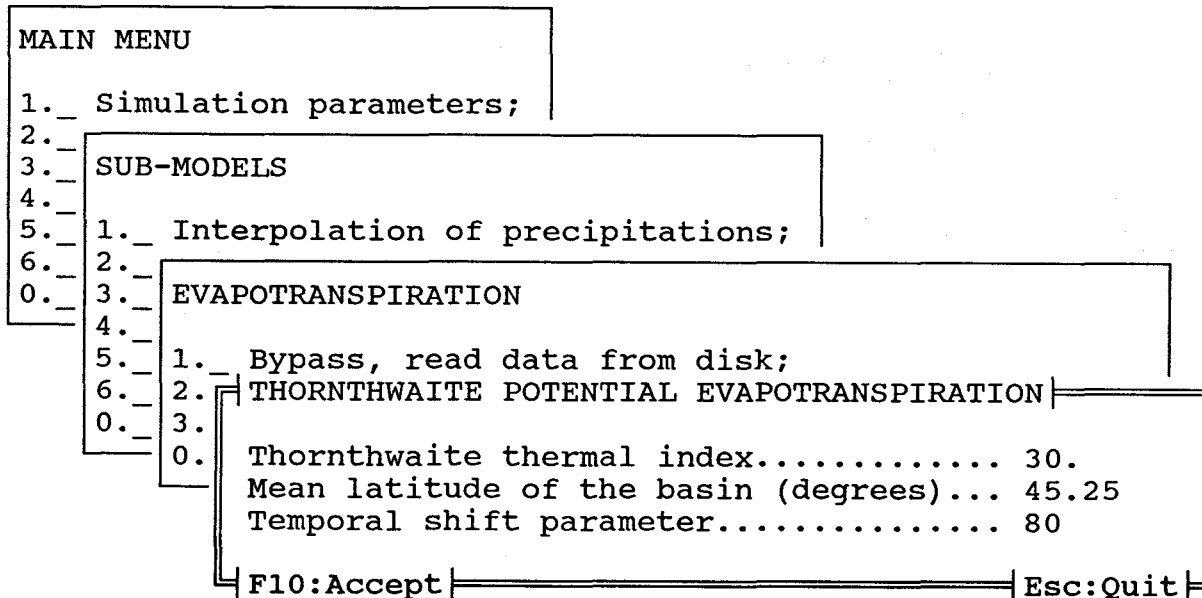
Figure 2.30 Sub-menu #3.3.1: input data for Thorthwaite PE.

See section 3.4.1 for more informations.

- 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).

2.3.5.4 Sub-menu #3.4: vertical water budget

```
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._  CEQUEAU (modified);              √
          3._  User's defined function;
          0._  Return to previous menu.
```
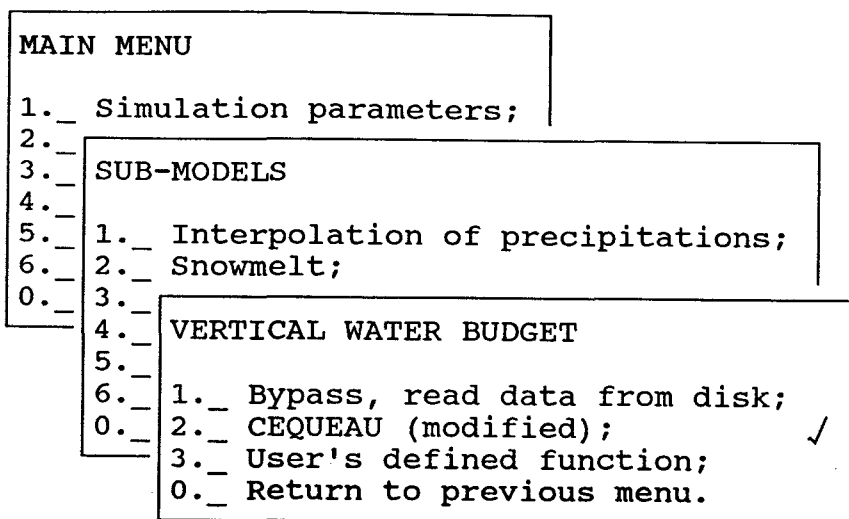
Figure 2.31 Sub-menu #3.4: vertical water budget.

Three options are currently available for the estimation of the vertical water budget on each square (figure 2.31). Select it and press "ENTER". After typing input values in each of the derived sub-menus, if you select option 2, 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 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.

2.3.5.4.1 Sub-menu #3.4.1: input data for CEQUEAU

```
┌─────────────────────────────────────────┐
│ MAIN MENU                                │
│                                  │       │
│ 1._  Simulation parameters;      │       │
│ 2._┌─────────────────────────────────────────┐
│ 3._│ SUB-MODELS                              │
│ 4._│                                         │
│ 5._│ 1._  Interpolation of precipitations;   │
│ 6._│ 2._  Snowmelt;                     │    │
│ 0._│ 3._                                │    │
└────│ 4._┌────────────────────────────────────────┐
     │ 5._│ VERTICAL WATER BUDGET                  │
     │ 6._│                                   │    │
     │ 0._│ 1._                               │    │
     └────│ 2._┌───────────────────────────────────────┐
          │ 3._│ CEQUEAU (MODIFIED)                    │
          │ 0._│                                       │
          └────│ 1._  Runoff on impervious areas;      │
               │ 2._  Unsaturated zone reservoir;      │
               │ 3._  Saturated zone reservoir;        │
               │ 4._  Lakes and marshes;               │
               │ 5._  Initial levels in reservoirs;    │
               │ 0._  Return to previous menu.         │
               └───────────────────────────────────────┘
```
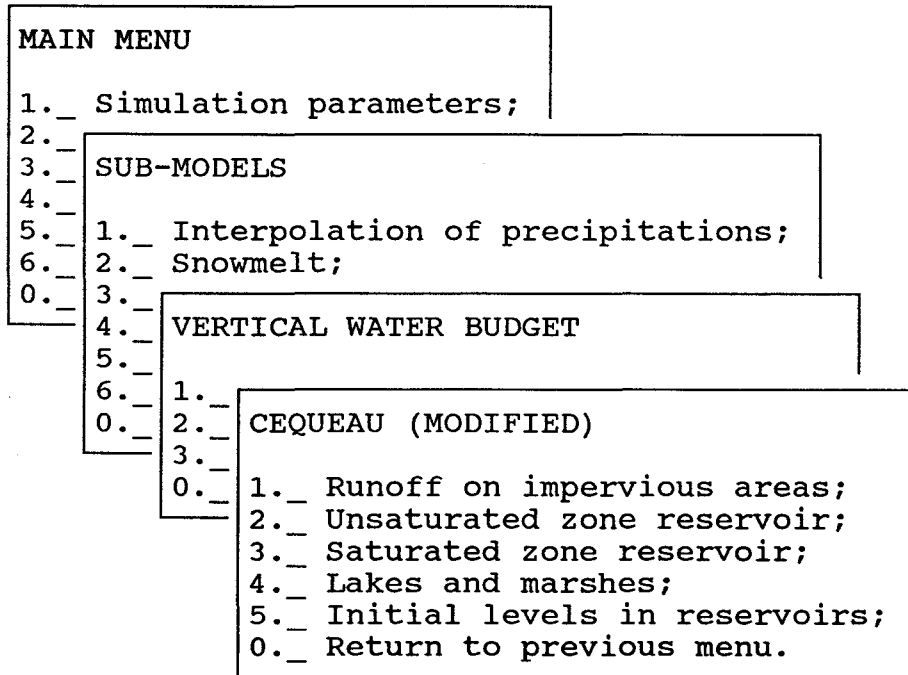
Figure 2.32 Sub-menu #3.4.1: input data for CEQUEAU.

See section 3.5 for more information.

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 2.32). 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 2.33)

```
┌─────────────────────────────────────┐
│ 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._                               │ │
     │ 0._│ 2._┌──────────────────────────────────────────────────────┐
     └────│ 3._│ CEQUEAU (MODIFIED)                                    │
          │ 0._│                                                      │ │
          └────│ 1.┌─┤RUNOFF ON IMPERVIOUS AREAS├════════════════════════════════╗
               │ 2.│                                                             ║
               │ 3.│  Depth threshold for surface runoff (mm)... 0.              ║
               │ 4.│                                                             ║
               │ 5.└─┤ F10:Accept├══════════════════════════════════┤Esc:Quit├═╝
               │ 0._  Return to previous menu.                        │
               └──────────────────────────────────────────────────────┘
```
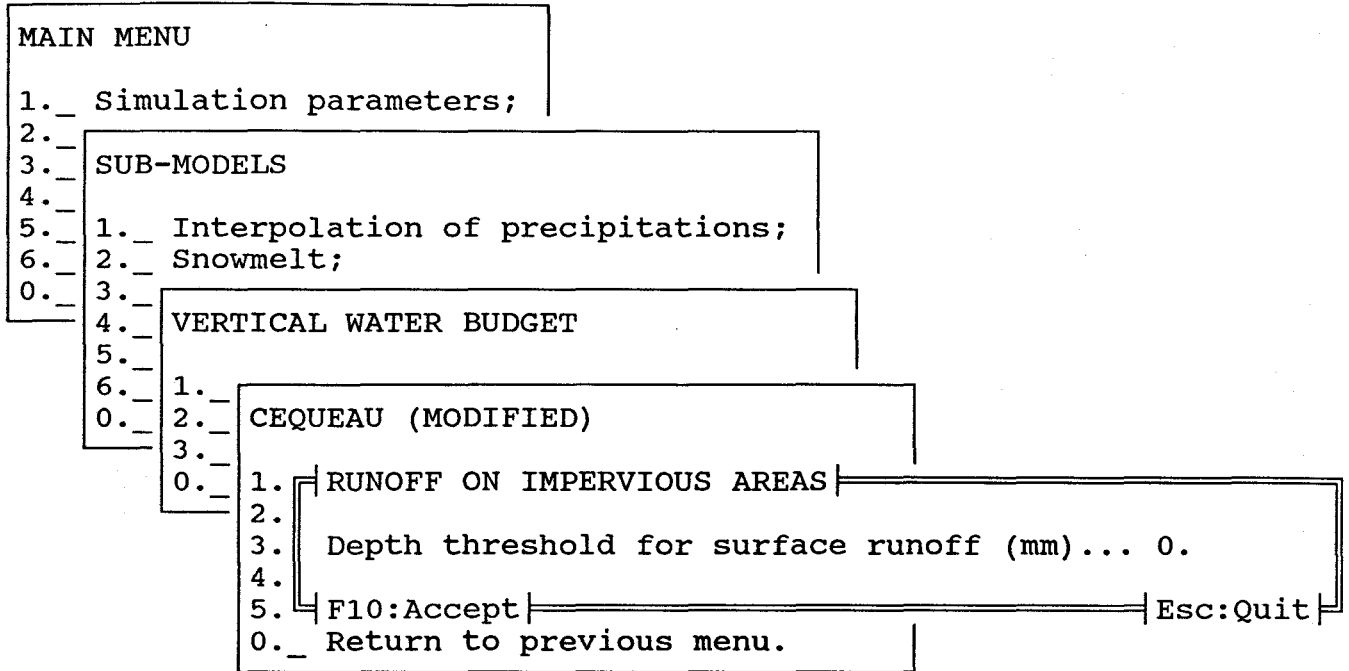
Figure 2.33 Sub-menu #3.4.1.1: runoff on impervious areas.

- 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 2.34)
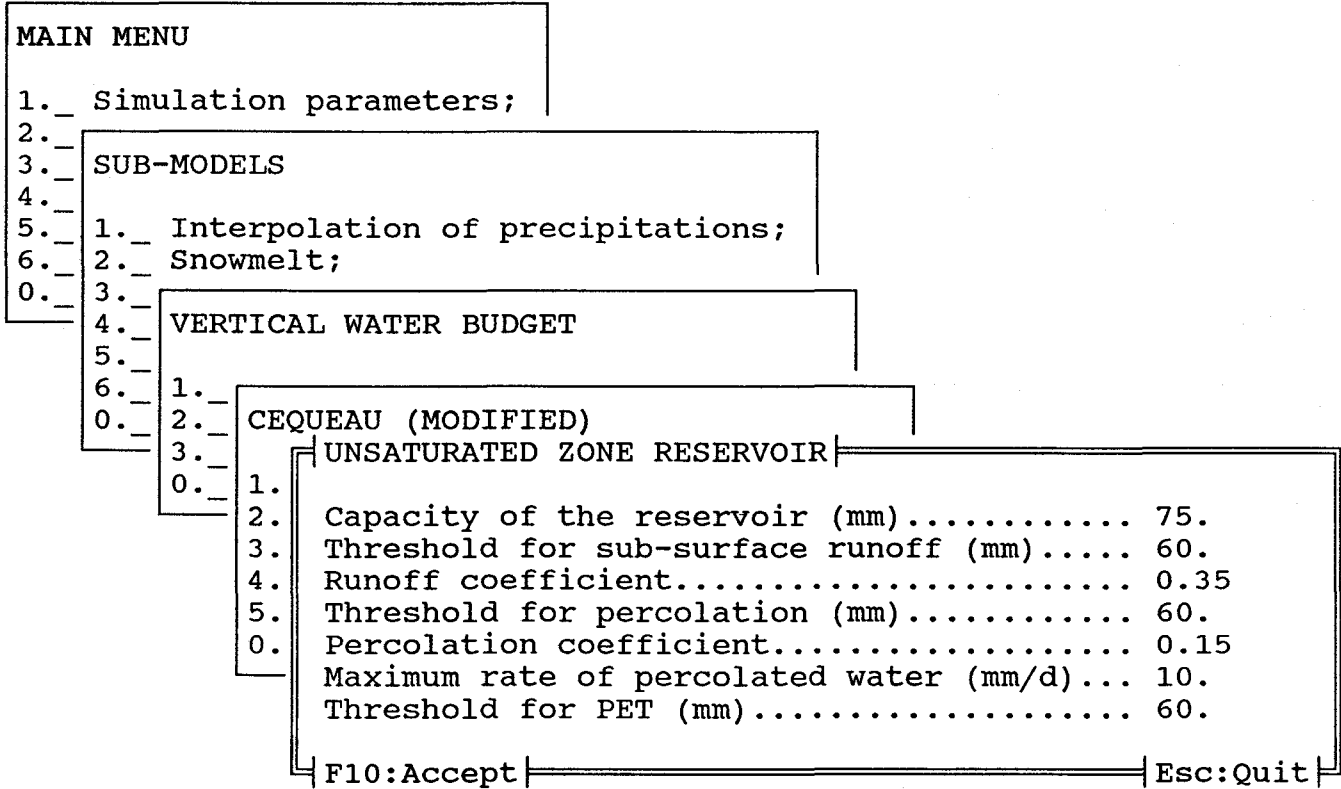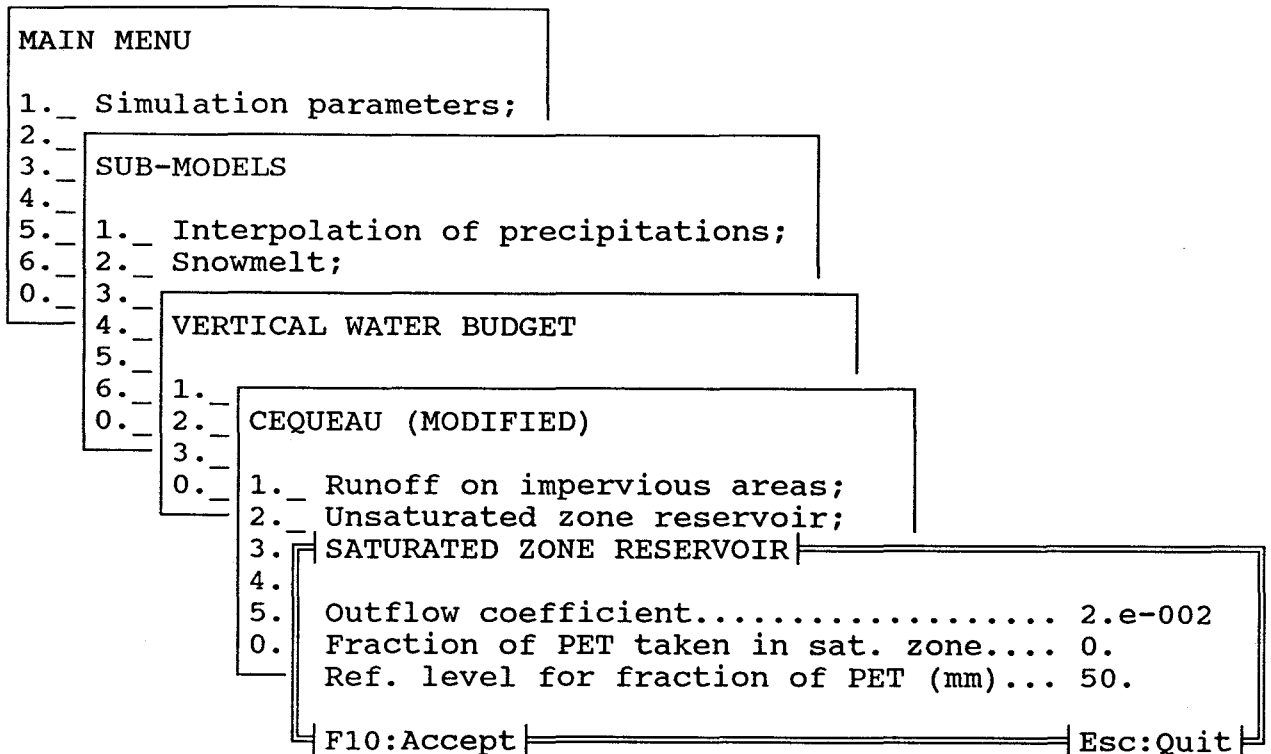
```
MAIN MENU

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._
     0._  2._  CEQUEAU (MODIFIED)
          3._
          0._  1.  UNSATURATED ZONE RESERVOIR
               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.
               0.  Percolation coefficient................... 0.15
                   Maximum rate of percolated water (mm/d)... 10.
                   Threshold for PET (mm).................... 60.

                   F10:Accept                        Esc:Quit
```

Figure 2.34 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 (millimiters) 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 2.35)

```
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._
     0._  2._  CEQUEAU (MODIFIED)
          3._
          0._  1._  Runoff on impervious areas;
               2._  Unsaturated zone reservoir;
               3.   SATURATED ZONE RESERVOIR
               4.
               5.   Outflow coefficient................... 2.e-002
               0.   Fraction of PET taken in sat. zone.... 0.
                    Ref. level for fraction of PET (mm)... 50.

                    F10:Accept                              Esc:Quit
```

Figure 2.35 Sub-menu #3.4.1.3: saturated zone reservoir.

- 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 2.36)
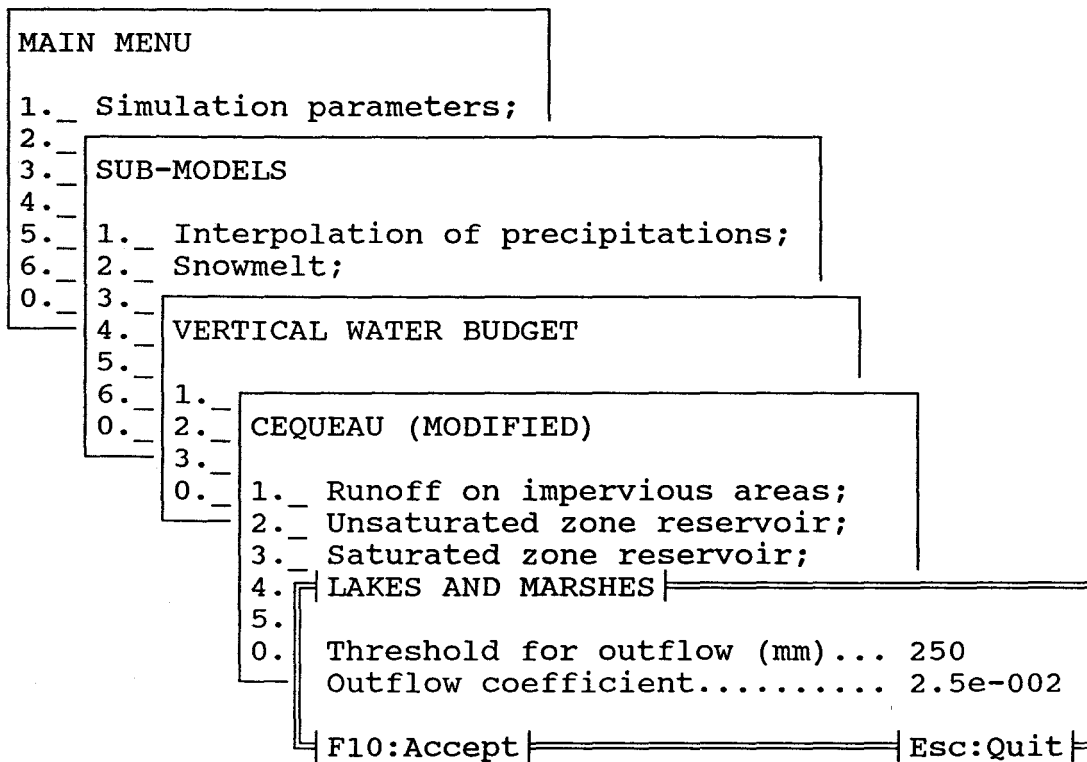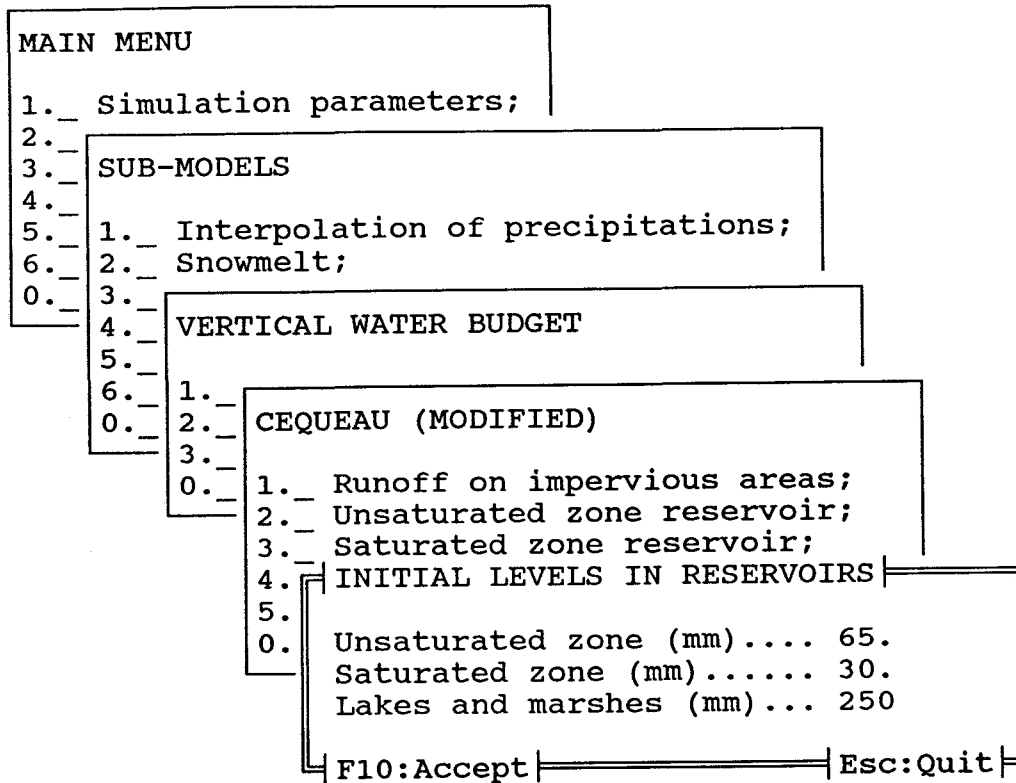
```
MAIN MENU

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._
    0._ 2._ CEQUEAU (MODIFIED)
        3._
        0._ 1._  Runoff on impervious areas;
            2._  Unsaturated zone reservoir;
            3._  Saturated zone reservoir;
            4._ LAKES AND MARSHES
            5.
            0.  Threshold for outflow (mm)... 250
                Outflow coefficient.......... 2.5e-002

            F10:Accept                        Esc:Quit
```

Figure 2.36 Sub-menu #3.4.1.4: lakes and marshes.

- 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 2.37)

```
┌────────────────────────────────────┐
│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._┌──────────────────────────────────┐
│   │0._│2._│CEQUEAU (MODIFIED)               │
│       │3._│                                  │
│       │0._│1._  Runoff on impervious areas; │
│           │2._  Unsaturated zone reservoir; │
│           │3._  Saturated zone reservoir;   │
│           │4._┤INITIAL LEVELS IN RESERVOIRS ├═══════┐
│           │5. │                                      │
│           │0. │ Unsaturated zone (mm).... 65.        │
│               │ Saturated zone (mm)...... 30.        │
│               │ Lakes and marshes (mm)... 250        │
│               └┤F10:Accept ├════════════┤Esc:Quit ├──┘
```

Figure 2.37 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.

2.3.5.5 Sub-menu #3.5: surface and sub-surface runoff

```
┌─────────────────────────────────────────┐
│ 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.               │
            └─────────────────────────────────────────────┘
```
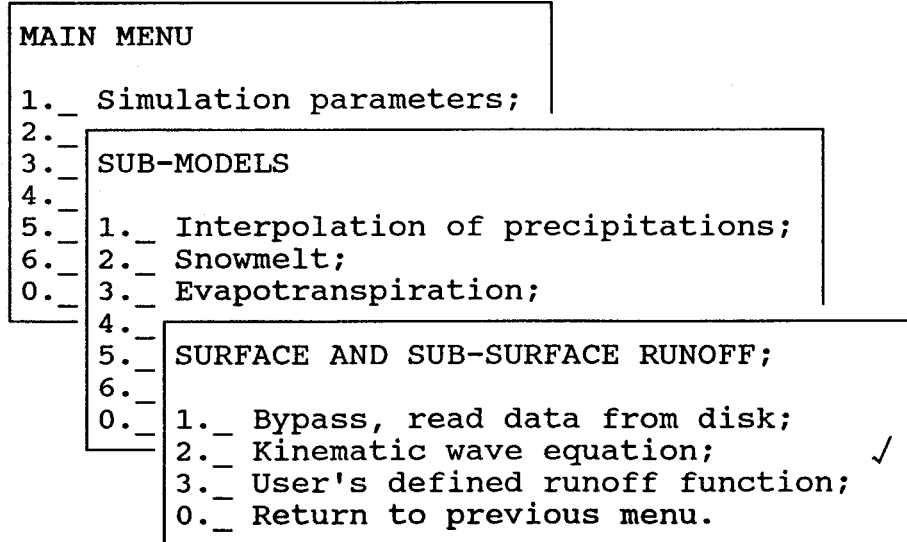
Figure 2.38 Sub-menu #3.5: surface and sub-surface runoff.

See section 3.6 for more information.

Three options are currently available for the simulation of surface and sub-surface runoff (figure 2.38). Select it 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".

2.3.5.6 Sub-menu #3.6: channel routing

```
┌─────────────────────────────────┐
│ MAIN MENU                       │
│                                 │
│ 1._  Simulation parameters;     │
│ 2._┌─────────────────────────────────────────┐
│ 3._│ SUB-MODELS                              │
│ 4._│                                         │
│ 5._│ 1._  Interpolation of precipitations;   │
│ 6._│ 2._  Snowmelt;                          │
│ 0._│ 3._  Evapotranspiration;                │
└────│ 4._  Vertical water budget;             │
     │ 5._                                     │
     │ 6._┌──────────────────────────────────────────────┐
     │ 0._│ CHANNEL ROUTING                              │
     └────│                                              │
          │ 1._  Bypass, read data from disk;            │
          │ 2._  Modified kinematic wave equation;    √  │
          │ 3._  User's defined channel routing function;│
          │ 0._  Return to previous menu.                │
          └──────────────────────────────────────────────┘
```
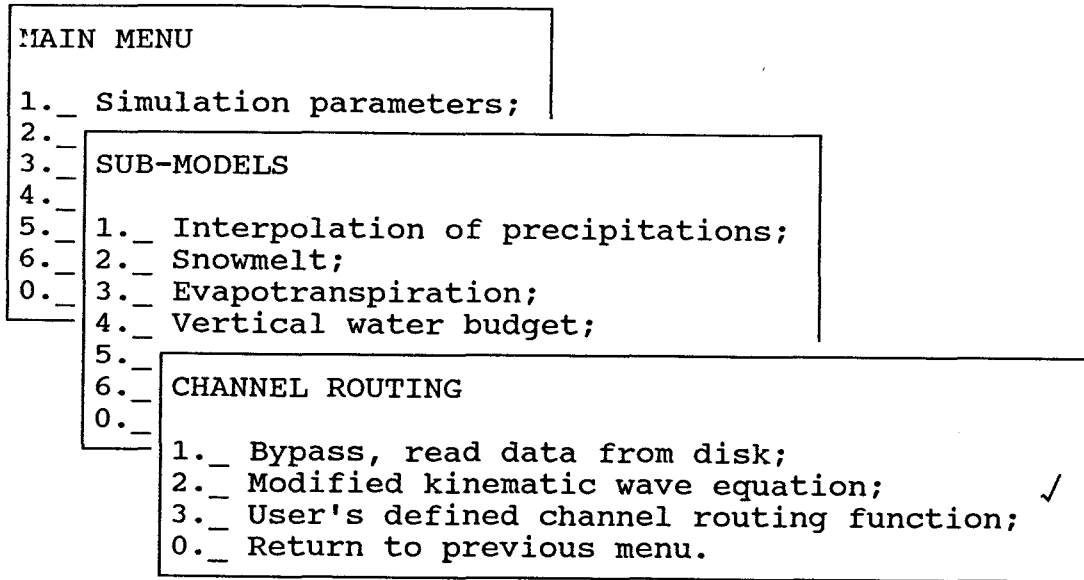
Figure 2.39 Sub-menu #3.6: channel routing.

See section 3.7 for more information.

Three options are currently available for the simulation of channel routing (figure 2.40).

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 its own vertical water budget, following the instructions given in this user's guide.

Initial values of water levels in the reaches com 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". 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 2.42) 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.

```
MAIN MENU

1._  Simulation parameters;
2._  Data input;
3._ ┌─────────────────────────────────────────────┐
4._ │ DATA OUTPUT                                   │
5._ │                                               │
6._ │ 1._  File name specification;                 │
0._ │ 2._  Data format specification;               │
 ───┘ 3._  Save data;                               │
    │ 4._  Display data;                            │
    │ 0._  Return to previous menu.                 │
    └───────────────────────────────────────────────┘
```
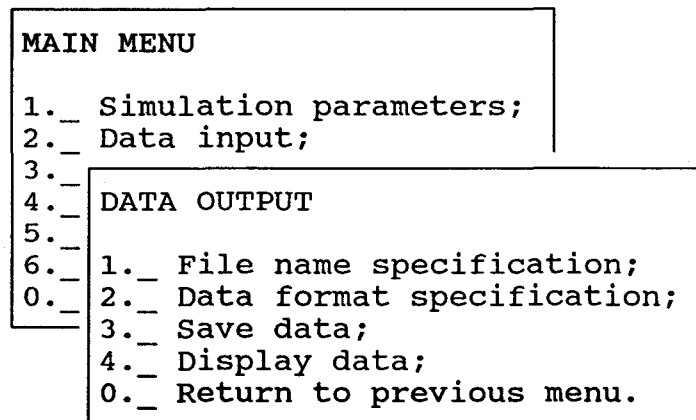
Figure 2.40   Sub-menu #4.0: data output.

2.3.6.1 Sub-menu #4.1: file name specification

Sub-menu #4.1 (figure 2.43) 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.

```
MAIN MENU

1._  Simulation parameters;
2._  Data input;
3._ ┌──────────────────────────────────────────────────────┐
4._ │ DATA OUTPUT                                            │
5._ │                                                        │
6._ │ 1._ ┌────────────────────────────────────────────┐    │
0._ │ 2._ │ FILE NAME SPECIFICATION                     │    │
 ───┘ 3._ │                                             │    │
    │ 4._ │ 1._  Intermediate results;                  │    │
    │ 0._ │ 2._  Final settings;                         │    │
    │     │ 0._  Return to previous menu.               │    │
    │     └─────────────────────────────────────────────┘    │
    └────────────────────────────────────────────────────────┘
```
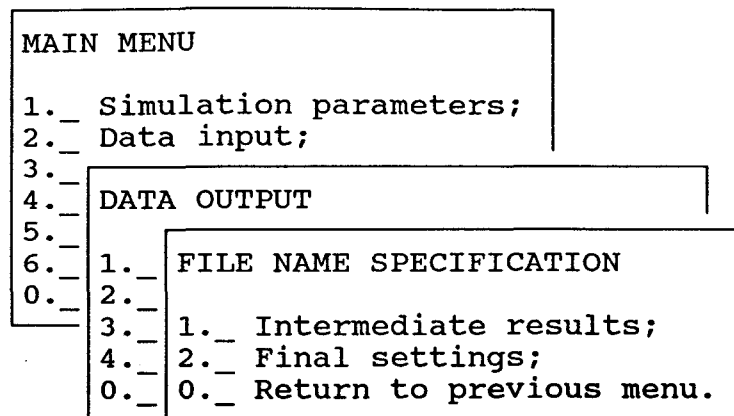
Figure 2.41   Sub-menu #4.1: file name specification.

2.3.6.1.1 Sub-menu #4.1.1: intermediate results

File names for files containing intermediate results can be given here
(figure 2.42).

```
MAIN MENU

1._  Simulation parameters;
2._  Data input;
3._
4._  DATA OUTPUT
5._
6._  1._  FILE NAME SPECIFICATION
0._  2._
     3._  1._  INTERMEDIATE RESULTS
     4._  2._
     0._  0._  Temperatures... clifton.tem
                Rain.......... clifton.pre
                melt.......... clifton.fon
                Pot. evap. .... clifton.etp
                Outflow........ clifton.pro
                Runoff........ clifton.rui
                Streamflows.... clifton.deb

           F10:Accept                Esc:Quit
```
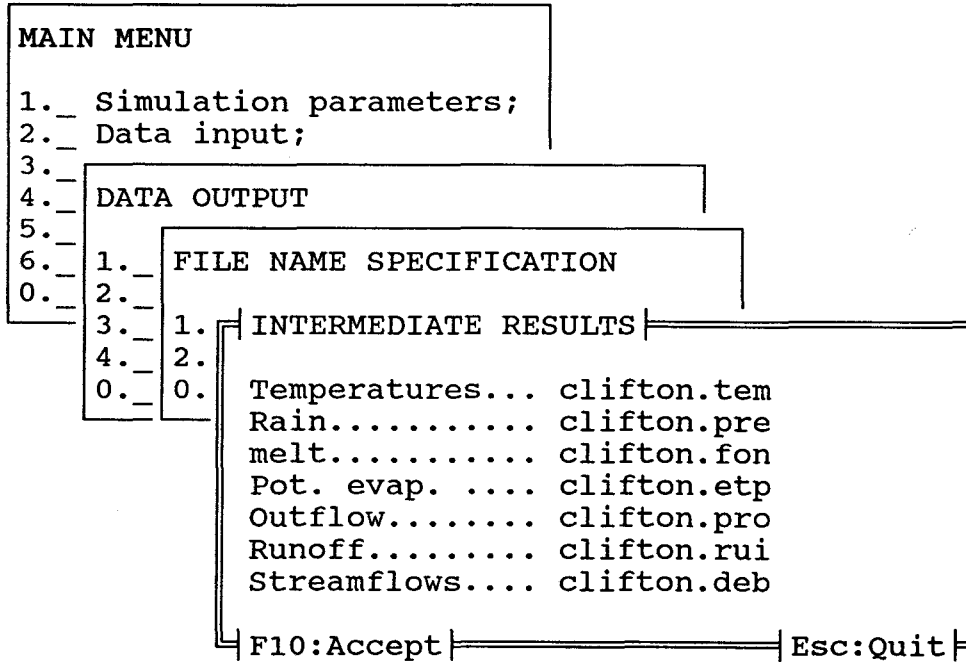
Figure 2.42 Sub-menu #4.1.1: intermediate results.

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 2.43). The initialization procedure is
explained at the end of Part 2.

```
MAIN MENU

1._  Simulation parameters;
2._  Data input;
3._ ┌──────────────────────────────────────────┐
4._ │ DATA OUTPUT                                │
5._ │                                            │
6._ │ 1._ ┌────────────────────────────────────┐ │
0._ │ 2._ │ FILE NAME SPECIFICATION            │ │
    └─│ 3._ │                                  │ │
      │ 4._ │ 1._  Intermediate results;       │ │
      │ 0._ │ 2.┌─FINAL SETTINGS──────────────────────┐
      └─────│ 0.│                                      │
            └───│ Water budget... clifton.pis          │
                │ Runoff......... clifton.ris          │
                │ Streamflows.... clifton.cis          │
                │                                      │
                └┤F10:Accept├──────────────┤Esc:Quit├──┘
```
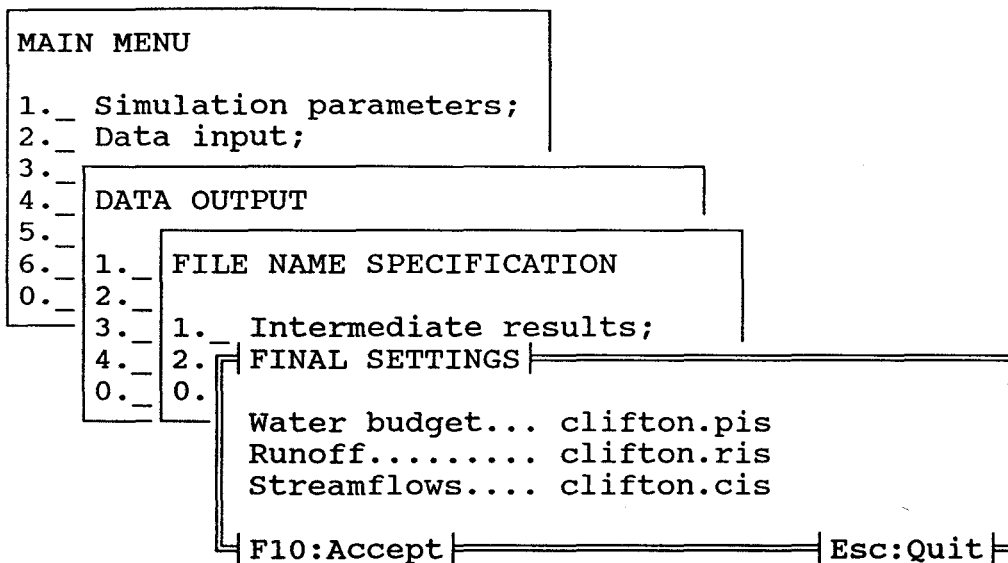
Figure 2.43 Sub-menu #4.1.2: final settings.

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 2.44).


```
┌──────────────────────────────────────────┐
│ MAIN MENU                                │
│                                          │
│ 1._  Simulation parameters;              │
│ 2._  Data input;                         │
│ 3._ ┌──────────────────────────────────────────┐
│ 4._ │ DATA OUTPUT                              │
│ 5._ │                                          │
│ 6._ │ 1._ ┌─────────────────────────────────────┐
│ 0._ │ 2._ │ DATA FORMAT SPECIFICATION           │
└─────│ 3._ │                                     │
      │ 4._ │ 1._  Intermediate results;          │
      │ 0._ │ 2._  Final settings;                │
      └─────│ 0._  Return to previous menu.       │
            └─────────────────────────────────────┘
```
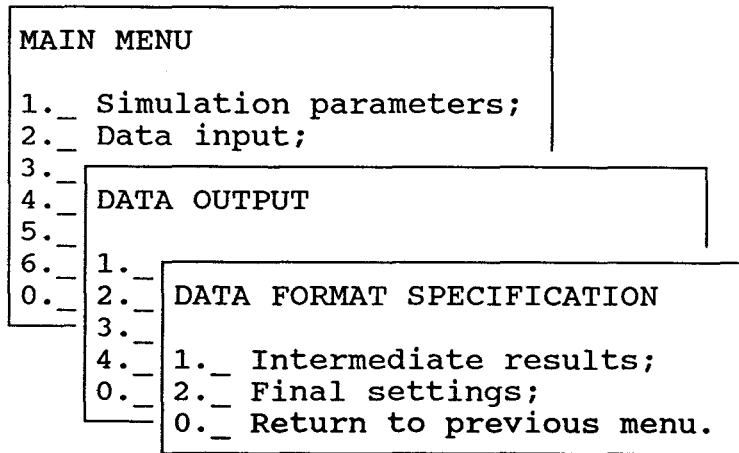
Figure 2.44 Sub-menu #4.2: data format specification.

2.3.6.2.1 Sub-menu #4.2.1: intermediate results

Only INRS ASCII text file format is available with HYDROTEL 1.1 (figure 2.45).

```
┌──────────────────────────────────────┐
│MAIN MENU                             │
│                                      │
│1._  Simulation parameters;          │
│2._  Data input;                     │
│3._┌──────────────────────────────────────────┐
│4._│DATA OUTPUT                              │
│5._│                                         │
│6._│1._                                      │
│0._│2._┌──────────────────────────────────────────────┐
│   │3._│DATA FORMAT SPECIFICATION                    │
└───│4._│                                             │
    │0._│1.┌─┤INTERMEDIATE RESULTS├──┐             │
    └───│2.│                        │             │
        │0.│  Temperatures... INRS  │             │
        └──│  Rain............ INRS  ┘             │
           │  melt............ INRS                │
           │  Pot. evap. .... INRS                │
           │  Outflow........ INRS                │
           │  Runoff......... INRS                │
           │  Streamflows.... INRS                │
           │                                      │
           └┤F10:Accept├══┤Esc:Quit├─────────────┘
```
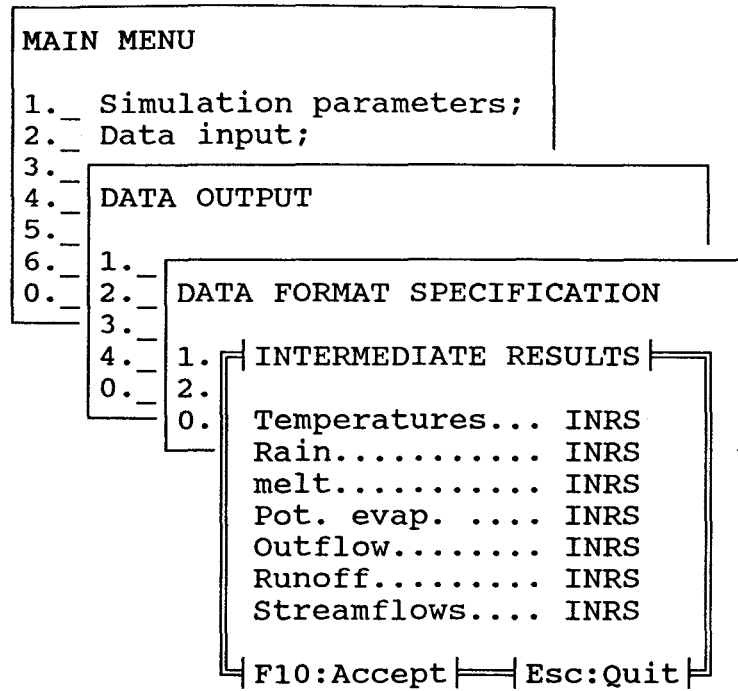
Figure 2.45 Sub-menu #4.2.1: intermediate results.

2.3.6.2.2 Sub-menu #4.2.2: final settings

Only INRS ASCII text file format is available with HYDROTEL 1.1 (figure 2.46).

```
MAIN MENU

1._ Simulation parameters;
2._ Data input;
3._
4._ DATA OUTPUT
5._
6._  1._
0._  2._ DATA FORMAT SPECIFICATION
     3._
     4._  1._ Intermediate results;
     0._  2._ FINAL SETTINGS
          0.
              Water budget... INRS
              Runoff.......... INRS
              Streamflows.... INRS

          F10:Accept    Esc:Quit
```
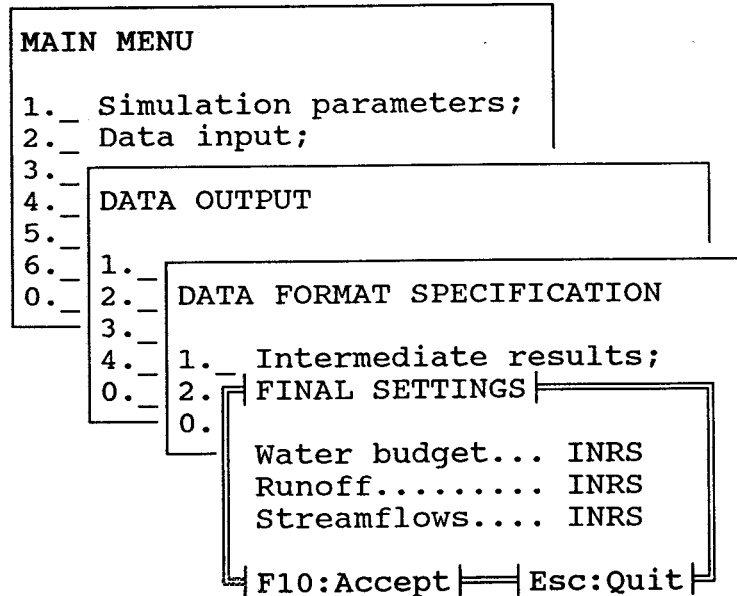
Figure 2.46 Sub-menu #4.2.2: final settings.

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 (fig. 2.47). Figure 2.48 shows an example of the matrices saved for a particular time. Intermediate results or final settings of state variables may be saved.

```
MAIN MENU

1._ Simulation parameters;
2._ Data input;
3._
4._ DATA OUTPUT
5._
6._  1._ File name specification;
0._  2._
     3._ SAVE DATA
     4._
     0._  1._ Intermediate results;
          2._ Final settings;
          0._ Return to previous menu.
```
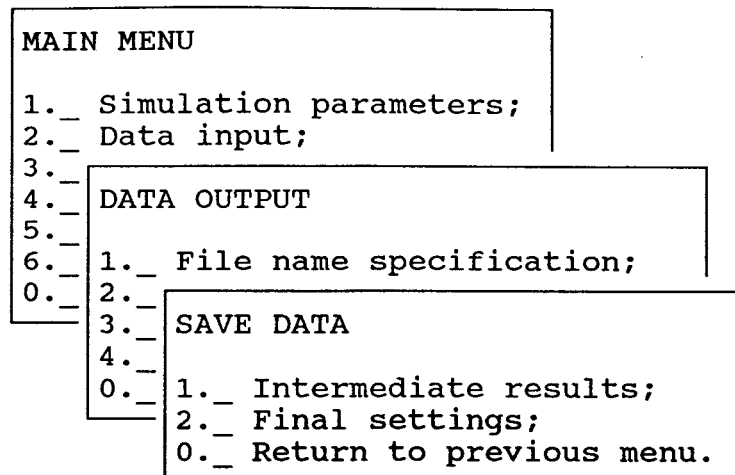
Figure 2.47 Sub-menu #4.3: save data

```
1
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 2.8 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0 0.0 0.0 0.0 2.8 2.8 2.8 4.1 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0 2.8 2.8 2.8 2.8 2.8 2.8 2.8 3.8 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0 2.8 2.8 2.8 2.8 2.8 2.8 2.8 3.8 3.8 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0 4.6 4.6 4.6 4.6 4.6 4.6 4.6 4.6 3.8 3.8 3.8 3.8 0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 4.6 4.6 4.6 4.6 4.6 4.6 4.6 4.6 4.6 13.5 13.5 13.5 3.8 3.8 0.0 0.0 0.0 0.0 0.0
0.0 0.0 4.6 4.6 4.6 4.6 4.6 4.6 4.6 4.6 4.6 13.5 13.5 13.5 13.5 3.8 3.8 0.0 0.0 0.0 0.0
0.0 4.6 4.6 4.6 4.6 4.6 4.6 4.6 4.6 4.6 4.6 13.5 13.5 13.5 13.5 13.5 13.5 13.5 0.0 0.0
0.0 4.6 4.6 4.6 4.6 4.6 4.6 4.6 4.6 4.6 4.6 13.5 13.5 13.5 13.5 13.5 13.5 13.5 13.5 0.0 0.0
0.0 4.6 4.6 4.6 4.6 4.6 4.6 4.6 4.6 4.6 4.6 13.5 13.5 13.5 13.5 13.5 13.5 13.5 13.5 13.5 0.0
0.0 0.0 0.0 4.6 4.6 4.6 1.6 4.6 4.6 4.6 4.6 13.5 13.5 13.5 13.5 13.5 13.5 13.5 13.5 13.5 0.0
0.0 0.0 0.0 4.6 4.6 4.6 4.5 4.6 4.6 4.6 4.6 13.5 13.5 13.5 13.5 13.5 13.5 13.5 13.5 13.5 0.0
0.0 0.0 0.0 4.6 4.6 4.6 4.5 4.6 4.6 4.6 4.6 13.5 13.5 13.5 13.5 13.5 13.5 13.5 0.0 0.0 0.0
0.0 0.0 0.0 0.0 4.6 4.6 4.6 4.6 0.0 0.0 0.0 13.5 13.5 13.5 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
2
```

Figure 2.48   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 2.49) can be saved if it is selected.


```
MAIN MENU

1._  Simulation parameters;
2._  Data input;
3._
4._  DATA OUTPUT
5._
6._  1._  File name specification;
0._  2._
     3._  SAVE DATA
     4._
     0._  1._  INTERMEDIATE RESULTS
          2._
          0._  1._  Temperatures;
               2._  Rain;
               3._  melt;
               4._  Potential evapotranspiration;
               5._  Outflow;
               6._  Runoff;
               7._  Streamflows;
               0._  Return to previous menu.
```
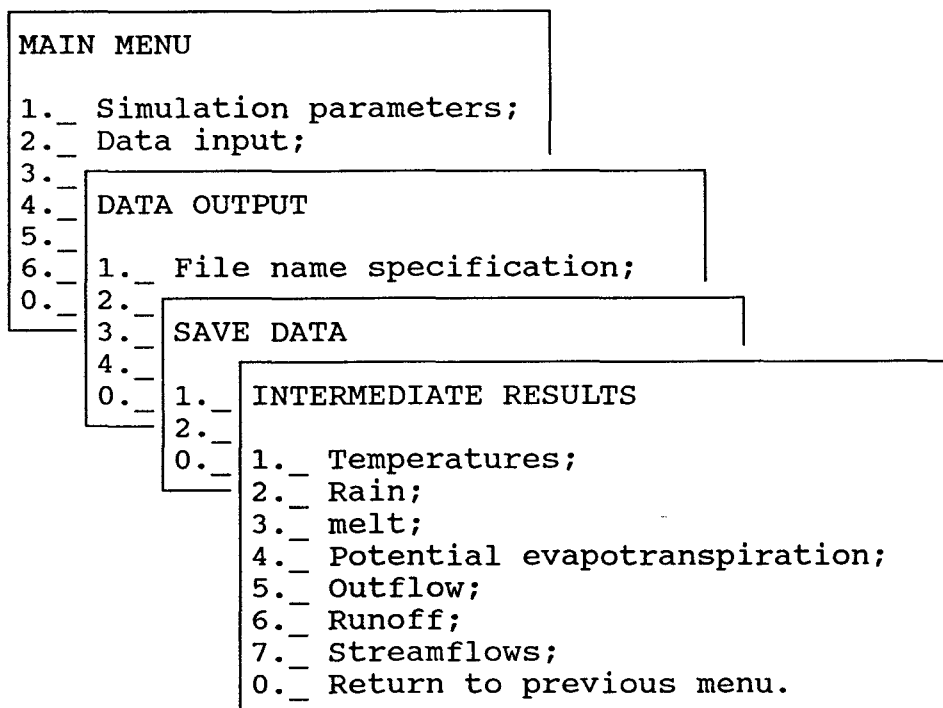
Figure 2.49   Sub-menu #4.3.1:   intermediate results.

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 2.50) can be saved if it is selected.

```
MAIN MENU

1._  Simulation parameters;
2._  Data input;
3._
4._  DATA OUTPUT
5._
6._  1._  File name specification;
0._  2._
     3._  SAVE DATA
     4._
     0._  1._
          2._  FINAL SETTINGS
          0._
               1._  Water budget;
               2._  Runoff;
               3._  Streamflows;
               0._  Return to previous menu.
```
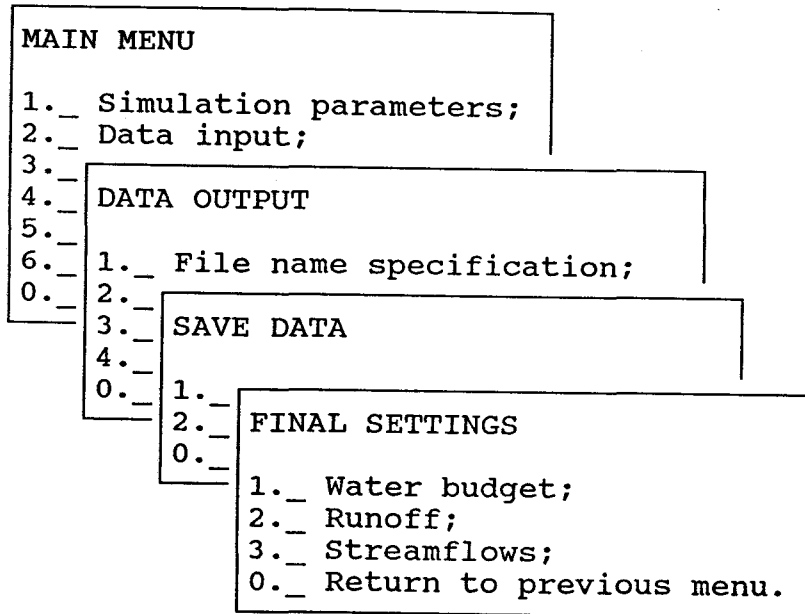
Figure 2.50 Sub-menu #4.3.2: final settings.

2.3.6.4 Sub-menu #4.4: display data

```
MAIN MENU

1._  Simulation parameters;
2._  Data input;
3._
4._  DATA OUTPUT
5._
6._  1._  File name specification;
0._  2._  Data format specification;
     3._
     4._  DISPLAY DATA
     0._
          1._  Watch water budget variables;
          2._  Watch runoff variables;
          3._  Watch channel routing variables;
          4._  Streamflow hydrograph;
          0._  Return to previous menu.
```
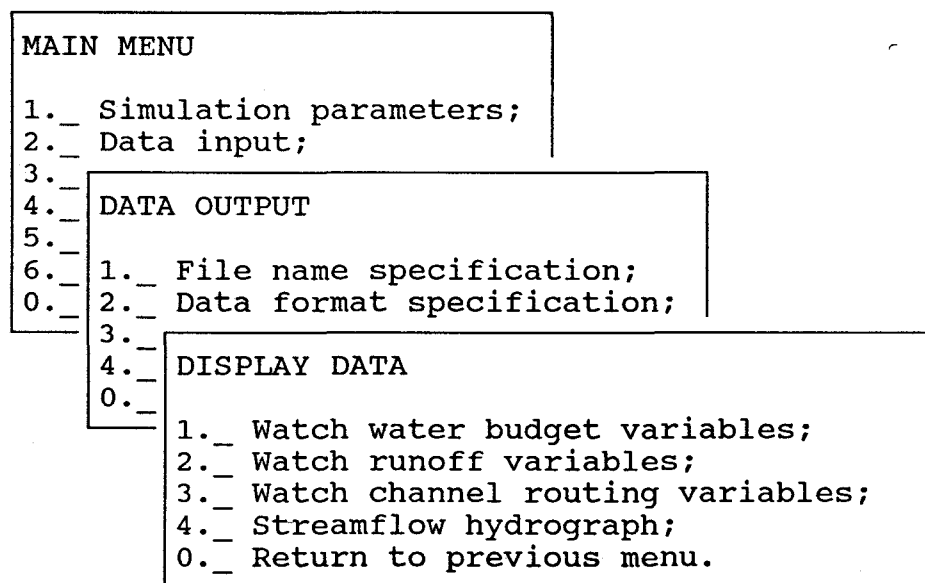
Figure 2.51 Sub-menu #4.4: display data.

Sub-menu 4.4 contains four options (figure 2.51). 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 2.52, 2.53 and 2.54). 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 reservoirs, depending on the option.

Easting:	303000
Northing:	5025000
Altitude:	3.8e+002
Slope:	2.e-002
Aspect:	6
Reach:	-1
Year:	78
Day:	152
Temp:	17
Rain & Melt:	0.
Etp:	3.7
Outflow:	7.17e-004
Runoff:	1.74e-006
F1:Step	F5:Go
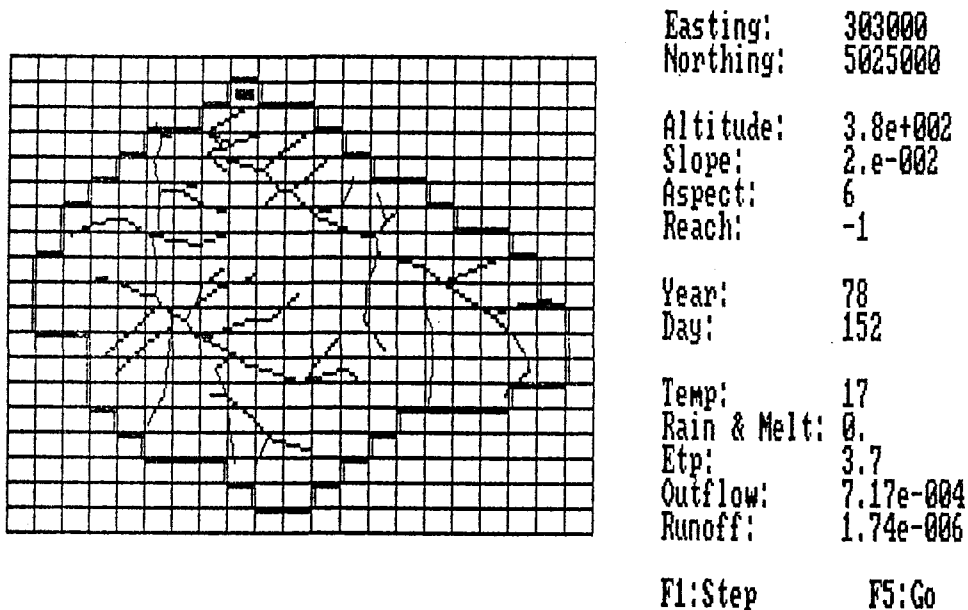
Figure 2.52 Tabular informations on variables related to squares.

Figure 2.53   Tabular informations on variables related to reaches.

Figure 2.54   Tabular informations on variables related to vertical 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.
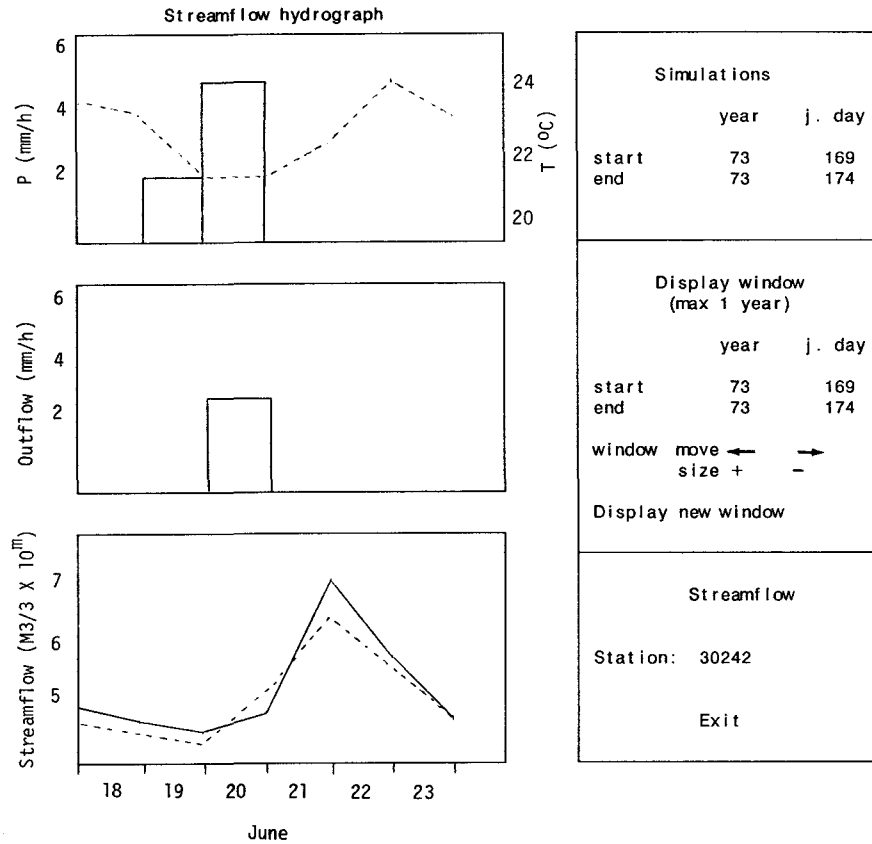
Figure 2.55 Streamflow hydrograph.

As mentionned previously, if option 4 is selected, the simulated hydrograph is displayed automatically at the end of the simulation. The display is divided into four windows (fig. 2.55). 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.

- <u>Direct modification of starting and ending dates in the display window</u>

    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.

- <u>Modification of the position or size of the display window</u>

    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 stramflow station corresponding to the outlet of the basin is displayed in the lower part of the interactive window.

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 a few days after the last rainfall.

In the case of the sub-model used in HYDROTEL 1.1 to simulate the vertical water budget, 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 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:

$$H = \frac{86.4 \; Q_0}{A \cdot C} \tag{2.1}$$

where:

H   = water level in saturated zone reservoir (mm)

Q_0 = measured streamflow (m^3s^{-1})

86.4 = constant (conversion of units)

A   = basin area (km^2)

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.

2.4.2.2 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

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_0.

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

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

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. <u>Do not forget to change back the values of the parameters afterward</u>.

2.5 <u>Integration of user's developed sub-models</u>

HYDROTEL 1.1 has been developed to facilitate integration of user's defined sub-models, both in "C" and "FORTRAN".

However, in order to release HYDROTEL 1.1 at the beginning of August 1989, it was not possible to do the tests we wanted to do for integration of "C" sub-models to HYDROTEL 1.1 by programmers others than the one who wrote most of the version. Integration of "C" written sub-models by another programmer will be undertaken in August, based on the informations given by the main programmer. This should help to write a better guide and save time to users. If users would like to start writing sub-programs, they should call INRS-Eau for more informations.

The same procedure will be used for FORTRAN sub-programs, and a guide should be included with release of HYDROTEL 2.0 in the Fall of 1989.

Finally, it is important to note that the structures of the intermediate files that will have to be used are already given in HYDROTEL 1.1. Intermediate file obtained with sub-models run outside of HYDROTEL 1.1 can already be used, provided they are written in the right format.

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 was not to
appear in the user's manual for HYDROTEL 1.0. However, it was felt by INRS-Eau
that such a description would indeed help the user to understand the model and
make better choices between availables options.

Only main equations and flow charts will be briefly explained here. A more
detailed chapter describing the model will be available starting with HYDROTEL
2.00. 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 1.0. However, simulation of snowpack processes using an energy budget method is planned and will be added in further versions 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 $[T_a - (STRNE + 2) \geq 0]$: all precipitation is considered to be liquid.

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

If $[(STRNE - 2) < T_a < (STRNE + 2)]$: 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°C to 151 kg m^{-3} at T_a = 0°C.

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

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):

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

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.

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 (mm d^{-1} °C^{-1}): melt factors for coniferous forests, deciduous forests and open areas respectively. Effective cover should be taken into account in deciding of a particular value. Use of information coming from remotely sensed data is planned for further versions of the model. The

smallest value should be given to CFR and the greatest to CFD. Actual values will usually range between 2 and 5 mm d^{-1} $°C^{-1}$;

- DSNGX (kg m^{-3}): maximum density of snowpack (usually at the end of the season). A value of DSNGX between approximately 450 to 600 km m^{-3} could be assumed. It is suggested to look at past records for snow 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 (°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

A relation using relatively few input data is first offered. More accurate relations will be added as soon as possible.

3.4.1 Thornthwaite_potential_evapotranspiration

3.4.1.1 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 for more precise equations of the Penman type.

The equation is:

$$E_{th} = \frac{16.2}{30.4} \quad \frac{10\,\overline{T}_a}{X_1}^{X^2} \quad C_1 \tag{3.3}$$

where:

E_{th} = Thornthwaite potential evapotranspiration (mm d^{-1});

$\overline{T}_a$ = 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.

3.4.1.2 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:

$X_1 = \sum_{i=1}^{12} (\frac{\overline{T}_{M_i}}{5})^{1.5}$. The variable $\overline{T}_{M_i}$ 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.

3.5 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 "function" explained below is concerned with the first of these processes, namely the vertical distribution of the incoming water.

The chosen function is essentially that used in the CEQUEAU model, a model previously developed by INRS-Eau (Morin et al., 1981).

3.5.1 CEQUEAU (modified)

3.5.1.1 Description of the function

In the CEQUEAU model 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 H_{sol}, 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 < H_{inf}. The percolation or sub-surface runoff is proportional to the difference between HS and the thresholds H_{int} and H_{inf}, respectively. In the same way, the water level H_n 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 H_n.
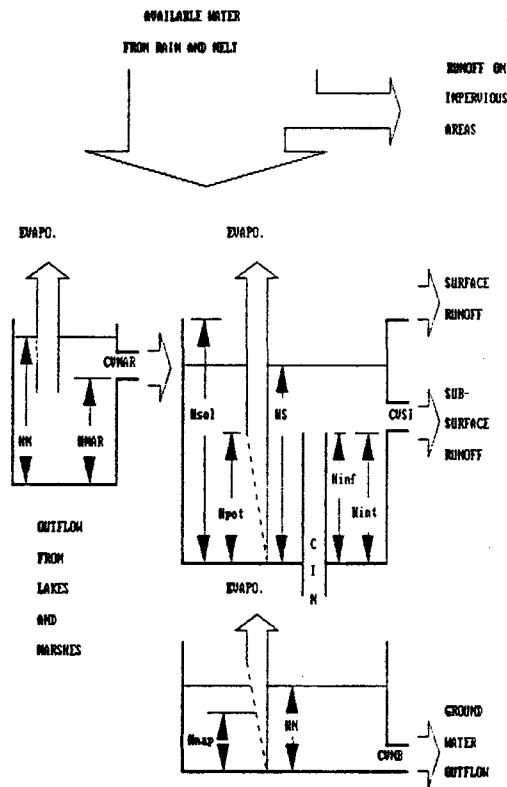
Figure 3.1   Vertical water budget adapted from the CEQUEAU model.

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:

- H_{sol} (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;

- H_{int} (mm): threshold level for sub-surface runoff. This value, as that of H_{inf} and H_{pot} 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 H_{int}, H_{inf} and H_{pot};

- 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;

- H_{inf} (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;

- H_{pot} (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 H_{int}, H_{pot} and H_{inf}, and is close to H_{int} 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.

3.6 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 3.2). 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).
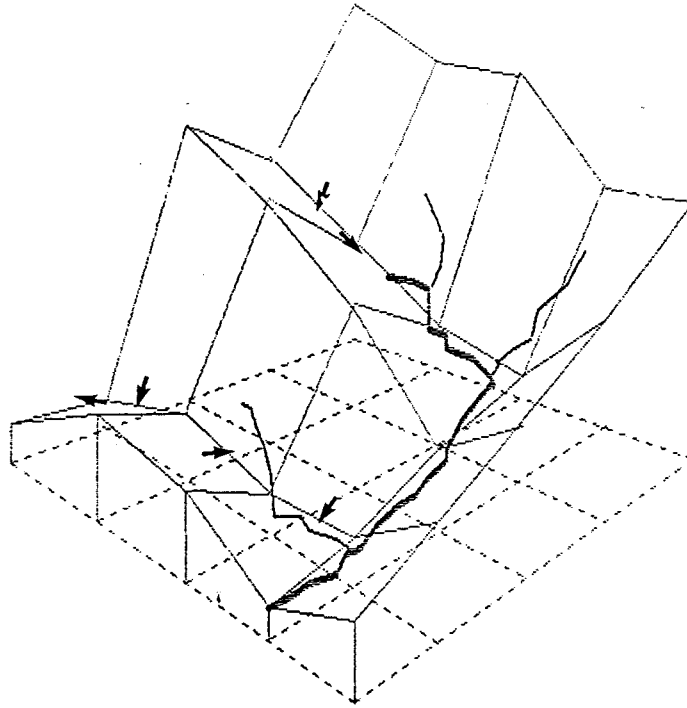
Figure 3.2   Surface and sub-surface runoff and channel flow.

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)
$$\frac{\partial R}{\partial x} + \frac{\partial h}{\partial t} = i \qquad (3.5)$$

(kinematic equation)
$$h = cR^d \qquad (3.6)$$

where:

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

h = flow depth (m);

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

$$C\ =\ (\frac{n}{1.49\ \sqrt{S_o}})^{3/5}\ ;$$

d = coefficient (d = 0.6);

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

S_o = 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 outsite ("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

The set of kinematic wave equations used in the current version 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

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q \tag{3.7}$$

- dynamic equation

$$\frac{\partial h}{\partial x} = S_o - S_f \tag{3.8}$$

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

- cross-section-discharge relationship

$$A = \alpha \, Q^\beta \, S_f^{-\beta/2} \tag{3.9}$$

- depth-discharge relationship

$$h = rQ^s \tag{3.10}$$

where:

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

A = flow cross section (m^2);

q = lateral inflow (m^2 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 . $\alpha^* = (\frac{n}{1.49} B^{2/3})^{0.6}$;

β = coefficient . $\beta^* = 0.6$;

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

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

B = channel width (m).

* For a rectangular cross-section.

3.7.2 Input data

In the current version, 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.

3.8 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). 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 as 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 exists. 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.

It should also be noted that the appropriate values should be given to the variables of the model depending on those classes, albedo, for instance.

REFERENCES

REFERENCES

LECONTE, R. (1984). Modélisation du régime hydrologique d'un grand bassin versant situé en région subartique. 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.