HYDROTEL 2.1
USER'S GUIDE

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PART 1

GENERAL INFORMATION

PART 1 GENERAL INFORMATION

1.1 SOFTWARE MAIN CHARACTERISTICS AND HARDWARE REQUIREMENTS

Name:	HYDROTEL 2.1
Objective:	Simulation of streamflows using ground and remotely sensed data.
Programming language:	"C".
Type of microcomputer:	IBM PC 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 INRS-Eau, Québec, Canada. and Claude Bocquillon and Roger Moussa Laboratoire Hydrologie et Modélisation, Université des Sciences et Techniques du Languedoc, Montpellier, France.

1.2 INTRODUCTION

Considering, as others (Peck <u>et al.</u>, 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. 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 programs instead of one. HYDROTEL is devoted to hydrological simulation. It has been developed so as to accept input data in the proper format from PHYSITEL (topography) and IMATEL (land-use and daily operational data (surface temperature, albedo, ...)).

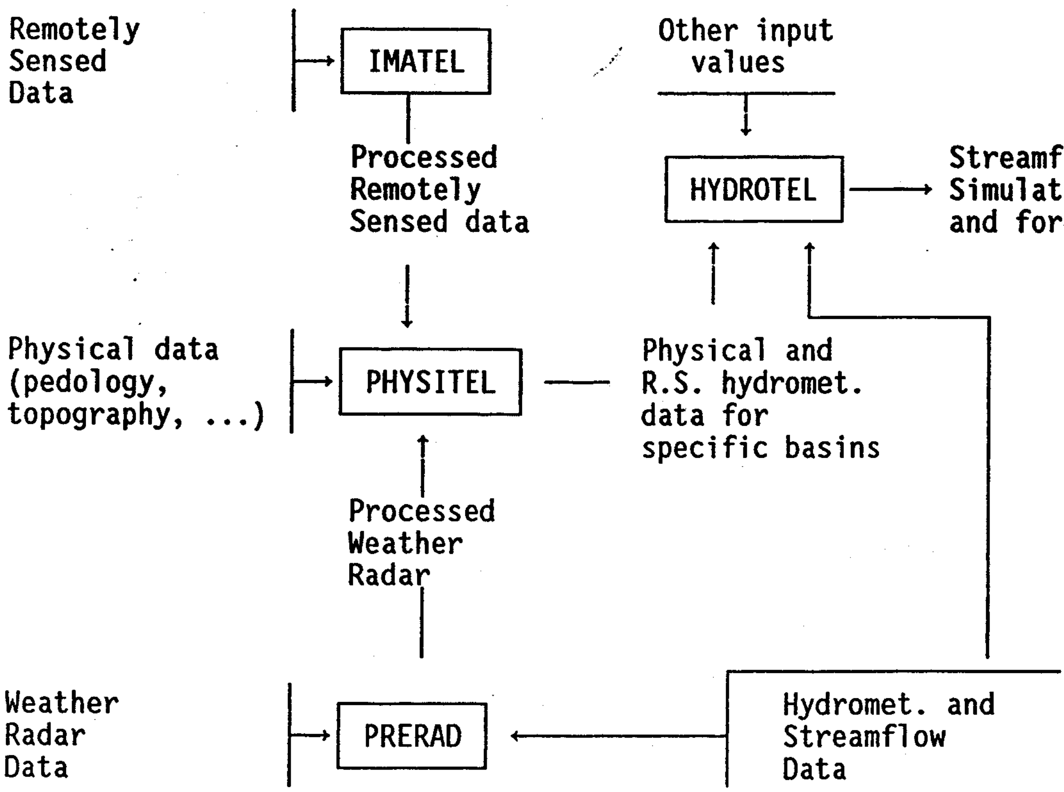

FIGURE 1.1 Integrated analysis of physical, remotely sensed and meteorological data for steamflow simulation and forecasting by PHYSITEL, IMATEL and HYDROTEL.

As seen by INRS-Eau the status of the current HYDROTEL version (V 2.1) is the following:

- HYDROTEL 2.1 structure has been conceived and programmed to answer users needs and facilitate the gradual addition of other options to a fully "à la carte" model, as well as the input and output of G.I.S. and time dependent data;

- HYDROTEL 2.1 runs with either individual grid cells or cells aggregated in "homogeneous hydrological units";

- HYDROTEL 2.1, 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 2.1 is presented with better data displays;

- HYDROTEL 2.1 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;

- HYDROTEL 2.1 allows saving of variables (intermediate or final values) for use as input in later simulations.

1.3 ORGANIZATION OF THE MANUAL

General information on HYDROTEL 2.1 is presented in part "ONE" of the manual.

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 simulation options, and input of data. Information on how to proceed for the calibration of model parameters with the optimization routine is also given.

A description of the main simulation methods available with HYDROTEL 2.1 is finally given in part "THREE", together with hints on how to select values for model parameters. Also a few informations are given for the use of HYDROTEL 2.1 for forecasting purposes. The manual is completed by five appendices on the internal structure of the program, the definition of configuration files, data files, user's defined functions and stand-alone programs.

1.4 SOFTWARE AVAILABILITY AND INFORMATION

The current version (2.1) of HYDROTEL is available only to Environment Canada and CCRS personnel participating in the testing of that version.

Agreements with other agencies is also possible.

For informations, contact:

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Québec (Québec)
G1X 4N8
CANADA
Téléphone: (418) 654-2591
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PART 2

THE HYDROTEL PROGRAM (2.1)

PART 2 THE HYDROTEL PROGRAM (2.1)

2.1 MODEL STRUCTURE

2.1.1 General 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.

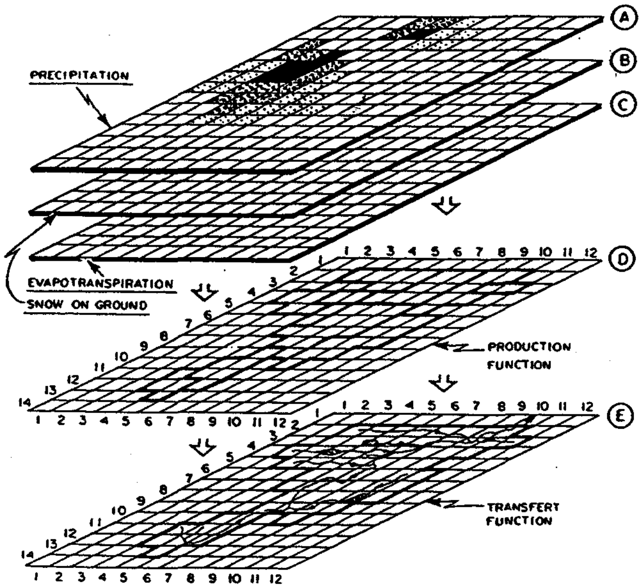


FIGURE 2.1 Spatial structure of the model.

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);

- PRECIPITATION (divided into 2 sub-modules: interpolation of precipitations and snowcover and snowmelt simulation);

- PHYSIOGRAPHY (management and storage of topography and land use data);

- EVAPOTRANSPIRATION (estimation of potential or actual evapotranspiration);

- HYDROLOGY (divided into 3 sub-modules: vertical water budget, surface and subsurface runoff and channel routing);

- OPTIMIZATION (best value for specific parameters);

- OUTPUT (screen display, files saving and retrieving, hard print).

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.

2.1.2 Cells or homogeneous hydrological units

Whether cells or homogeneous hydrological units (HHU's) are used to represent the watershed, the only question to answer is: "Are the spatial and temporal variations of the various processes on the watershed well represented?" This is the main criterium to use, when discretizing a watershed.

Let us start with cells. How many cells? There is no clear answer to that question. That answer is: enough cells to represent the spatial and temporal variations of the various processes on the watershed, as well as of its physical characteristics. It should be understood that a vertical water budget will be estimated on each of those cells, which means that the time taken by a simulation will be a function of the number of cells. More cells means more time! Thus a compromise has to be reached. As a starting value, a hundred (100) cells could be quite enough. The objective should be to get a good representation of a watershed with as few cells as possible.

The following strategy could be used. Prepare a first representation of the watershed using small cells and calibrate the model. Using PHYSITEL, prepare more sets of larger and larger cells, proceed to simulations and notice the changes, if any, in the simulations. This will give you an idea of the number of cells to use for that watershed and similar ones.

HHU's can also be made up from cells. The idea is to work on units that are not necessarily squares, as the cells are, and may represent more closely homogeneous hydrological units, that is sub-watersheds that, when compared to the whole watershed, may be considered relatively homogeneous. It is then possible to use much smaller cells to build up the HHU's. This allows the definition of HHU's of various shapes and sizes, which should be more appropriate to describe the characteristics of the watershed. For instance, if streamflows are needed both at the outlet of a watershed and at some point on the river inside of it, the sub-watershed corresponding to that point could be described by smaller HHU's to respect its internal variability,while larger HHU's could represent the remaining parts of the whole watershed. Also, small HHU's can be used in certain parts of a watershed with larger ones in other parts, depending on the variability of the physical characteristics. Again, try to use as few HHU's as possible to speed up the simulations.

Since, less HHU's should be needed than cells, and routing ofsurface runoff is estimated once and for all at the beginning of the simulation, using HHU's should lead to faster simulations.

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 and required complementary software

HYDROTEL 2.1 is sent on one 1.2 M floppy disk.

Disk #1: Program disk. The content of this disk is in compacted form. Once expanded the content is:

AUTOEXEC. BAT	Example of autoexec.bat file
CONFIG.SYS	Example of config.sys file
HYDROTEL.CFG	Startup parameters
HYDROTEL.ENE	Error data file
HYDROTEL.ENM	Menu data file
HYDROTEL.EXE	The program...
KERNEL.SYS	Graphics sub-system configuration
\EXT	Example of a stand-alone program
\SOURCES	Source code of HYDROTEL
\TEST	Simulation of the Clifton river
\BASINS	Clifton data for 1973

Display and printer drivers as well as GSSCGI.SYS driver controler necessary to run the program with the graphics options can be bougth from:

Graphic Software Systems Inc.
9590 SW Gemini Drive
P.O. Box 4900
Beaverton, OR 97076-4900
U.S.A.
Tel. (503) 641-2200
Fax (503) 643-8642

2.2.2 Installing HYDROTEL 2.1

1. Change to source drive, i.e. the drive that will contain the program disk.

   ex.: a:

2. Type: install drive: path

   where:

   "drive" is the target disk;
   "path" is the full path name of the target directory.

   ex.: install c: \hydrotel

3. Update the file "autoexec.bat". You must add the line:

   SET KERNEL=C:\path
   SET HYDROTEL=C:\datapath

   where:

"path" is the full name of the directory containing HYDROTEL
and
"datapath" is the full name of the directory containing data.

ex.: SET KERNELL=C:\HYDROTEL
SET HYDROTEL=C:\HYDROTEL\BASINS\

4. Update the file "config.sys". You must add the line:

DEVICE=drive:\driverpath\name.SYS
DEVICE=drive:\driverpath\GSSCGI.SYS [/T]

where:

"drive" is the drive where we can find the graphic drivers and
"driverpath" is the path to the graphic drivers.

You must add one device driver by type of device you plan to use with HYDROTEL. Specify a printer driver only if you want a hardcopy of graphics displayed. That driver is not necessary for the normal use of hydrotel.

ex.: DEVICE=C:\DRIVERS\HRVGA.SYS
DEVICE=C:\DRIVERS\LASERJET.SYS
DEVICE=C:\DRIVERS\GSSCGI.SYS

The optional parameter [/T] permits to load only the essential parts of the graphic sub-system at boot time, leaving more space to run other programs. If that option is specified the full graphic sub-system must be loaded. Before using HYDROTEL, run the program DRIVERS.EXE. To unload the graphic sub-system run the same program with the option /R. The program DRIVERS.EXE must be accessible, i.e. in the current directory or one specified in the PATH variable.

5. Reboot the computer.

2.2.3 Test data and structure of data files

In order to familiarize the user with HYDROTEL 2.1, a data set is included with the program. It should be looked at as an example, for the preparation of other data sets. A set of intermediate result files is also provided to test the program.

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.

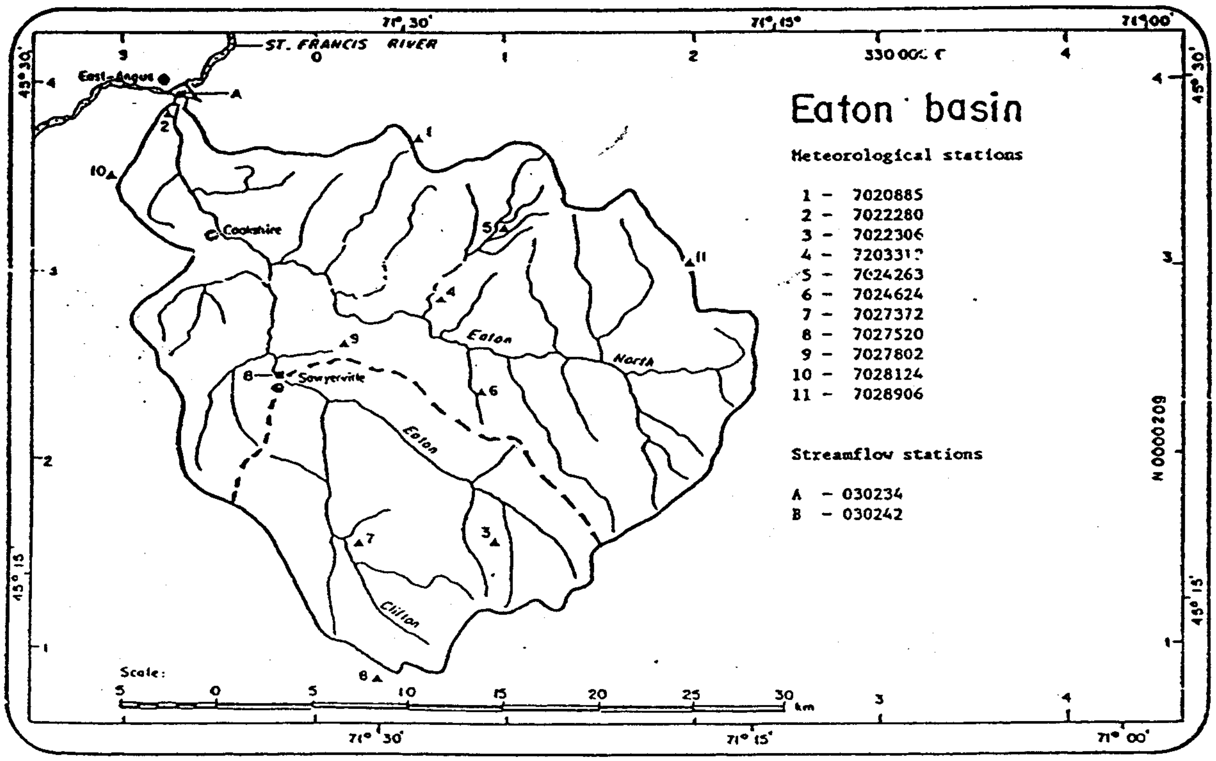


FIGURE 2.2 Streamflow and climatological stations on the Eaton basin.

TEST DATA:

File names and content:

Clifton.CFG	Current setting of HYDROTEL parameters
Clifton.DEB	Results, daily streamflow
Clifton.ETP	Results, potential or real evapotranspiration
Clifton.FON	Results, snowmelt
Clifton.NEI	Results, daily snowfall
Clifton.PLU	Results, daily rainfall
Clifton.PRO	Results, daily water budget outflow
Clifton.RUI	Results, daily runoff on each square
Clifton.TPN	Results, minimum daily temperature
Clifton.TPX	Results, maximum daily temperature

TOPOGRAPHIC DATA:

File names and content:

Clifton.ALT	Mean altitude of each cell (m)
Clifton.ORI	aspect of each cell to eight points of the compass, identified 1 to 8 counterclockwise from East (=1)
Clifton.PTE	Slope of each cell (m/m)
Clifton.MSK	Basin mask (for simulations using cells)
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)
Clifton.ZON	Identification of the homogeneous hydrological unit (HHU) to which each particular cell is belonging
Clifton.REL	Identification, for each cell of a particular HHU (defined by *.ZON), of the downstream HHU.

LAND-USE DATA:

File names and content:

Clifton.CLA	Spatial distribution of land-use classes
Albedo.YY	Albedo values of each land-use class as a function of time for year "YY"
Hau_veg.YY	Height of each land-use class as a function of time, for year "YY"
Pro_rac.YY	Depth reached by the root system, of each land-use class, as a function of time, for year "YY"
Inf_fol.YY	Leaf-area index of each land-use class, as a function time, for year "YY"

SOIL DATA:

File names and content:

Clifton.SOL	Hydraulic characteristics of soil types
Clifton.TSO	Spatial distribution of soil types in the watershed

STREAMFLOW AND METEOROLOGICAL DATA:

File names and content:

Clifton.STM	List of meteorological stations
Clifton.STH	List of streamflow stations
M7020885.73	Meteorological data, Bury, 1973
M7020885.74	Meteorological data, Bury, 1974
M7022280.73	Meteorological data, East-Angus, 1973
M7022280.74	Meteorological data, East-Angus, 1974
M7022306.73	Meteorological data, Eaton 2nd Branch, 1973

M7022306.74	Meteorological data, Eaton 2nd Branch, 1974
M7023312.73	Meteorological data, Island Brook, 1973
M7023312.74	Meteorological data, Island Brook, 1974
M7024263.73	Meteorological data, Lawrence, 1973
M7024263.74	Meteorological data, Lawrence, 1974
M7024624.73	Meteorological data, Maple Leaf East, 1973
M7024624.74	Meteorological data, Maple Leaf East, 1974
M7027372.73	Meteorological data, St-Isidore d'Auckland, 1973
M7027372.74	Meteorological data, St-Isidore d'Auckland, 1974
M7027520.73	Meteorological data, St-Malo d'Auckland, 1973
M7027520.74	Meteorological data, St-Malo d'Auckland, 1974
M7027802.73	Meteorological data, Sawyerville Nord, 1973
M7027802.74	Meteorological data, Sawyerville Nord, 1974
M7028124.73	Meteorological data, Sherbrooke A, 1973
M7028124.74	Meteorological data, Sherbrooke A, 1974
M7028906.73	Meteorological data, West Ditton, 1973
M7028906.74	Meteorological data, West Ditton, 1974
H0030242.73	Streamflow data at streamgauge station 030242 for 1973
H0030242.74	Streamflow data at streamgauge station 030242 for 1974

2.3 USING HYDROTEL (2.1)

2.3.1 Starting HYDROTEL 2.1

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 quitting HYDROTEL 2.1 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 easily through all steps in the initialization process.

2.3.2 HYDROTEL main menu

The main menu contains 8 options (figure 2.3). To choose an option, first go to that option using the arrows on the keyboard. Then, press 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 "Quit HYDROTEL" 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.

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._ Data input;
4._ Sub-models;
5._ Data output;
6._ Run;
7._ DOS shell;
0._ Quit HYDROTEL.
```

FIGURE 2.3 HYDROTEL main menu.

2.3.3 Sub-menu #1.0: simulation parameters

Sub-menu #1.0 (figure 2.4) leads to three complementary sub-menus in which simulation parameters are defined. You can return to the previous (main) menu (by selecting option "0" followed by the "ENTER" key).

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

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):

```
HYDROTEL
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
7._
0._ Qu  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 leave the initialization process by pushing "ESC". The paths and basin name appearing on the screen remains in effect. No change is made to the previously stored name.

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

2.3.3.2 Sub-menu #1.2: temporal parameters

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

- start of simulation (YY MM DD): year (last two digits), month and day of the first day of the simulation;

- end of simulation (YY MM DD): year (last two digits), month and day of the last day of the simulation;

- time step (hours): 1, 2, 3, 4, 6, 8, 12, 24.

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".

Note that the correspondance between calendar days and julian days is presented in table 1. This should be helpful when looking at intermediate data files, for instance.

```
HYDROTEL
1._ SIMULATION PARAMETERS
2._
3._ 1._ Path to files;
4._ 2.  TEMPORAL PARAMETERS
5._ 3.
6._ 0.  Start of simulation (YY-MM-DD)... 73 12 29
7._     End of simulation (YY-MM-DD)..... 73 12 30
0._ Qu  Time step (hours)................ 1

        F10:Accept                         Esc:Quit
```

FIGURE 2.6 Sub-menu #1.2: temporal parameters.

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;

- 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;

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.

- stream outlet: press any key to get a display of the river reaches. The point (lower end of a reach) at which streamflows are needed can be selected with the cursor.

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

```
HYDROTEL
1._ SIMULATION PARAMETERS
2._
3._ 1._ Path to files;
4._ 2._ Temporal parameters;
5._ 3.  SPATIAL PARAMETERS
6._ 0.
7._      UTM zone.................... 19
0._ Qu   Upper left corner (UTM).... 295000    5026000
         Lower right corner (UTM)... 316000    5007000
         Resolution (m)............. 1000
         Stream outlet.

         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 "HYDROTEL main menu".

2.3.4 Sub-menu #2.0: optimization parameters

Sub-menu #2.0 (figure 2.8) allows the user to switch ON the optimization and determine the characteristics of the process.

- optimization: when OFF, the optimization will not be performed, when ON, the optimization will take place. Press the "SPACE BAR" to toggle between ON and OFF;

- max. number of iteration: maximum number of iteration after which the iteration process will stop even if the tolerance threshold has not been reached;

- tolerance threshold (variable): difference between two successive estimations of the value taken by a variable under which the process will go to another variable;

- tolerance threshold (Powell): difference between the evaluation of the objective function in two successive Powell iterations under which the optimization will stop.

```
HYDROTEL

1._ Simulation parameters;
2. OPTIMIZATION PARAMETERS
3.
4.  Optimization........................ OFF
5.  Max. number of iteration............ 50
6.  Tolerance threshold (variable)...... 1.e-002
7.  Tolerance threshold (Powell)........ 1.e-002
0.
    F10:Accept                          Esc:Quit
```

FIGURE 2.8 Sub-menu #2.0: optimization parameters.

2.3.5 Sub-menu #3.0: data input

Sub-menu #3.0 (figure 2.9) leads the user to sub-menus in which he will be able to provide the informations on input data needed for the simulation.

```
HYDROTEL

1._ Simulation parameters;
2._┌──────────────────────────────┐
3._│DATA INPUT                    │
4._│                              │
5._│1._ File specification;       │
6._│2._ Read data;                │
7._│3._ Display data;             │
0._│0._ Return to previous menu.  │
   └──────────────────────────────┘
```

FIGURE 2.9 Sub-menu #3.0: data input.

2.3.5.1 Sub-menu #3.1: file name specification

Sub-menu #3.1 leads to three sub-menus in which the necessary file informations can be given for meteorological and streamflow data, basin data, initial settings and intermediate data.

```
HYDROTEL

1._ Simulation parameters;
2._┌──────────────────────────────┐
3._│DATA INPUT                    │
4._│   ┌──────────────────────────────┐
5._│1._│FILE SPECIFICATION            │
6._│2._│                              │
7._│3._│1._ Meteo & hydro data;       │
0._│0._│2._ Basin data;               │
       │3._ Initial settings;         │
       │4._ Intermediate data;        │
       │0._ Return to previous menu.  │
       └──────────────────────────────┘
```

FIGURE 2.10 Sub-menu #3.1: file name specification.

2.3.5.1.1 *Sub-menu #3.1.1: meteo and hydro data*

For each needed meteorological or streamflow variable, select the proper format. Remember that formats cannot be mixed. All formats used in a simulation have to be INRS or ENVCAN or USER'S.

```
HYDROTEL

1._ Simulation parameters;
2._
3._ DATA INPUT
4._
5._ 1._ FILE SPECIFICATION
6._ 2._
7._ 3._ 1. METEO & HYDRO DATA
0._ 0._ 2.
        3.  Meteo data......... INRS
        4.  Windspeed data..... ENVCAN
        0.  Rel. humidity data. ENVCAN
            Sunshine data...... ENVCAN
            Global solar rad... ENVCAN
            Streamflow data.... INRS

           F10:Accept          Esc:Quit
```

FIGURE 2.11 Sub-menu #3.1.1: meteo and hydro data.

2.3.5.1.2 *Sub-menu #3.1.2: basin data*

Appropriate file names corresponding to all types of basin data listed in sub-menu #3.1.2 (figure 2.12), together with the proper format, should appear in that window. Unless modifications are made in the source program, only INRS formats described in Appendix C should be used.

```
HYDROTEL

1._ Simulation parameters;
2._
3._ DATA INPUT
4._
5._ 1._ FILE SPECIFICATION
6._ 2._
7._ 3._ 1._ Meteo & hydro data;
0._ 0._ 2.  BASIN DATA
        3.
        4.  Meteo station id......... clifton.stm       INRS
        0.  Streamflows station id... clifton.sth       INRS
            Zones.................... clifton.msk       INRS
            Zones connection......... clifton.rel       INRS
            Altitude................. clifton.alt       INRS
            Aspect of squares........ clifton.orl       INRS
            Slope.................... clifton.pte       INRS
            Land-use classes......... clifton.cla       INRS
            Reach ends............... clifton.ndl       INRS
            Reaches.................. clifton.trl       INRS

            F10:Accept                               Esc:Quit
```

FIGURE 2.12 Sub-menu #3.1.2: basin data.

2.3.5.1.3 *Sub-menu #3.1.3: initial settings*

Initial values can be given to variables representing the hydrological state of the basin at the beginning of the simulation. File names and proper formats 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-menus #4.4.1.5 and #4.4.2.2. Informations on how to determine these initial values are given in the section on "initialization of state variables" at the end of Part 2. See also Appendix C for structure and content of data files. Unless modifications are made in the source program, only INRS formats should be used.

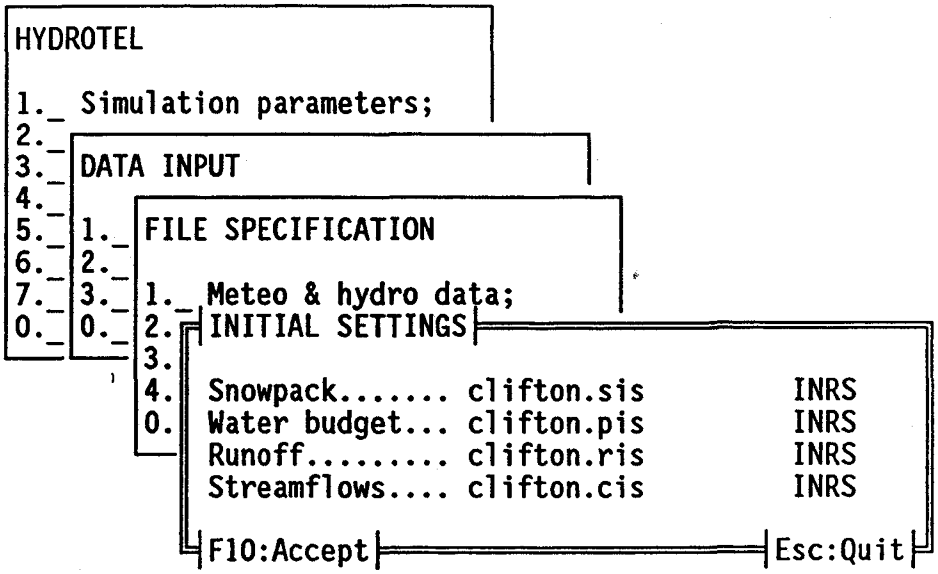


FIGURE 2.13 Sub-menu #3.1.3: initial settings.

2.3.5.1.4 *Sub-menu #3.1.4: intermediate data*

Names and proper formats of the files containing intermediate data are given here (figure 2.13). See Appendix C for structure and content of data files. Unless modifications are made in the source program, only INRS formats should be used.

```
HYDROTEL

1._ Simulation parameters;
2._
3._ DATA INPUT
4._
5._ 1._ FILE SPECIFICATION
6._ 2._
7._ 3._ 1._ Meteo & hydro data;
0._ 0._ 2._ Basin data;
        3._ Initial settings;
        4.  INTERMEDIATE DATA
        0.
            Max temp....... clifton.tpx        INRS
            Min temp....... clifton.tpn        INRS
            Rain........... clifton.plu        INRS
            Snow........... clifton.nei        INRS
            Melt........... clifton.fon        INRS
            Evapo.......... clifton.evp        INRS
            Outflow........ clifton.pro        INRS
            Runoff......... clifton.rui        INRS
            Streamflows.... clifton.deb        INRS

            F10:Accept                         Esc:Quit
```

FIGURE 2.14 Sub-menu #3.1.4: intermediate data.

2.3.5.2 Sub-menu #3.2: read data

With HYDROTEL 2.1, sub-menu #3.2 (figure 2.15) is optional. Basin data will be read automatically, but not initial settings of the state variables.

```
HYDROTEL

1._ Simulation parameters;
2._
3._ DATA INPUT
4._
5._ 1._ File name specification;
6._ 2._
7._ 3._ READ DATA
0._ 4._
    0._ 1._ Basin data;
        2._ Initial settings;
        0._ Return to previous menu.
```

FIGURE 2.15 Sub-menu #3.2: read data.

2.3.5.2.1 *Sub-menu #3.2.1: basin data*

With HYDROTEL 2.1, sub-menu #3.2.1 (figure 2.16) is optional. Data will be read automatically.

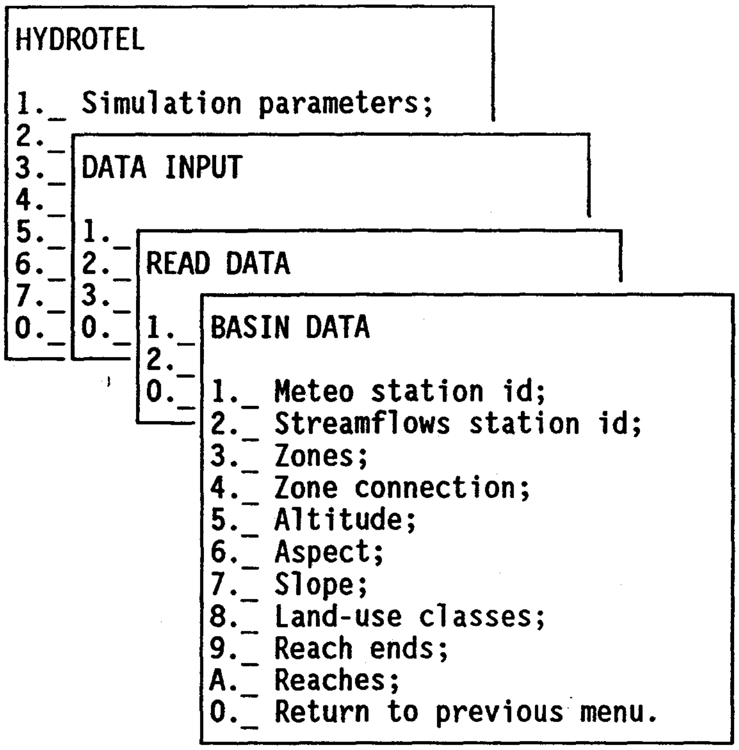


FIGURE 2.16 Sub-menu #3.2.1: basin data.

2.3.5.2.2 *Sub-menu #3.2.2: initial settings*

With HYDROTEL 2.1, sub-menu #3.2.2 (figure 2.17) 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, streamflow and snowpack values will default to zero and water budget variables will have to be read at sub-menu #4.4.1.5 or #4.4.2.2.

```
HYDROTEL

1._ Simulation parameters;
2._
3._ DATA INPUT
4._
5._ 1._
6._ 2._ READ DATA
7._ 3._
0._ 0._ 1._
        2._ INITIAL SETTINGS
        0._
            1._ Snowpack;
            2._ Water budget;
            3._ Runoff;
            4._ Streamflows;
            0._ Return to previous menu.
```

FIGURE 2.17 Sub-menu #3.2.2: initial settings.

2.3.5.3 Sub-menu #3.3: display data

If one wants to have a visual representation of files containing basin data, he can select options 1 to 6 in sub-menu #3.4 (figure 2.18). The selected variable will be displayed on the screen, together with an appropriate legend. If option 7 is selected sub-menu #3.3.1 will appear.

```
HYDROTEL

1._ Simulation parameters;
2._
3._
4._
5._
6._
7._
0._
```

```
DATA INPUT

1._ File name specification;
2._ Data format specification;
3._
4._
0._
```

```
DISPLAY DATA

1._ Basin mask;
2._ Altitude;
3._ Aspect;
4._ Slope;
5._ Reach ends;
6._ Reaches;
7._ Streamflows, temp. & prec.
0._ Return to previous menu.
```

FIGURE 2.18 Sub-menu #3.3: display data.

2.3.5.3.1 *Sub-menu #3.3.1: streamflows, temp. & prec.*

With this menu the user can select a simulation period by diplaying the observed streamflows, temperatures and precipitations for a given year. The user selects the year he wants to look at by entering the last two digits of that year. The user can also select specific hydrological or meteorological stations among those available by pressing the "Space" bar, once on the related field.

See figure 2.85 and related description for more details on how to use the interactive vertical window when the meteorological and streamflow data are displayed.

```
HYDROTEL

1._ Simulation parameters;
2._
3._ DATA INPUT
4._
5._ 1._ File name specification;
6._ 2._ Data format specification;
7._ 3._
0._ 4._ DISPLAY DATA
    0._
        1._ Basin mask;
        2._ Altitude;
        3._ Aspect;
        4._ Slope;
        5._ Reach ends;
        6._ Reaches;
        7._ STREAMFLOW, TEMP & PREC
        0.
            Year......................... 73
            Hydrological station no....... 0030242
            Meteorological station no..... 7020885

            F10:Display                    Esc:Quit
```

FIGURE 2.19 Sub-menu #3.3.1: streamflows, temp. & prec..

2.3.6 Sub-menu #4.0: sub-models

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._
4._ SUB-MODELS
5._
6._ 1._ Interpolation of precipitations;
7._ 2._ Snowmelt;
0._ 3._ Evapotranspiration;
    4._ Vertical water budget;
    5._ Surface and sub-surface runoff;
    6._ Channel routing;
    0._ Return to previous menu.
```

FIGURE 2.20 Sub-menu #4.0: sub-models.

All options (figure 2.20) can be selected by moving to each of those options and pressing "ENTER". After typing all necessary data, in the sub-menus corresponding to those options return to the "main menu" by selecting option "0" and pressing "ENTER". It is possible to "by pass" any of the submodels. In HYDROTEL 2.1, intermediate data corresponding to the output from that sub-model has then to be read.

The first five options applies to cells or HHU's, while channel routing is applied for the river network build up by the reaches.

2.3.6.1 Sub-menu #4.1: interpolation of precipitation

See section 3.2 for more informations.

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._
4._ SUB-MODELS
5._
6._ 1._ INTERPOLATION OF PRECIPITATIONS
7._ 2._
0._ 3._ 1._ Bypass;
    4._ 2._ Read meteo data from disk;
    5._ 3._ Thiessen polygons;
    6._ 4._ Weighted mean of nearest three stations;
    0._ 5._ User's defined interpolation;
        6._ Stand alone program;
        0._ Return to previous menu.
```

FIGURE 2.21 Sub-menu #4.1: interpolation of precipitation.

Six options are available for the interpolation of precipitations (figure 2.21). Select one of those and press "ENTER". After typing the input values, return to "sub-menu #4.0" by selecting option "0" and pressing "ENTER".

Option 1 is chosen if no output is required from the sub-model in a particular run.

Option 2 allows the user to read 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 #3.1.4 (intermediate data) to be used by the next sub-models. Two well known interpolation methods are provided as options 3 and 4. It will be also possible for the user to write its own interpolation submodel (options 5 and 6), following the instructions given in Appendix D or E.

2.3.6.1.1 *Sub-menu #4.1.1: Thiessen polygons (figure 2.26)*

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._
4._ SUB-MODELS
5._
6._ 1._ INTERPOLATION OF PRECIPITATIONS
7._ 2._
0._ 3._ 1._ Bypass, read data from disk;
    4._ 2.  THIESSEN POLYGONS
    5._ 3.
    6._ 4.  Precipitation vert. grad. (%/100m)... 0.
    0._ 5.  Temperature lapse rate (C/100m)...... 0.
        0.
            F10:Accept                    Esc:Quit
```

FIGURE 2.22 Sub-menu #4.1.1: Thiessen polygons.

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

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

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

2.3.6.1.2 *Sub-menu #4.1.2: weighted mean of nearest three stations*

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._
4._ SUB-MODELS
5._
6._ 1._ INTERPOLATION OF PRECIPITATIONS
7._ 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 2.23 Sub-menu #4.1.2: weighted mean of nearest three stations.

As seen in figure 2.23, this sub-menu is similar to 4.1.1. The information given in 2.3.6.1.1 applies.

2.3.6.2 Sub-menu #4.2: snowmelt

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._
4._ SUB-MODELS
5._
6._ 1._
7._ 2._ SNOWMELT
0._ 3._
    4._ 1._ Bypass;
    5._ 2._ Read snowmelt data from disk; «
    6._ 3._ Modified degree/day method;
    0._ 4._ User's defined snowmelt;
        5._ Stand alone program;
        0._ Return to previous menu.
```

FIGURE 2.24 Sub-menu #4.2: snowmelt.

Five options are currently available for snowcover simulation and melting (figure 2.24). Select one and press "ENTER".

Option is chosen if no output is required from the sub-model in a particular run.

Option 2 allows the user to read melt water matrices obtained from a previous run or elsewhere. For instance, melt values derived from passive microwave data could be read here. Values are read from the file specified in sub-menu #3.1.4 (intermediate data) to be used by the next sub-models. A modified degree-day method is provided as option 3. It will be also possible for the user to write its own snowmelt subprograms (options 4 and 5), following the instructions given in Appendix D or E.

2.3.6.2.1 *Sub-menu #4.2.1: modified degree-day method (figure 2.29)*

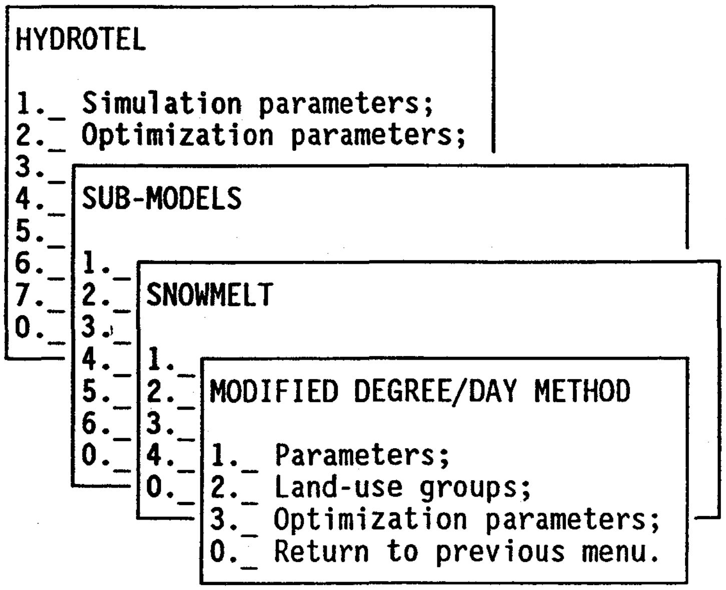


FIGURE 2.25 Sub-menu #4.2.1: modified degree-day method.

Sub-menu #4.2.1 (figure 2.25) is essentially an intermediate menu. Option 1 "parameters", gives access to the menu in which values of the parameters of the snowmelt sub-model are determined. Option 2, "land-use groups", allows integration of original land-use groups to suit the sub-model. Option 3, "optimization parameters" gives access to the menu in which the value of the optimization parameter related to the modified degree-day method can be initialized.

2.3.6.2.1.1 Sub-menu #4.2.1.1: parameters (figure 2.30)

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._ SUB-MODELS
4._
5._
6._ 1._ SNOWMELT
7._ 2._
0._ 3._
    4._ 1._ MODIFIED DEGREE/DAY METHOD
    5._ 2._   PARAMETERS
    6._ 3._
    0._ 4._ 1.
        0._ 2. Temp. for transf. of rain into snow (°C).... 0.
            3. Melt factor (coniferous forest) (mm/d°C).... 2.
            0. 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 (kg/m3)......... 550
               Settlement constant......................... 0.1

               F10:Accept                          Esc:Quit
```

FIGURE 2.26 Sub-menu #4.2.1.1: parameters.

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) of the snowpack.

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).

2.3.6.2.1.2 Sub-menu #4.2.1.2: land-use groups

Land-use groups corresponding to the types of land-uses needed in the snowmelt sub-model are defined in sub-menu #4.2.1.2 (figure 2.27). Three land-use groups are considered for snowmelt, namely: coniferous forest, deciduous or broad-leaved forest and open areas.

```
HYDROTEL

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

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

RESIN


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

FEUIL
```

FIGURE 2.27 Sub-menu #4.2.1.2: land-use groups.

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

2.3.6.2.1.3 Sub-menu #4.2.1.3: optimization parameters

In sub-menu #4.2.1.3 "optimization parameters" (figure 2.28) the user can set initial values and limits for the parameters to vary within. When the field "state" is ON the optimization process will consider this variable. If "state" is OFF, the variable will be ignored. The other three fields "minimum", "initial" and "maximum" are related to a coefficient multiplying the melt factors (sub-menu #4.2.1.1). "initial" is the initial value of the coefficient, "minimum" is the lower limit on the coefficient and "maximum" is the upper limit on the same coefficient.

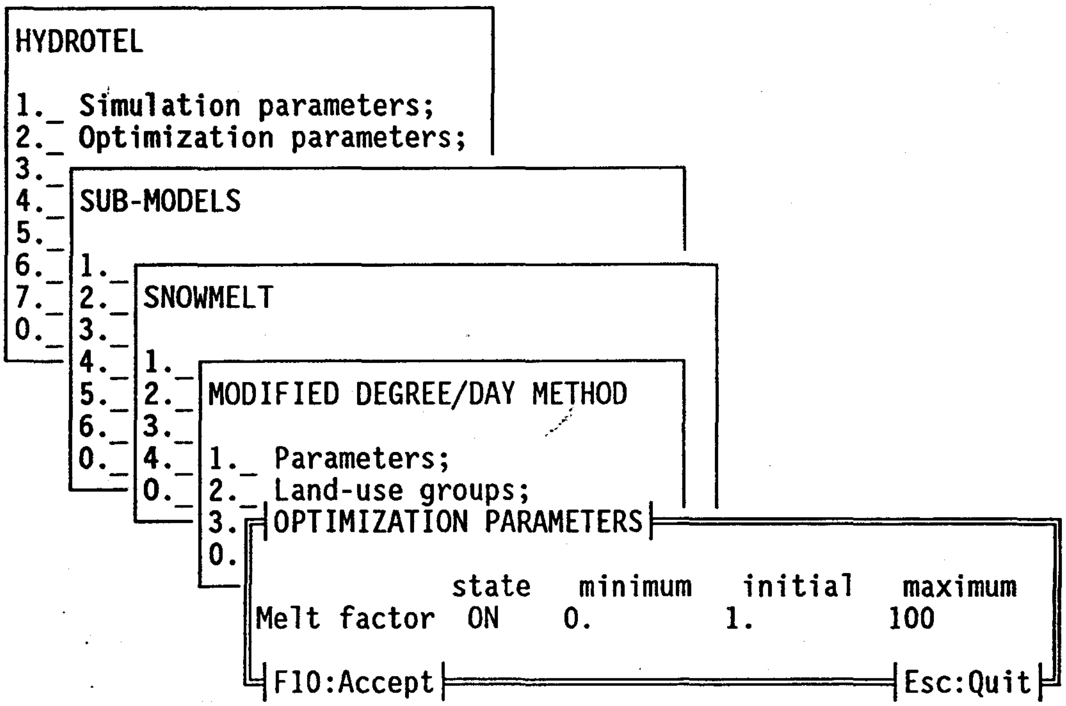


FIGURE 2.28 Sub-menu #4.2.1.3: optimization parameters.

2.3.6.3 Sub-menu #4.3: evapotranspiration

In HYDROTEL 2.1, the user is allowed to choose between formulae for the determination of potential or actual evapotranspiration (figure 2.29). A few options are offered so as to make use of available data. Select option 1 or 2 to have access to the sub-menus containing the options. Note that potential or actual evapotranspiration data will be saved in intermediate data files depending on the option chosen here.

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._
4._ SUB-MODELS
5._
6._ 1._ Interpolation of precipitations;
7._ 2._
0._ 3._ EVAPOTRANSPIRATION
    4._
    5._ 1._ Potential evapotranspiration;
    6._ 2._ Actual evapotranspiration;
    0._ 0._ Return to previous menu.
```

FIGURE 2.29 Sub-menu #4.3: evapotranspiration.

2.3.6.3.1 *Sub-menu #4.3.1: potential evapotranspiration*

Seven options are currently available for the estimation of potential evapotranspiration (figure 2.30). Select one and press "ENTER".

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._
4._ SUB-MODELS
5._
6._ 1._ Interpolation of precipitations;
7._ 2._
0._ 3._ EVAPOTRANSPIRATION
    4._
    5._ 1._ POTENTIAL EVAPOTRANSPIRATION
    6._ 2._
    0._ 0._ 1._ Bypass;
            2._ Read PET data from disk;
            3._ THORNTHWAITE;
            4._ LINACRE;
            5._ PENMAN;
            6._ PRIESTLEY-TAYLOR;
            7._ User's defined;
            8._ Stand alone program;
            0._ Return to previous menu.
```

FIGURE 2.30 Sub-menu #4.3.1: potential evapotranspiration.

Option 1 is chosen if no output is required from the sub-model in a particular run.

Option 2 allows the user to read PET matrices obtained from a previous run or elsewhere. Values are read from the file specified in sub-menu #3.1.4 (intermediate data) to be used by the next sub-models.

Options 3 to 6 are suggested to the user, to choose from, depending on available data at the meteorological stations listed in file *.STM. The Penman equation should be the most accurate, but requires more informations than the other ones.

Two more user's defined options are available (options 7 and 8), if equations other than those offered are preferred. Instructions on how to write those are given in Appendix D or E.

2.3.6.3.1.1 Sub-menu #4.3.1.1: Thorthwaite PE (figure 2.31)

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._
4._ SUB-MODELS
5._
6._ 1._ Interpolation of precipitations;
7._ 2._
0._ 3._ EVAPOTRANSPIRATION
    4._
    5._ 1._ POTENTIAL EVAPOTRANSPIRATION
    6._ 2._
    0._ 0._ 1._
            2._ THORNTHWAITE P.E.
            3._
            4._ 1._ Simulation parameters;
            5._ 2._ Optimization parameters;
            6._ 0._ Return to previous menu.
            7._
            0._ Return to previous menu.
```

FIGURE 2.31 Sub-menu #4.3.1.1: Thorthwaite PE.

Option 1 leads to a sub-menu where simulation parameters concerning Thornthwaite potential evapotranspiration can be set. Option 2 allows the user to set optimization parameters.

2.3.6.3.1.1.1 Sub-menu #4.3.1.1.1: simulation parameters (figure 2.32)

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._
4._ SUB-MODELS
5._
6._ 1._ Interpolation of precipitations;
7._ 2._
0._ 3._ EVAPOTRANSPIRATION
    4._
    5._ 1._ POTENTIAL EVAPOTRANSPIRATION
    6._ 2._
    0._ 0._ 1._
            2._ THORNTHWAITE P.E.
            3._
            4._ 1.  SIMULATION PARAMETERS
            5._ 2.
            6._ 0.  Thornthwaite thermal index............. 30.
            7._     Mean latitude of the basin (degrees)... 45.25
            0._ Re  Temporal shift parameter............... 80

                    F10:Accept                              Esc:Quit
```

FIGURE 2.32 Sub-menu #4.3.1.1.1: simulation parameters.

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

- Thorthwaite thermal index: type Thorthwaite thermal index value;

- mean latitude of the basin (degrees): type mean latitude of the basin, in degrees and hundredths of a degree;

- temporal shift parameter: type temporal shift parameter in days.

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

2.3.6.3.1.1.2 Sub-menu #4.3.1.1.2: optimization parameters (figure 2.33)

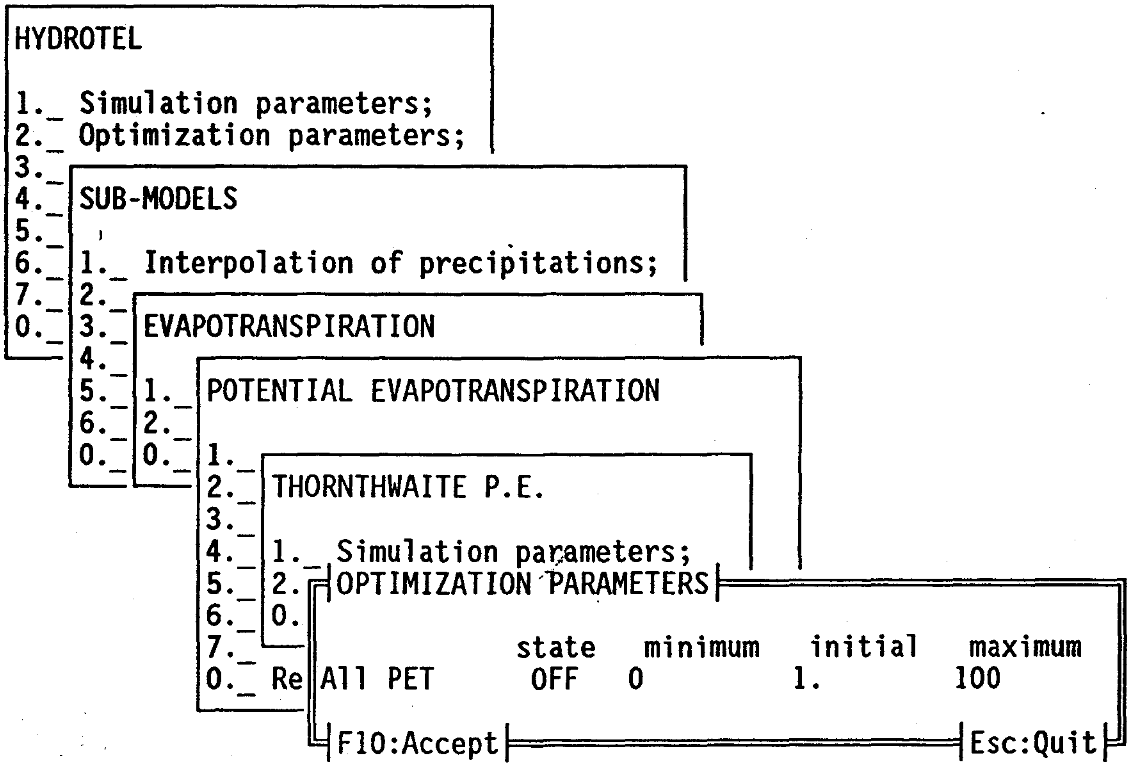


FIGURE 2.33 Sub-menu #4.3.1.1.2: optimization parameters.

In sub-menu #4.3.1.1.2 "optimisation parameters" (figure 2.37) the user can set initial values and limits for the parameters to vary within. When the field "state" is ON the optimization process will consider this variable. If "state" is OFF, then the variable will be ignored. The other three fields, "minimum", "initial" and "maximum", are related to a coefficient that will multiply the potential evapotranspirations for each land-use class. "Initial" is the initial value of the coefficient, "minimum" is the lower limit on the coefficient and "maximum" is the upper limit on the same coefficient.

2.3.6.3.1.2 Sub-menu #4.3.1.2: Linacre P.E. (figure 2.34)

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._ SUB-MODELS
4._
5._ 1._ Interpolation of precipitations;
6._ 2._
7._ 3._ EVAPOTRANSPIRATION
0._ 4._
    5._ 1._ POTENTIAL EVAPOTRANSPIRATION
    6._ 2._
    0._ 0._ 1._ Bypass, read data from disk;
            2._
            3._ LINACRE P.E.
            4._
            5._ 1._ Simulation parameters;
            6._ 2._ Optimization parameters;
            7._ 0._ Return to previous menu.
            0._
```

FIGURE 2.34 Sub-menu #4.3.1.2: Linacre P.E.

Option 1 leads to a sub-menu where simulation parameters concerning Linacre potential evapotranspiration can be set. Option 2 allows the user to set optimization parameters.

2.3.6.3.1.2.1 Sub-menu #4.3.1.2.1: simulation parameters (figure 2.35)

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._
4._ SUB-MODELS
5._
6._ 1._ Interpolation of precipitations;
7._ 2._
0._ 3._ EVAPOTRANSPIRATION
    4._
    5._ 1._ POTENTIAL EVAPOTRANSPIRATION
    6._ 2._
    0._ 0._ 1._ By SIMULATION PARAMETERS
            2._
            3._ LI  File name of albedo values............. albedo.73
            4._     Mean latitude of the basin (degrees)... 45.25
            5._ 1.  Linear approximation for (Δ/Δ+gamma)=(A+B*T)
            6._ 2.         -intersect for T=0°C ........... 0.4
            7._ 0.         -slope (1/°C) .................. 1.25e-002
            0._     Mean temperature of coldest month(°C).. -10
                    Mean temperature of warmest month(°C).. 20

                F10:Accept                             Esc:Quit
```

FIGURE 2.35 Sub-menu #4.3.1.2.1: simulation parameters.

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

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

- Mean latitude of the basin (degrees): type mean latitude of the basin, in degrees and hundredths of a degree.

- Linear approximation for $(\Delta/\Delta + \gamma) = (A + B * T)$

- intersect for T = O°C: enter the proper value.
- slope (°C^{-1}): enter the proper value.

- Mean temperature of coldest month (°C): enter the proper value, with a "-" for temperatures below O°C.

- Mean temperature of warmest month (°C): enter the proper value.

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

2.3.6.3.1.2.2 Sub-menu #4.3.1.2.2: optimization parameters (figure 2.36)

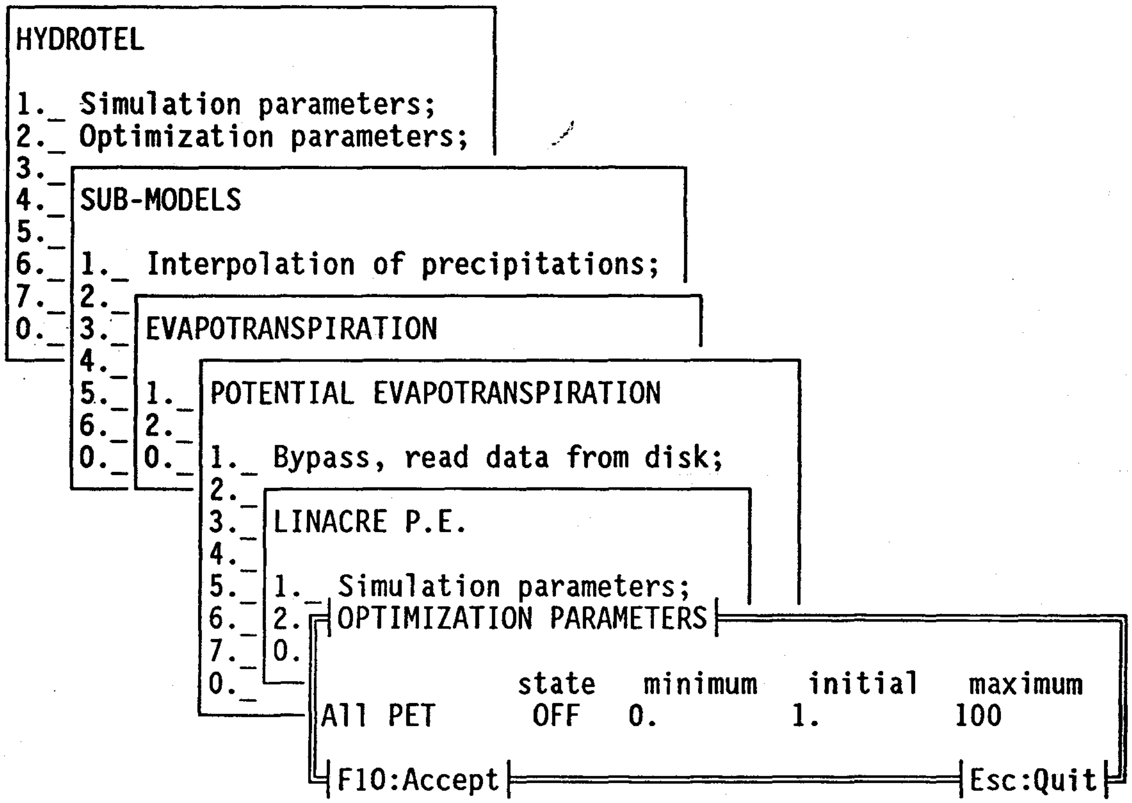


FIGURE 2.36 Sub-menu #4.3.1.2.2: optimization parameters.

In sub-menu #4.3.1.2.2 "optimisation parameters" (figure 2.36) the user can set initial values and limits for the parameters to vary within. When the field "state" is ON the optimization process will consider this variable. If "state" is OFF, then the variable will be ignored. The other three fields, "minimum", "initial" and "maximum", are related to a coefficient that will multiply the potential evapotranspirations for each land-use class. "Initial" is the initial value of the coefficient, "minimum" is the lower limit on the coefficient and "maximum" is the upper limit on the same coefficient.

2.3.6.3.1.3 Sub-menu #4.3.1.3: Penman P.E. (figure 2.37)

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._
4._ SUB-MODELS
5._
6._ 1._ Interpolation of precipitations;
7._ 2._
0._ 3._ EVAPOTRANSPIRATION
    4._
    5._ 1._ POTENTIAL EVAPOTRANSPIRATION
    6._ 2._
    0._ 0._ 1._ Bypass, read data from disk;
            2._ THORNTHWAITE P.E.;
            3._
            4._ PENMAN P.E.
            5._
            6._ 1._ Simulation parameters;
            7._ 2._ Optimization parameters;
            0._ 0._ Return to previous menu.
```

FIGURE 2.37 Sub-menu #4.3.1.3: Penman P.E.

Option 1 leads to a sub-menu where simulation parameters concerning Penman potential evapotranspiration can be set. Option 2 allows the user to set optimization parameters.

2.3.6.3.1.3.1 Sub-menu #4.3.1.3.1: simulation parameters (figure 2.38)

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._
4._ SUB-MODELS
5._
6._ 1._ Interpolation of precipitations;
7._ 2._
0._ 3._ EVAPOTRANSPIRATION
    4._
    5._ 1._ POTENTIAL EVAPOTRANSPIRATION
    6._ 2._
    0._ 0._ 1._ Bypass, read data from disk;
            2._ TH SIMULATION PARAMETERS
            3._
            4._ PE  File name of albedo values.............. albedo.73
            5._     File name of land-use heights........... hau_veg.73
            6._ 1.  Value of A and B in RG = IGA(A+B*h/H) A: 0.2
            7._ 2.  (not used if file RG available)       B: 0.55
            0._ 0.  Height of wind observation(m)........... 10.
                    Wind function: AERODYNAMIC RESISTANCE

                   F10:Accept                              Esc:Quit
```

FIGURE 2.38 Sub-menu #4.3.1.3.1: simulation parameters.

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

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

- File name of land-use heights: give the filemane of the land-use heights (see file structure in Appendix C).

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

  Enter the proper values.
- Height of wind observations (m): enter the height of the anemometer.

- Wind function:
  - aerodynamic resistance
  - empirical

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

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

2.3.6.3.1.3.2 Sub-menu #4.3.1.3.2: optimization parameters (figure 2.39)

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._
4._ SUB-MODELS
5._
6._ 1._ Interpolation of precipitations;
7._ 2._
0._ 3._ EVAPOTRANSPIRATION
    4._
    5._ 1._ POTENTIAL EVAPOTRANSPIRATION
    6._ 2._
    0._ 0._ 1._ Bypass, read data from disk;
            2._ THORNTHWAITE P.E.;
            3._
            4._ PENMAN P.E.
            5._
            6._ 1. OPTIMIZATION PARAMETERS
            7._ 2.
            0._ 0.          state   minimum   initial   maximum
                 All PET     OFF     0.        1.        100

                 F10:Accept                              Esc:Quit
```

FIGURE 2.39 Sub-menu #4.3.1.3.2: optimization parameters.

In sub-menu #4.3.1.3.2, "optimisation parameters" (figure 2.39) the user can set initial values and limits for the parameters to vary within. When the field "state" is ON the optimization process will consider this variable. If "state" is OFF, then the variable will be ignored. The other three fields, "minimum", "initial" and "maximum", are related to a coefficient that will multiply the potential evapotranspirations for each land-use class. "Initial" is the initial value of the coefficient, "minimum" is the lower limit on the coefficient and "maximum" is the upper limit on the same coefficient.

2.3.6.3.1.4 Sub-menu #4.3.1.4: Priestley-Taylor P.E. (figure 2.40)

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._
4._ SUB-MODELS
5._
6._ 1._ Interpolation of precipitations;
7._ 2._
0._ 3._ EVAPOTRANSPIRATION
    4._
    5._ 1._ POTENTIAL EVAPOTRANSPIRATION
    6._ 2._
    0._ 0._ 1._ Bypass, read data from disk;
            2._ THORNTHWAITE P.E.;
            3._ LINACRE P.E.;
            4._
            5._ PRIESTLEY-TAYLOR P.E.
            6._
            7._ 1._ Simulation parameters;
            0._ 2._ Optimization parameters;
                0._ Return to previous menu.
```

FIGURE 2.40 Sub-menu #4.3.1.4: Priestley-Taylor P.E.

Option 1 leads to a sub-menu where simulation parameters concerning Priestley-Taylor potential evapotranspiration can be set. Option 2 allows the user to set optimization parameters.

2.3.6.3.1.4.1 Sub-menu #4.3.1.4.1: simulation parameters (figure 2.41)

```
HYDROTEL

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

                    F10:Accept                          Esc:Quit
```

FIGURE 2.41 Sub-menu #4.3.1.4.1: simulation parameters.

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

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

- Values of A and B in RG = IGA (A + B * h/H) A:
  (not used if RG available) B:
  Enter the proper values.

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

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

2.3.6.3.1.4.2 Sub-menu #4.3.1.4.2: optimization parameters (figure 2.42)

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._
4._ SUB-MODELS
5._
6._ 1._ Interpolation of precipitations;
7._ 2._
0._ 3._ EVAPOTRANSPIRATION
    4._
    5._ 1._ POTENTIAL EVAPOTRANSPIRATION
    6._ 2._
    0._ 0._ 1._ Bypass, read data from disk;
            2._ THORNTHWAITE P.E.;
            3._ LINACRE P.E.;
            4._
            5._ PRIESTLEY-TAYLOR P.E.
            6._    OPTIMIZATION PARAMETERS
            7._ 1.
            0._ 2.              state   minimum   initial   maximum
                0. All PET      OFF     0.        1.        100

                   F10:Accept                              Esc:Quit
```

FIGURE 2.42 Sub-menu #4.3.1.4.2: optimization parameters.

In sub-menu #4.3.1.4.2 "optimisation parameters" (figure 2.42) the user can set initial values and limits for the parameter to vary within. When the field "state" is ON the optimization process will consider this variable. If "state" is OFF, then the variable will be ignored. The other three fields, "minimum", "initial" and "maximum", are related to a coefficient that will multiply the potential evapotranspirations for each land-use class. "Initial" is the initial value of the coefficient, "minimum" is the lower limit on the coefficient and "maximum" is the upper limit on the same coefficient.

2.3.6.3.2 *Sub-menu #4.3.2: actual evapotranspiration*

Four options are available for the estimation of actual evapotranspiration (figure 2.43). Select one and press "ENTER". After typing input values in the derived sub-menus, return to "sub-menu #4.3" by selecting option "0" and pressing "ENTER".

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._
4._ SUB-MODELS
5._
6._ 1._ Interpolation of precipitations;
7._ 2._
0._ 3._ EVAPOTRANSPIRATION
    4._
    5._ 1._
    6._ 2._ ACTUAL EVAPOTRANSPIRATION
    0._ 0._
            1._ Bypass;
            2._ Read AET data from disk;
            3._ User's defined;
            4._ Stand alone program;
            0._ Return to previous menu.
```

FIGURE 2.43 Sub-menu #4.3.2: actual evapotranspiration.

Option 1 is chosen if no output is required from the sub-model in a particular run. Option 2 allows the user to read actual evapotranspiration values, from the file specified in sub-menu #3.1.4 (intermediate data), to be used in the next submodels. Option 3 is a user's defined option, since no algorithm of the estimation of actual evapotranspiration is programmed yet. Finally, option 4 is the option allowing a stand alone program. The instructions on how to write these user's defined options one given in Appendix D or E.

2.3.6.4 Sub-menu #4.4: vertical water budget

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._
4._ SUB-MODELS
5._
6._ 1._ Interpolation of precipitations;
7._ 2._ Snowmelt;
0._ 3._
    4._ VERTICAL WATER BUDGET
    5._
    6._ 1._ Bypass;
    0._ 2._ Read outflow data from disk;
        3._ CEQUEAU (modified);
        4._ BV3C;
        5._ User's defined function;
        6._ Stand alone program;
        0._ Return to previous menu.
```

FIGURE 2.44 Sub-menu #4.4: vertical water budget.

Six options are currently available for the estimation of the vertical water budget on each square or homogeneous hydrological unit (figure 2.48). Select one and press "ENTER". After typing input values in each of the derived sub-menus, return to "sub-menu #4.0" by selecting option "0" and pressing "ENTER".

Option 1 is chosen if no output is required from the sub-model in a particular run.

Option 2 allows the user to read "outflow" matrices computed in a previous run or elsewhere for use in the next sub-models. Two vertical water budget sub-models are available as options 3 and 4. The first one is the vertical water profile used in the CEQUEAU model previously developped by INRS-Eau. The second one (BV3C) is a more physical model of the vertical water budget adapted for remote sensing. Values are read from the file specified in sub-menu #3.1.4 (intermediate data). It is also possible for the user to write its own vertical water budget (option 5 and 6), following the instructions given in Appendix D or E.

2.3.6.4.1 *Sub-menu #4.4.1: CEQUEAU (modified)*

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._
4._ SUB-MODELS
5._
6._ 1._ Interpolation of precipitations;
7._ 2._ Snowmelt;
0._ 3._
    4._ VERTICAL WATER BUDGET
    5._
    6._ 1._
    0._ 2._ CEQUEAU (MODIFIED)
        3._
        4._ 1._ Runoff on impervious areas;
        5._ 2._ Unsaturated zone reservoir;
        0._ 3._ Saturated zone reservoir;
            4._ Lakes and marshes;
            5._ Initial levels in reservoirs;
            6._ Land-use groups;
            7._ Optimization parameters;
            0._ Return to previous menu.
```

FIGURE 2.45 Sub-menu #4.4.1: input data for CEQUEAU.

See section 3.5.1 for more informations.

The usual separation of the terrestrial part of the hydrologic cycle into components has been used to group the parameters of the CEQUEAU function (figure 2.45). 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 #4.4" by selecting option "0" and pressing "ENTER".

2.3.6.4.1.1 Sub-menu #4.4.1.1: runoff on impervious areas (figure 2.46)

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._
4._ SUB-MODELS
5._
6._ 1._ Interpolation of precipitations;
7._ 2._ Snowmelt;
0._ 3._
    4._ VERTICAL WATER BUDGET
    5._
    6._ 1._
    0._ 2._ CEQUEAU (MODIFIED)
        3._
        4._ 1. RUNOFF ON IMPERVIOUS AREAS
        5._ 2.
        0._ 3.  Depth threshold for surface runoff (mm)... 0.
            4.
            5.  F10:Accept                          Esc:Quit
            6._ Land-use groups;
            7._ Optimization parameters;
            0._ Return to previous menu.
```

FIGURE 2.46 Sub-menu #4.4.1.1: runoff on impervious areas.

- Depth threshold for surface runoff (mm): type the depth threshold (in millimeters) that 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).

2.3.6.4.1.2 Sub-menu #4.4.1.2: unsaturated zone reservoir (figure 2.47)

```
HYDROTEL

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

FIGURE 2.47 Sub-menu #4.4.1.2: 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 sub-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).

2.3.6.4.1.3 Sub-menu #4.4.1.3: saturated zone reservoir (figure 2.48)

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._ SUB-MODELS
4._
5._
6._ 1._ Interpolation of precipitations;
7._ 2._ Snowmelt;
0._ 3._ VERTICAL WATER BUDGET
    4._
    5._
    6._ 1._
    0._ 2._ CEQUEAU (MODIFIED)
        3._
        4._ 1._ Runoff on impervious areas;
        5._ 2._ Unsaturated zone reservoir;
        0._ 3. SATURATED ZONE RESERVOIR
            4.
            5.  Outflow coefficient.................. 2.e-002
            6.  Fraction of PET taken in sat. zone.... 0.
            7.  Ref. level for fraction of PET (mm)... 50.
            0.
                F10:Accept                        Esc:Quit
```

FIGURE 2.48 Sub-menu #4.4.1.3: 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).

2.3.6.4.1.4 Sub-menu #4.4.1.4: lakes and marshes (figure 2.49)

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._ SUB-MODELS
4._
5._ 1._ Interpolation of precipitations;
6._ 2._ Snowmelt;
7._ 3._ VERTICAL WATER BUDGET
0._ 4._
    5._ 1._
    6._ 2._ CEQUEAU (MODIFIED)
    0._ 3._
        4._ 1._ Runoff on impervious areas;
        5._ 2._ Unsaturated zone reservoir;
        0._ 3._ Saturated zone reservoir;
            4. LAKES AND MARSHES
            5.
            6. Threshold for outflow (mm)... 250
            7. Outflow coefficient.......... 2.5e-002
            0.
               F10:Accept                    Esc:Quit
```

FIGURE 2.49 Sub-menu #4.4.1.4: 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).

2.3.6.4.1.5 Sub-menu #4.4.1.5: initial levels in reservoirs (figure 2.50)

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._
4._ SUB-MODELS
5._
6._ 1._ Interpolation of precipitations;
7._ 2._ Snowmelt;
0._ 3._
    4._ VERTICAL WATER BUDGET
    5._
    6._ 1._
    0._ 2._ CEQUEAU (MODIFIED)
        3._
        4._ 1._ Runoff on impervious areas;
        5._ 2._ Unsaturated zone reservoir;
        0._ 3. INITIAL LEVELS IN RESERVOIRS
            4.
            5.  Unsaturated zone (mm).... 65.
            6.  Saturated zone (mm)...... 30.
            7.  Lakes and marshes (mm)... 250
            0.
                F10:Accept                Esc:Quit
```

FIGURE 2.50 Sub-menu #4.4.1.5: 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 lakes and marshes" 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 or HHU, whereas individual values can be given to each square or HHU, if the appropriate file name is given in sub-menu #3.1.3 and option 1 is selected in sub-menu #3.2.2.

2.3.6.4.1.6 Sub-menu #4.4.1.6: land-use groups (figure 2.51)

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._
4._ SUB-MODELS
5._
6._ 1._ Interpolation of precipitations;
7._ 2._ Snowmelt;
0._ 3._
    4._ VERTICAL WATER BUDGET
    5._
    6._ 1._
    0._ 2._ CEQUEAU (MODIFIED)
        3._
        4._ 1._ Runoff on impervious areas;
        5._ 2._ Unsaturated zone reservoir;
        0._ 3._ Saturated zone reservoir;

CLASS CODES (SEPARATED BY "+") FOR WATER SURFACES

EAU1+EAU2

CLASS CODES (SEPARATED BY "+") FOR IMPERVIOUS SURFACES

route

CLASS CODES (SEPARATED BY "+") FOR FORESTED SURFACES

resin+feuil
```

FIGURE 2.51 Sub-menu #4.4.1.6: land-use groups.

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

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

2.3.6.4.1.7 Sub-menu #4.4.1.7: optimization parameters (figure 2.52)

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._
4._ SUB-MODELS
5._
6._ 1._ Interpolation of precipitations;
7._ 2._ Snowmelt;
0._ 3._
    4._ VERTICAL WATER BUDGET
    5._
    6._ 1._
    0._ 2._ CEQUEAU (MODIFIED)
        3._
        4._ 1. OPTIMIZATION PARAMETERS
        5._ 2.
        0._ 3.                       state  minimum   initial   maximum
            4. THRESHOLD FOR PET     OFF    0         1.        100
            5. CAPACITY OF U.Z.R.    OFF    0         1.        100
            6. OUTFLOW COEF.         OFF    0         1.        100
            7. RUNOFF COEF.          OFF    0         1.        100
            0.
               F10:Accept                                      Esc:Quit
```

FIGURE 2.52 Sub-menu #4.4.1.7: optimization parameters.

In sub-menu #4.4.1.7 "optimisation parameters" (figure 2.52) the user can set initial values and limits for the parameters to vary within. When the field "state" is ON the optimization process will consider this variable. If "state" is OFF, then the variable will be ignored. The other three fields, "minimum", "initial" and "maximum", are related to a coefficient that will multiply the variables. "Initial" is the initial value of the coefficient, "minimum" is the lower limit on the coefficient and "maximum" is the upper limit on the same coefficient. The values of the parameters "THRESHOLD FOR PET", "CAPACITY OF U.Z.R.(unsaturated zone reservoir)" and "RUNOFF COEF." are initialized in sub-menu #4.4.1.2. "OUTFLOW COEF." is initialized in sub-menu #4.4.1.3.

2.3.6.4.2 *Sub-menu #4.4.2: BV3C (figure 2.53)*

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._
4._ SUB-MODELS
5._
6._ 1._ Interpolation of precipitations;
7._ 2._ Snowmelt;
0._ 3._
    4._ VERTICAL WATER BUDGET
    5._
    6._ 1._ Bypass, read data from disk;
    0._ 2._
        3._ BV3C
        4._
        5._ 1._ Soil and land-use files;
        0._ 2._ Parameters characterizing layers;
            3._ General parameters;
            4._ Land-use groups;
            5._ Optimization parameters;
            0._ Return to previous menu.
```

FIGURE 2.53 Sub-menu #4.4.2: BV3C.

See section 3.5.2 for more informations.

Most input data necessary for BV3C are contained in files, so that few supplementary values are needed. Select each one of the options in sub-menu #4.4.2 to complete input of all necessary informations.

2.3.6.4.2.1 Sub-menu #4.4.2.1: soil and land-use files

```
HYDROTEL

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

FIGURE 2.54 Sub-menu #4.4.2.1: soil and land-use files.

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

- leaf-area index on day D;
- root depth on day D;
- hydraulic properties of soil types;
- spatial distribution of soil types.

See Appendix C for file structures and contents.

2.3.6.4.2.2 Sub-menu #4.4.2.2: parameters characterizing layers (figure 2.55)

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._
4._ SUB-MODELS
5._
6._ 1._ Interpolation of precipitations;
7._ 2._ Snowmelt;
0._ 3._
    4._ VERTICAL WATER BUDGET
    5._
    6._ 1._ Bypass;
    0._ 2._ Read output data from disk;
        3._
        4._ BV3C
        5._
        6._ 1. PARAMETERS CHARACTERIZING LAYERS
        0._ 2.
            3.  Layer                             1      2      3
            4.  Relative water content...(θ/θs). 0.3    0.3    0.3
            5.  Bottom of each layer........(m). 0.15   0.9    2.
            0.
                F10:Accept                                Esc:Quit
```

FIGURE 2.55 Sub-menu #4.4.2.2: parameters characterizing layers.

The relative initial water content and bottom of each layer, should be given in sub-menu #4.4.2.2.

- Relative water content of each layer:
  $\theta 1$: $\theta 2$: $\theta 3$:

  Enter relative ($\theta/\theta s$) initial water content values of each layer.

- Bottom of each layer (m):
  Z1: Z2: Z3:

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

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

Note that identical values are given to each square or HHU, whereas individual values can be given to each square or HHU, if the appropriate file name is given in sub-menu #3.1.3 and option 1 is selected in sub-menu #3.2.2.

2.3.6.4.2.3 Sub-menu #4.4.2.3: general parameters (figure 2.56)

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._
4._ SUB-MODELS
5._
6._ 1._ Interpolation of precipitations;
7._ 2._ Snowmelt;
0._ 3._
    4._ VERTICAL WATER BUDGET
    5._
    6._ 1._ Bypass, read data from disk;
    0._ 2._
        3._ BV3C
        4._
        5._ 1._ Soil and land-use files;
        0._ 2. GENERAL PARAMETERS
            3.
            4.  Extinction coefficient  DES......: 0.6
            5.  Recession coefficient............: 8.33e-005
            0.  Max. variation of θ/time step....: 0.3

                F10:Accept                          Esc:Quit
```

FIGURE 2.56 Sub-menu #4.4.2.3: general parameters.

The values of two coefficients are entered in that menu.

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

- Recession coefficient: enter the proper coefficient value for recession flow.

- Max. variation of θ/time step: enter the maximum variation that you allow any θ to vary per time step.

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

2.3.6.4.2.4 Sub-menu #4.4.2.4: land-use groups (figure 2.57)

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._
4._ SUB-MODELS
5._
6._ 1._ Interpolation of precipitations;
7._ 2._ Snowmelt;
0._ 3._
    4._ VERTICAL WATER BUDGET
    5._
    6._ 1._ Bypass, read data from disk;
    0._ 2._
        3._ BV3C
        4._
        5._ 1._ Soil and land-use files;

CLASS CODES (SEPARATED BY "+") FOR IMPERVIOUS SURFACES

ROUTE

CLASS CODES (SEPARATED BY "+") FOR WATER SURFACES

eau1+eau2
```

FIGURE 2.57 Sub-menu #4.4.2.4: land-use groups.

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

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

2.3.6.4.2.5 Sub-menu #4.4.2.5: optimization parameters (figure 2.58)

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._
4._ SUB-MODELS
5._
6._ 1._ Interpolation of precipitations;
7._ 2._ Snowmelt;
0._ 3._
    4._ VERTICAL WATER BUDGET
    5._
    6._ 1._ Bypass, read data from disk;
    0._ 2._
        3._ BV3C
        4._    OPTIMIZATION PARAMETERS
        5._ 1.
        0._ 2.                     state   minimum   initial   maximum
            3. SOIL CLASS           OFF    0.        1.        10
            4. REDUCTION FACTOR     OFF    0.        1.        100
            5. DEPTH LAYERS 2&3     OFF    0.        1.        100
            0. RECESSION COEF.      OFF    0.        1.        100

               F10:Accept                                     Esc:Quit
```

FIGURE 2.58 Sub-menu #4.4.2.5: optimization parameters.

In sub-menu #4.4.2.5 "optimisation parameters" (figure 2.58) the user can set initial values and limits for the parameters to vary within. When the field "state" is ON the optimization process will consider this variable. If "state" is OFF, then the variable will be ignored. The other three fields, "minimum", "initial" and "maximum", are related to a coefficient that will multiply the variables. "Initial" is the initial value of the coefficient, "minimum" is the lower limit on the coefficient and "maximum" is the upper limit on the same coefficient.

"SOIL CLASS" refers to soil types (see table 3.1) and can only vary between 0 and the number of soil types -1 available in the file "hydraulic properties of soil types file" (see sub-menu #4.4.2.1).

"DRYNESS COEF." relates to the dryness coefficient for evaporation from bare soil (C_s) and to the dryness coefficient for transpiration from vegetation (C_t). For more informations on C_s and C_t, see equ. 3.28 and 3.31 section 3.5.2.1.

"DEPTH LAYERS 2&3" is the bottom of layers 2 and 3 as initialized (z2, z3) in sub-menu #4.4.2.2.

"RECESSION COEF." is initialized in sub-menu #4.4.2.3.

2.3.6.5 Sub-menu #4.5: surface and sub-surface runoff (figure 2.59)

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._
4._ SUB-MODELS
5._
6._ 1._ Interpolation of precipitations;
7._ 2._ Snowmelt;
0._ 3._ Evapotranspiration;
    4._
    5._ SURFACE AND SUB-SURFACE RUNOFF;
    6._
    0._ 1._ Bypass;
        2._ Read runoff data from disk;
        2._ Kinematic wave equation;        «
        3._ User's defined runoff function;
        4._ Stand alone program;
        0._ Return to previous menu.
```

FIGURE 2.59 Sub-menu #4.5: surface and sub-surface runoff.

See section 3.6 for more information.

Five options are currently available for the simulation of surface and sub-surface runoff (figure 2.59). Select one and press "ENTER".

Option 1 is chosen if no output is required from the sub-model in a particular run.

Option 2 allows the user to read "runoff" values from a previous run or computed elsewhere. Values are read from the file specified in sub-menu #3.1.4 (intermediate data) to be used by the next sub-model. Only one simulation method is provided, option 3. It is also possible for the user to write its own surface and sub-surface runoff sub-model (options 4 and 5), following the instructions given in Appendix D or E.

Initial values of water in transit can be obtained from the file whose name appears in sub-menu #3.1.3 if option 2 is selected in sub-menu #3.2.2.

Otherwise, initial runoff values are initialized to "zero". Return to sub-menu #4.5 by selecting option "0" and pressing "ENTER".

2.3.6.5.1 *Sub-menu #4.5.1: kinematic wave equation*

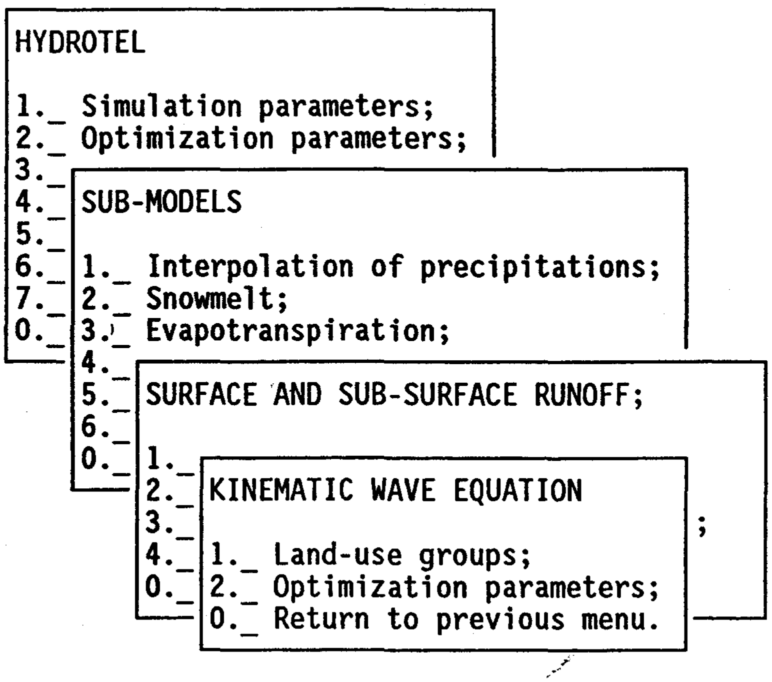


FIGURE 2.60 Sub-menu #4.5.1: kinematic wave equation.

Three options are available in sub-menu #4.5.1 (figure 2.64). Option 1 is used to set the values or roughness coefficients overland. Option 2 leads to a menu where the user can specify land-use groups proper to the kinematic wave equation. Option 2 allows the user to set optimization parameters for the same model.

2.3.6.5.1.1 Sub-menu #4.5.1.1: roughness coefficients

Only two values of the overland roughness coefficients are asked for, one for forested areas and one for open areas. Type the proper values if you do not wish the default values.

Press "ENTER" to confirm your entries and leave the menu.

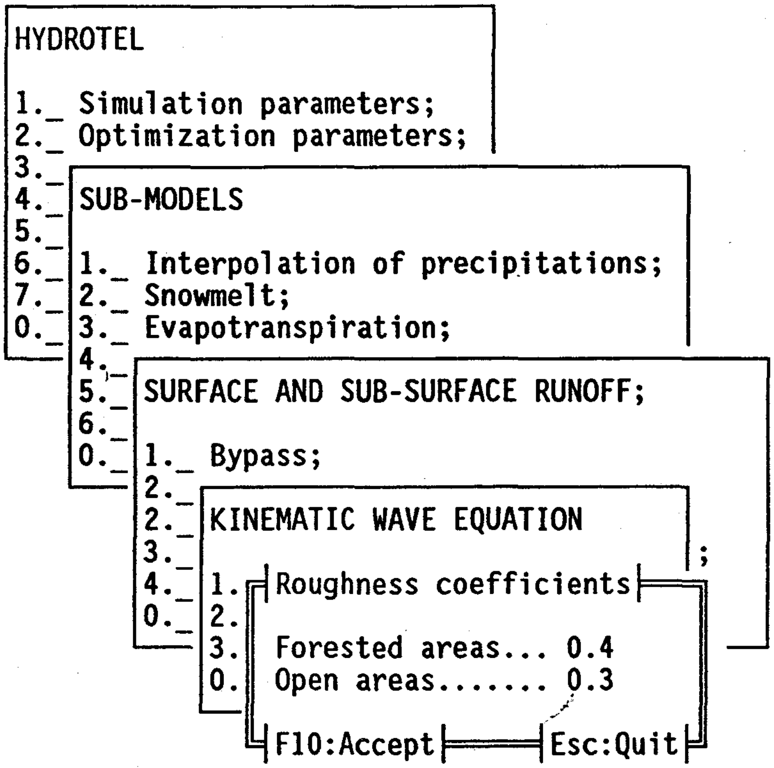


FIGURE 2.61 Sub-menu #4.5.1.1: roughness coefficients.

2.3.6.5.1.2 Sub-menu #4.5.1.2: land-use groups

```
HYDROTEL

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

CLASS CODES (SEPARATED BY "+") FOR FOREST

RESIN+FEUIL

        0._ 2._ Optimization parameters;
            0._ Return to previous menu.
```

FIGURE 2.62 Sub-menu #4.5.1.2: land-use groups for surface and sub-surface runoff.

Only two overland classes are considered, forested areas and open areas. As required, type the class code (s) of the original land-use class(es) corresponding to "forested areas". Those include both coniferous and deciduous forests. All other land-use classes are grouped together.

Press "ENTER" to confirm your entries and leave the menu.

2.3.6.5.1.3 Sub-menu #4.5.1.3: optimization parameters

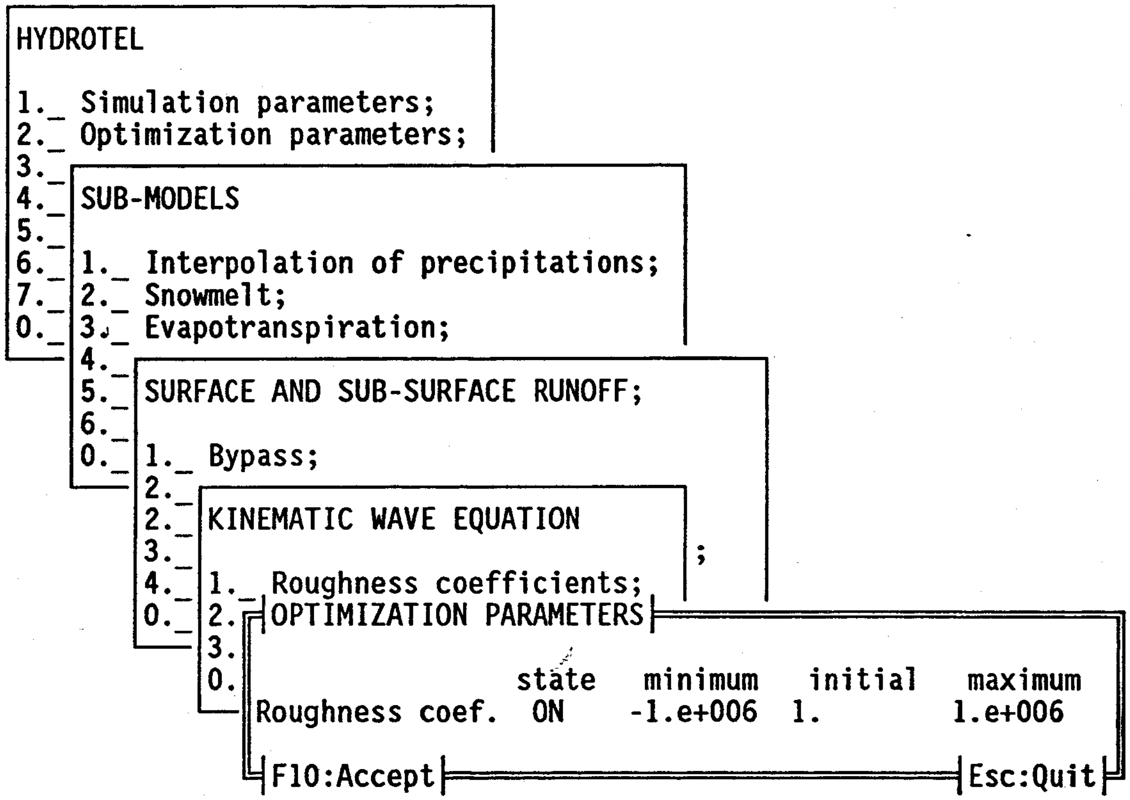


FIGURE 2.63 Sub-menu #4.5.1.3: optimization parameters.

In sub-menu #4.5.1.3 "optimization parameters" (figure 2.63) the user can set initial values and limits for the parameters to vary within. When the field "state" is ON the optimization process will consider this variable. If "state" is OFF, then the variable will be ignored. The other three fields, "minimum", "initial" and "maximum", are related to a coefficient that will multiply Manning's roughness coefficients (see equ. 3.37 section 3.6). "Initial" is the initial value of the coefficient, "minimum" is the lower limit on the coefficient and "maximum" is the upper limit on the same coefficient.

2.3.6.6 Sub-menu #4.6: channel routing

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._
4._ SUB-MODELS
5._
6._ 1._ Interpolation of precipitations;
7._ 2._ Snowmelt;
0._ 3._ Evapotranspiration;
    4._ Vertical water budget;
    5._
    6._ CHANNEL ROUTING
    0._
        1._ Bypass;
        2._ Read streamflow data from disk;
        3._ Modified kinematic wave equation;        «
        4._ Diffusive wave equation;
        5._ User's defined channel routing function;
        6._ Stand alone program;
        0._ Return to previous menu.
```

FIGURE 2.64 Sub-menu #4.6: channel routing.

See section 3.7 for more information.

Six options are currently available for the simulation of channel routing (figure 2.64).

Option 1 is chosen if no output is required from the sub-model in a particular run.

Option 2 allows the user to read "streamflow" values from a previous run or computed elsewhere. Values are read from the file specified in sub-menu #3.1.4 (intermediate data) to be used by future added sub-models (water quality as an example). Two sub-models, are programmed in HYDROTEL 2.1 as options 3 and 4, namely: a modified kinematic wave equation and a diffusive wave equation. It is also possible for the user to write his own model (options 5 and 6), following the instructions given in Appendix D or E.

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

Initial values of water levels in the reaches can be obtained from the file whose name appears in sub-menu #3.1.3, if option 3 is selected in sub-menu #3.2.2. Otherwise, initial runoff values are initialized to "zero". If option 3, the diffusive wave equation, is chosen it is necessary to have "initial values of water levels" different from zero. One way is to proceed to a first run with option 2 and save the values, as mentionned above.

Return to sub-menu #4.6 by selecting option "0" and pressing "ENTER".

2.3.6.6.1 *Sub-menu #4.6.1: modified kinematic wave equation*

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._
4._ SUB-MODELS
5._
6._ 1._ Interpolation of precipitations;
7._ 2._ Snowmelt;
0._ 3._ Evapotranspiration;
    4._ Vertical water budget;
    5._
    6._ CHANNEL ROUTING
    0._
        1._
        2._ MODIFIED KINEMATIC WAVE EQUATION
        3._
        4._ 1._ Optimization parameters;        tion;
        5._ 0._ Return to previous menu.
        0._
```

FIGURE 2.65 Sub-menu #4.6.1: modified kinematic wave equation.

Sub-menu #4.6.1. (figure 2.65) is only an intermidiate menu that allows the user to go to the "optimization parameters" menu (option 1).

2.3.6.6.1.1 Sub-menu #4.6.1.1: optimization parameters

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._
4._ SUB-MODELS
5._
6._ 1._ Interpolation of precipitations;
7._ 2._ Snowmelt;
0._ 3._ Evapotranspiration;
    4._ Vertical water budget;
    5._
    6._ CHANNEL ROUTING
    0._
        1._
        2._ MODIFIED KINEMATIC WAVE EQUATION
        3._
        4._ 1. OPTIMIZATION PARAMETERS
        5._ 0.
        0._                     state   minimum    initial    maximum
              ROUGHNESS COEF.    OFF    0          1.         100
              CHANNEL WIDTH      OFF    0          1.         100

              F10:Accept                                      Esc:Quit
```

FIGURE 2.66 Sub-menu #4.6.1.1: optimization parameters.

In sub-menu #4.6.1.1 "optimization parameters" (figure 2.66) the user can set initial values and limits for the parameters to vary within. When the field "state" is ON the optimization process will consider this variable. If "state" is OFF, then the variable will be ignored. The other three fields, "minimum", "initial" and "maximum", are related to a coefficient that will multiply the variables. "Initial" is the initial value of the coefficient, "minimum" is the lower limit on the coefficient and "maximum" is the upper limit on the same coefficient.

"ROUGHNESS COEF." refers to the Manning's roughness coefficient (n in equ. 3.40 section 3.7.1.1).

"CHANNEL WIDTH" relates to the width of all river reaches (B in equ. 3.40 section 3.7.1.1).

2.3.6.6.2 *Sub-menu #4.6.2: diffusive wave equation*

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._
4._ SUB-MODELS
5._
6._ 1._ Interpolation of precipitations;
7._ 2._ Snowmelt;
0._ 3._ Evapotranspiration;
    4._ Vertical water budget;
    5._
    6._ CHANNEL ROUTING
    0._
        1._ Bypass, read data from disk;
        2._                              on;
        3._ DIFFUSIVE WAVE EQUATION
        4._                                 function;
        5._ 1._ Optimization parameters;
        0._ 0._ Return to previous menu.
```

FIGURE 2.67 Sub-menu #4.6.2: diffusive wave equation.

Sub-menu #4.6.2 (figure 2.67) is only an intermidiate menu that allows the user to go to the "optimization parameters" menu (option 1).

2.3.6.6.2.1 Sub-menu #4.6.2.1: optimization parameters

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._
4._ SUB-MODELS
5._
6._ 1._ Interpolation of precipitations;
7._ 2._ Snowmelt;
0._ 3._ Evapotranspiration;
    4._ Vertical water budget;
    5._
    6._ CHANNEL ROUTING
    0._
        1._ Bypass, read data from disk;
        2._                           on;
        3._ DIFFUSIVE WAVE EQUATION
        4._   OPTIMIZATION PARAMETERS
        5._ 1.
        0._ 0.
                               state   minimum   initial   maximum
              ROUGHNESS COEF.  ON      0.        1.        100
              CHANNEL WIDTH    ON      0.        1.        100

              F10:Accept                                   Esc:Quit
```

FIGURE 2.68 Sub-menu #4.6.2.1: optimization parameters.

In sub-menu #4.6.2.1 "optimization parameters" (figure 2.68) the user can set initial values and limits for the parameters to vary within. When the field "state" is ON the optimization process will consider this variable. If "state" is OFF, then the variable will be ignored. The other three fields, "minimum", "initial" and "maximum", are related to a coefficient that will multiply the variables. "Initial" is the initial value of the coefficient, "minimum" is the lower limit on the coefficient and "maximum" is the upper limit on the same coefficient.

"ROUGHNESS COEF." refers to Manning's roughness coefficient (n in equ. 3.40 section 3.7.1.1).

"CHANNEL WIDTH" relates to the width of all river reaches (B in equ. 3.40 section 3.7.1.1).

2.3.7 Sub-menu #5.0: data output

Sub-menu #5.0 (figure 2.69) leads to three sub-menus in which informations needed to output data will be given. The following menus are similar to those related to sub-menus #2.0.

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._ Data input;
4._
5._ DATA OUTPUT
6._
7._ 1._ File specification;
0._ 2._ Save data;
    3._ View results;
    0._ Return to previous menu.
```

FIGURE 2.69 Sub-menu #5.0: data output.

2.3.7.1 <u>Sub-menu #5.1: file name specification</u>

Sub-menu #5.1 (figure 2.70) leads to two sub-menus in which the file specifications 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.

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._ Data input;
4._
5._ DATA OUTPUT
6._
7._ 1._ FILE SPECIFICATION
0._ 2._
    3._ 1._ Intermediate results;
    4._ 2._ Final settings;
    0._ 0._ Return to previous menu.
```

FIGURE 2.70 Sub-menu #5.1: file name specification.

2.3.7.1.1 *Sub-menu #5.1.1: intermediate results*

File names for files containing intermediate results can be given here (figure 2.71), as well as the proper format. Unless modifications are made in the source program, only INRS formats should be used.

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._ Data input;
4._
5._ DATA OUTPUT
6._
7._ 1._ FILE SPECIFICATION
0._ 2._
    3._ 1.  INTERMEDIATE RESULTS
    0._ 2.
        0.
            Max temp....... clifton.tpx        INRS
            Min temp....... clifton.tpn        INRS
            Rain........... clifton.plu        INRS
            Snow........... clifton.nei        INRS
            Melt........... clifton.fon        INRS
            Evapo.......... clifton.evp        INRS
            Outflow........ clifton.pro        INRS
            Runoff......... clifton.rui        INRS
            Streamflows.... clifton.deb        INRS

           F10:Accept                          Esc:Quit
```

FIGURE 2.71 Sub-menu #5.1.1: intermediate results.

2.3.7.1.2 *Sub-menu #5.1.2: final settings*

File names and proper formats for values of state variables that will be used in a later run as initial values are given here (figure 2.72). The initialization procedure is explained at the end of Part 2.

Unless modifications are made in the source program, only INRS formats should be used.

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._ Data input;
4._
5._ DATA OUTPUT
6._
7._ 1._ FILE SPECIFICATION
0._ 2._
    3._ 1._ Intermediate results;
    0._ 2.  FINAL SETTINGS
        0.
            Snowpack....... clifton.sis        INRS
            Water budget... clifton.pis        INRS
            Runoff......... clifton.ris        INRS
            Streamflows.... clifton.cis        INRS

            F10:Accept                         Esc:Quit
```

FIGURE 2.72 Sub-menu #5.1.2: final settings.

2.3.7.2 Sub-menu #5.2: save data

To be used in other runs of HYDROTEL or otherwise, data have to be saved (figure 2.73). Figure 2.74 shows an example of the matrices saved for a particular time. Intermediate results or final settings of state variables may be saved.

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._ Data input;
4._
5._|DATA OUTPUT
6._|
7._|1._ File specification;
0._|2._
   |3._|SAVE DATA
   |4._|
   |0._|1._ Intermediate results;
       |2._ Final settings;
       |0._ Return to previous menu.
```

FIGURE 2.73 Sub-menu #5.2: 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	0.0	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	13.5	3.8	3.8	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	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	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	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	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
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 2.74 Available water from rain and/or melt.

2.3.7.2.1 *Sub-menu #5.2.1: intermediate results*

Any of the variables appearing in sub-menu #5.2.1 (figure 2.75) can be saved if it is selected.

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._ Data input;
4._
5._ DATA OUTPUT
6._
7._ 1._ File specification;
0._ 2._
    3._ SAVE DATA
    0._
        1._ INTERMEDIATE RESULTS
        2._
        0._ 1._ Temperatures;
            2._ Precipitations;
            3._ Melt;
            4._ Evapotranspiration;
            5._ Outflow;
            6._ Runoff;
            7._ Streamflows;
            0._ Return to previous menu.
```

FIGURE 2.75 Sub-menu #5.2.1: intermediate results.

2.3.7.2.2 *Sub-menu #5.2.2: final settings*

The final values of any of the state variables appearing in sub-menu #5.2.2 (figure 2.76) can be saved if it is selected. When final settings are needed for a particular variable, the date can be specified in a pop-up window. The default date is the last day of the simulation period. The possibility of setting a day other than the last one can be used for forecasting purposes.

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._ Data input;
4._
5._ DATA OUTPUT
6._
7._ 1._ File specification;
0._ 2._
    3._ SAVE DATA
    0._
        1._
        2._ FINAL SETTINGS
        0._
            4._ Snowpack;
            1._ Water budget;
            2._ Runoff;
            3._ Streamflows;
            0._ Return to previous menu.
```

FIGURE 2.76 Sub-menu #5.2.2: final settings.

2.3.7.3 Sub-menu #5.3: run

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._ Data input;
4._
5._ RUN
6._
7._ 1._ Run;
0._ 2._ Run and watch c
    3._ Run and watch s Display from:  73/06/11
    4._ Run and watch w
    5._ Run and watch runoff variables;
    6._ Run and watch channel routing variables;
    0._ Return.
```

FIGURE 2.77 Sub-menu #5.3: run.

Sub-menu #5.3 contains six options (figure 2.77). Option 1 is selected to run the program without the watch options. Options 2 to 6 allow the user to monitor selected variables both in time and space during the simulation. <u>They are mutually exclusive</u>. In other words, only one of them may be active for a particular simulation. It is necessary to select those options before the simulation. When options 2 to 6 are selected it is possible to look at only a portion of a simulation, by specifying the beginning of the period you want to monitor. Press F1 for step by step monitoring with spatial pan at any time step (for spatial monitoring) and F5 for continuous simulation. Typing F1 when in continuous mode returns control to step by step simulation.

With option two ("color code maps"), one can visualize a particular variable all over the basin at the same time. After a few moments, a empty grid will appear with a legend and the sound of a bell. The user can now select the variable that he wants to observe. The user can activate fields in blue by typing a "v" for "variable", an "s" for "scale" or an "o" for "origin" then the related field will turn red. The user uses the "UP" and "DOWN" arrows to make its choice among the available variables, scales or origins. It should be noted that different variables have different scales and their origins can be mobile or not. Table 2.2 lists the available variables with their names, available scales and the origin corresponding to every scale with in parenthesis an indicator which tells if the origin is mobile (Y) or not (N). With the F1 mode, it is possible to look at more than one variable, sequentially at each time step. Figure 2.78 is an example of what is displayed on the screem when the user ask for color code maps.

TABLE 2.2 Monitored variables in color coded maps.

VARIABLE	NAME	SCALE (units)	ORIGIN
liquid precipitation	RAIN	2 mm 5 10	0(N) 0(N) 0(N)
snow	SNOW	2 cm 5 10	0(N) 0(N) 0(N)
snowpack water equivalent coniferous forest	SNOWPACK CONIF	2 mm 5 10 20	0(N) 0(N) 0(N) 0(N)
snowpack water equivalent decidous forest	SNOWPACK LEAF	2 mm 5 10 20	0(N) 0(N) 0(N) 0(N)
snowpack water equivalent open areas	SNOWPACK OPEN	2 mm 5 10 20	0(N) 0(N) 0(N) 0(N)
snowmelt	MELT	1 mm 2	0(N) 0(N)
maximum temperature	MAX. TEMP.	0.5 C 1 2	0(Y) 0(Y) 0(Y)
minimum temperature	MIN. TEMP.	0.5 C 1 2	0(Y) 0(Y) 0(Y)
potential evapotranspiration	POT. ETP.	0.5 mm 1	0(N) 0(Y)
water content layer 1 (BV3C model only)	WAT. CONT. L1.	0.02 m^3m^{-3} 0.04 0.05	0(Y) 0(N) 0(N)

TABLE 2.2 (suited)

VARIABLE	NAME	SCALE (units)	ORIGIN
water content layer 2 (BV3C model only)	WAT. CONT. L2.	0.04 m^3m^{-3} 0.05	0(N) 0(N)
water content layer 3 (BV3C model only)	WAT. CONT. L3.	0.04 m^3m^{-3} 0.05	0(N) 0(N)
water content unsaturated reservoir	WAT.CONT.UNSAT	1 mm 2 5 10	0(Y) 0(Y) 0(Y) 0(Y)
water content saturated reservoir	WAT.CONT.SAT	1 mm 2 5 10	0(Y) 0(Y) 0(Y) 0(Y)
water content lake and marsh	WAT.CONT.L&M	1 mm 2 5 10	0(Y) 0(Y) 0(Y) 0(Y)
surface and subsurface flow	SURF&SUB.FLOW	0.5 m^2s^{-1} 1 5 10	0(N) 0(N) 0(N) 0(N)

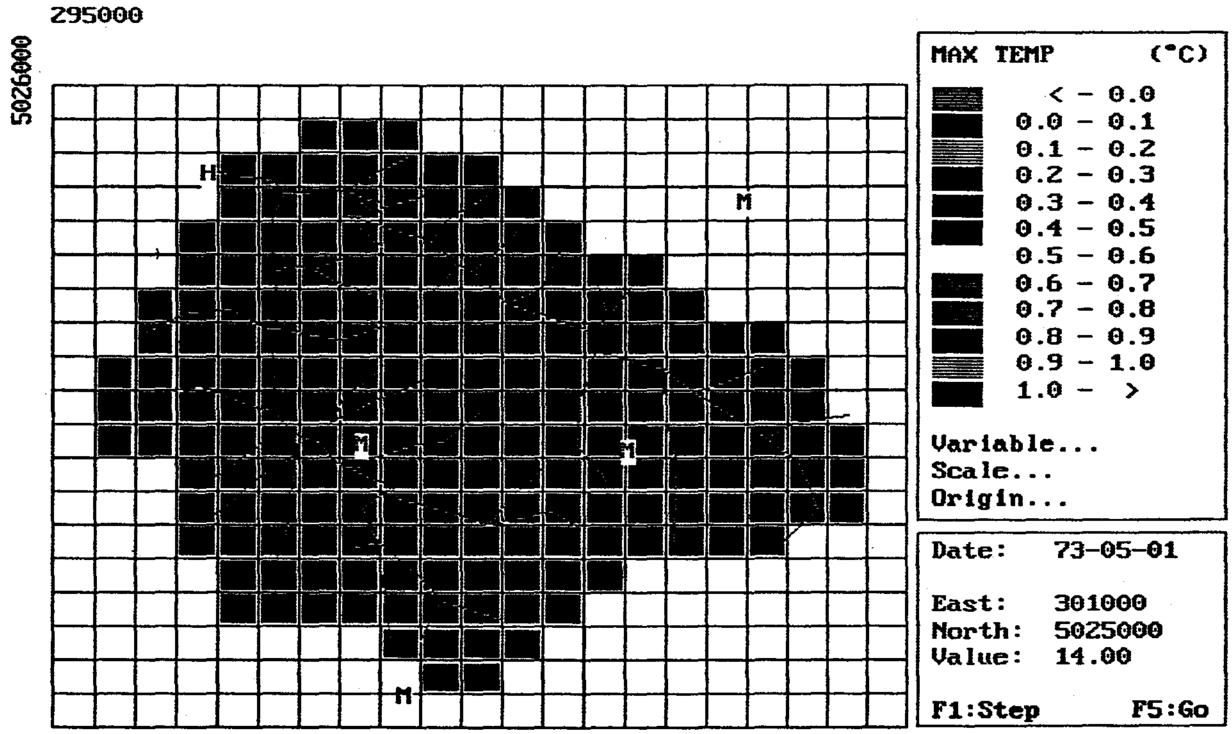


FIGURE 2.78 Color code maps.

If options 3 to 6 are chosen, a discretized map of the basin appears in the left portion of the screen (figures 2.79 to 2.83). A rectangular cursor is "on" and can be moved from square to square, HHU to HHU or reach to reach, by the "arrows" on the keyboard. To the right of the map, tabular information is given relative to square (or HHU) or reach, depending on the option. If the vertical water budget is chosen the information is related to the sub-model chosen in sub-menu #4.4 (either CEQUEAU or BV3C).

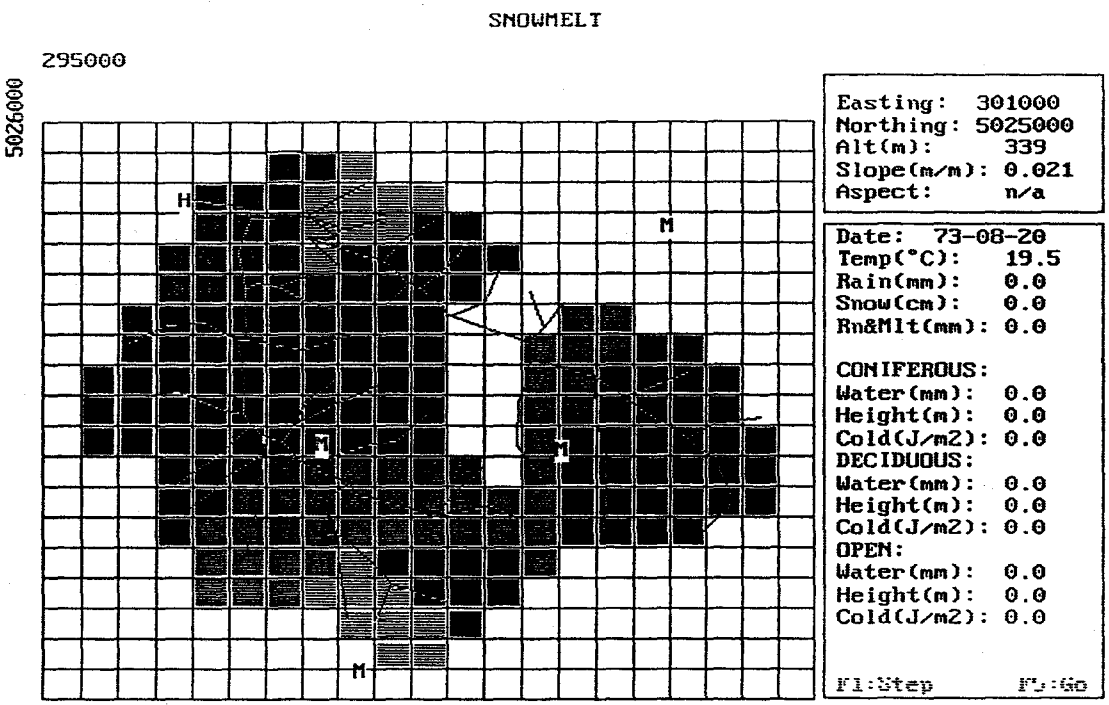


FIGURE 2.79 Tabular informations on variables related to snow melt.

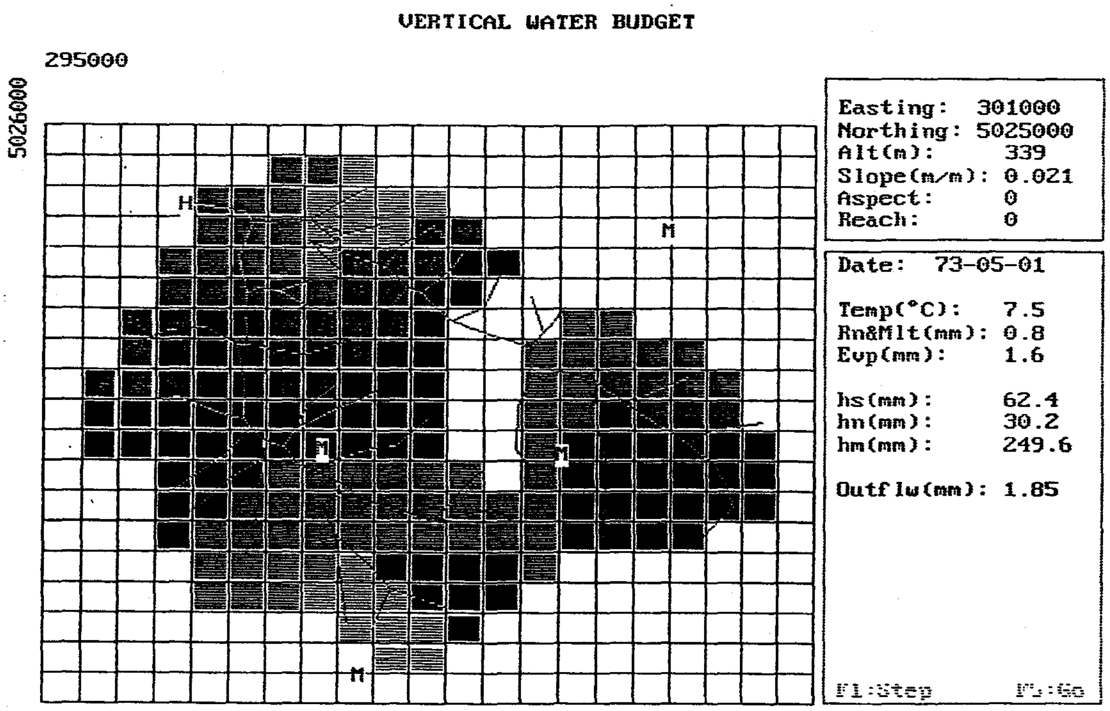


FIGURE 2.80 Tabular informations on variables related to water budget (CEQUEAU).

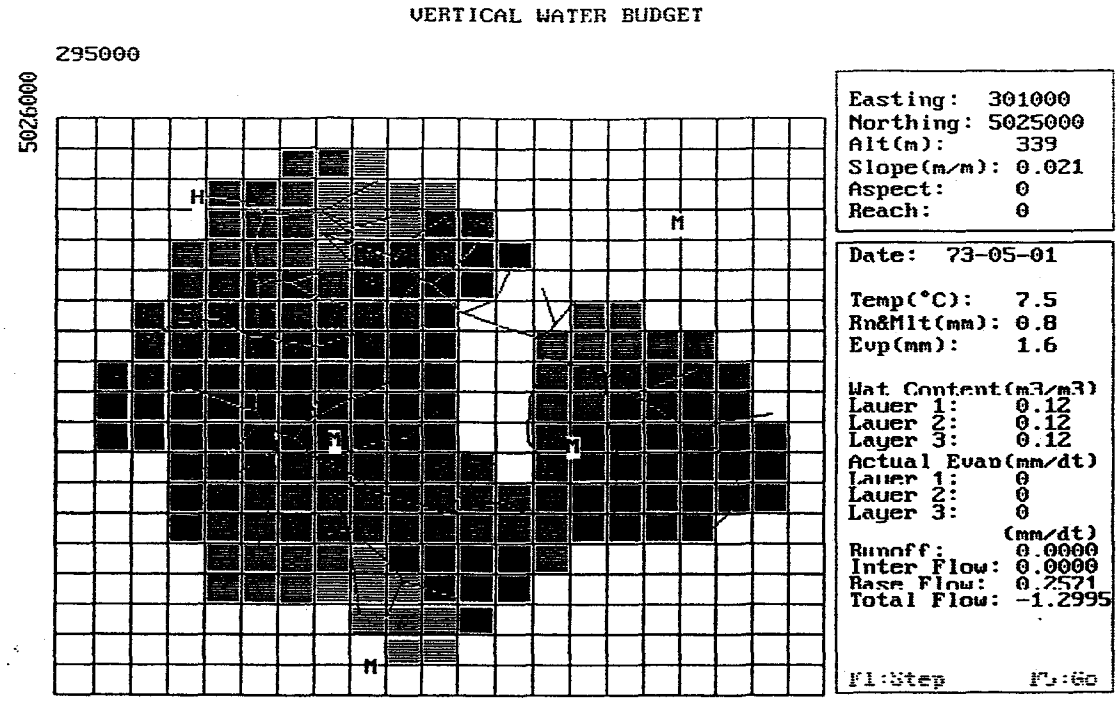


FIGURE 2.81 Tabular informations on variables related to water budget (BV3C).

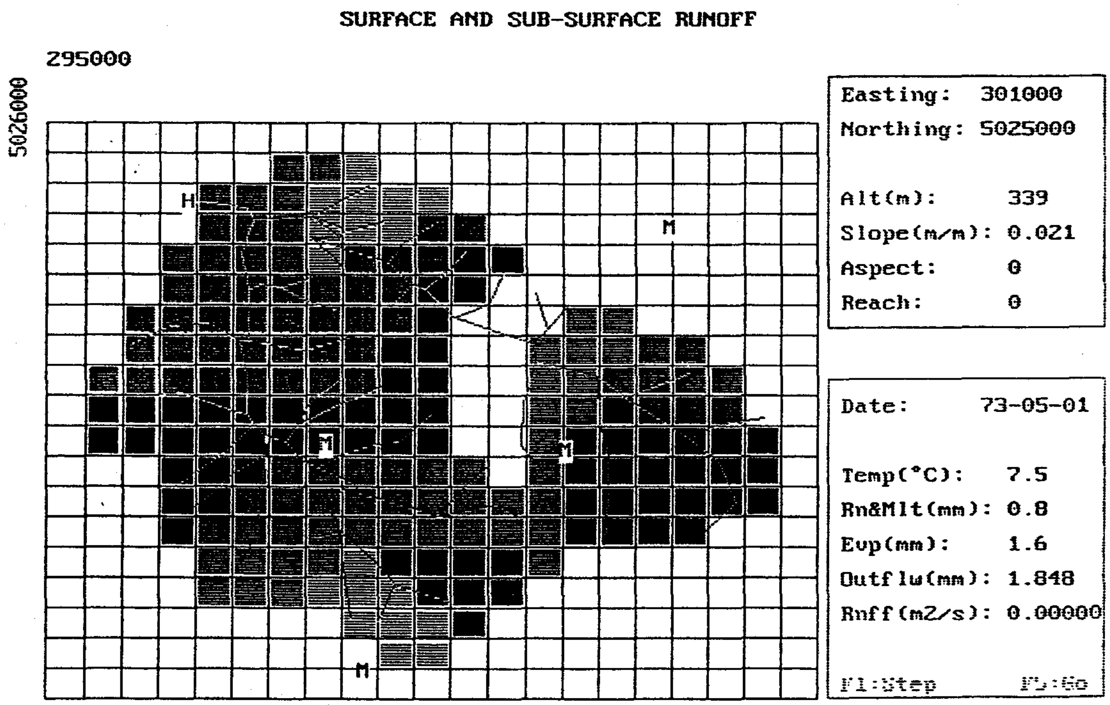


FIGURE 2.82 Tabular informations on variables related to surface runoff.

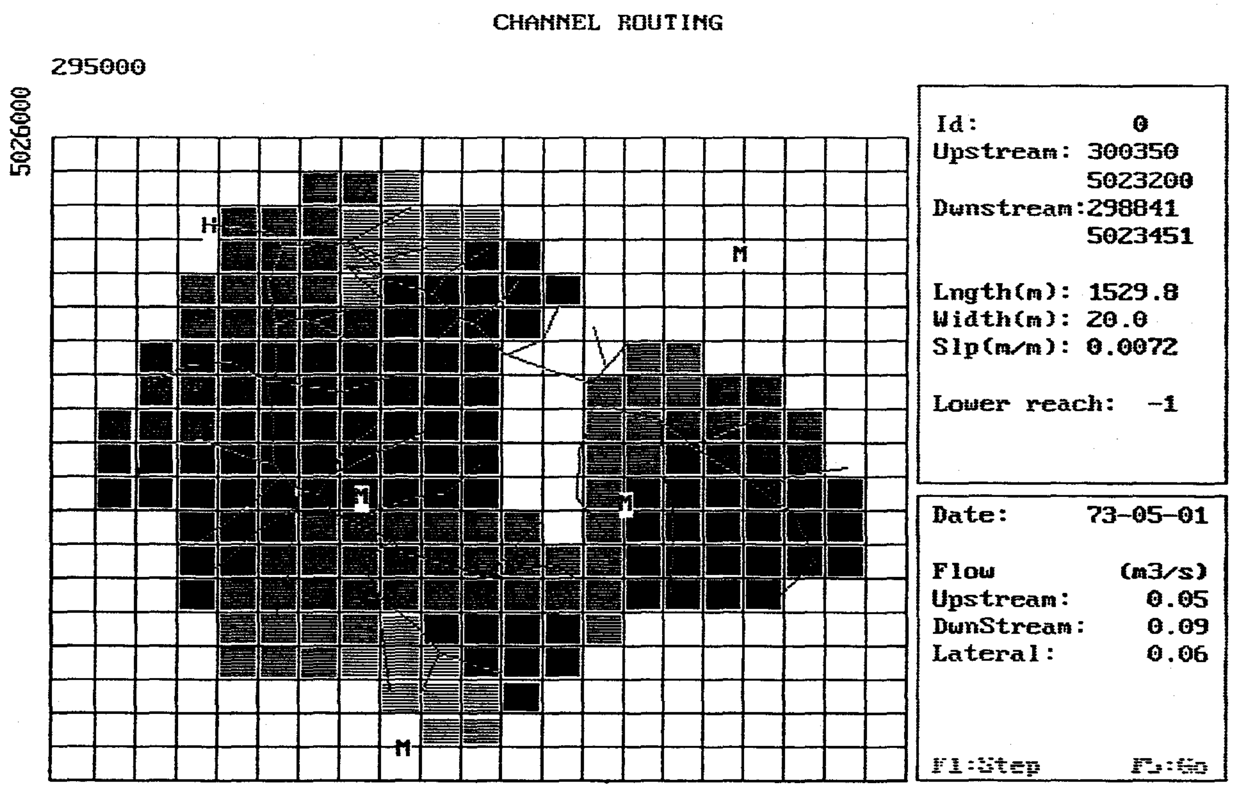


FIGURE 2.83 Tabular informations on variables related to channel routing.

2.3.7.4 Sub-menu #5.4: view final results

Sub-menu #5.4 contains three options (figure 2.84). The first option allows the user to display color coded maps of the last values taken by any of the variables listed in Table 2.2. See the section on color-coded maps under menu #5.3 for informations on how to select variables and scales.

Both the simulated and measured hydrographs at the location specified in sub-menu #1.3 can be displayed, if option 2 is selected . If there is no streamflow station in the vicinity (100 meters) of that location, only the simulated hydrograph is shown.

```
HYDROTEL

1._ Simulation parameters;
2._ Optimization parameters;
3._ Data input;
4._
5._ DATA OUTPUT
6._
7._ 1._ File specification;
0._ 2._
    3._ VIEW FINAL RESULTS
    0._
        1._ Color code maps;
        2._ Streamflow hydrograph;
        3._ Statistics;
        0._ Return to previous menu.
```

FIGURE 2.84 Sub-menu #5.4: view final results.

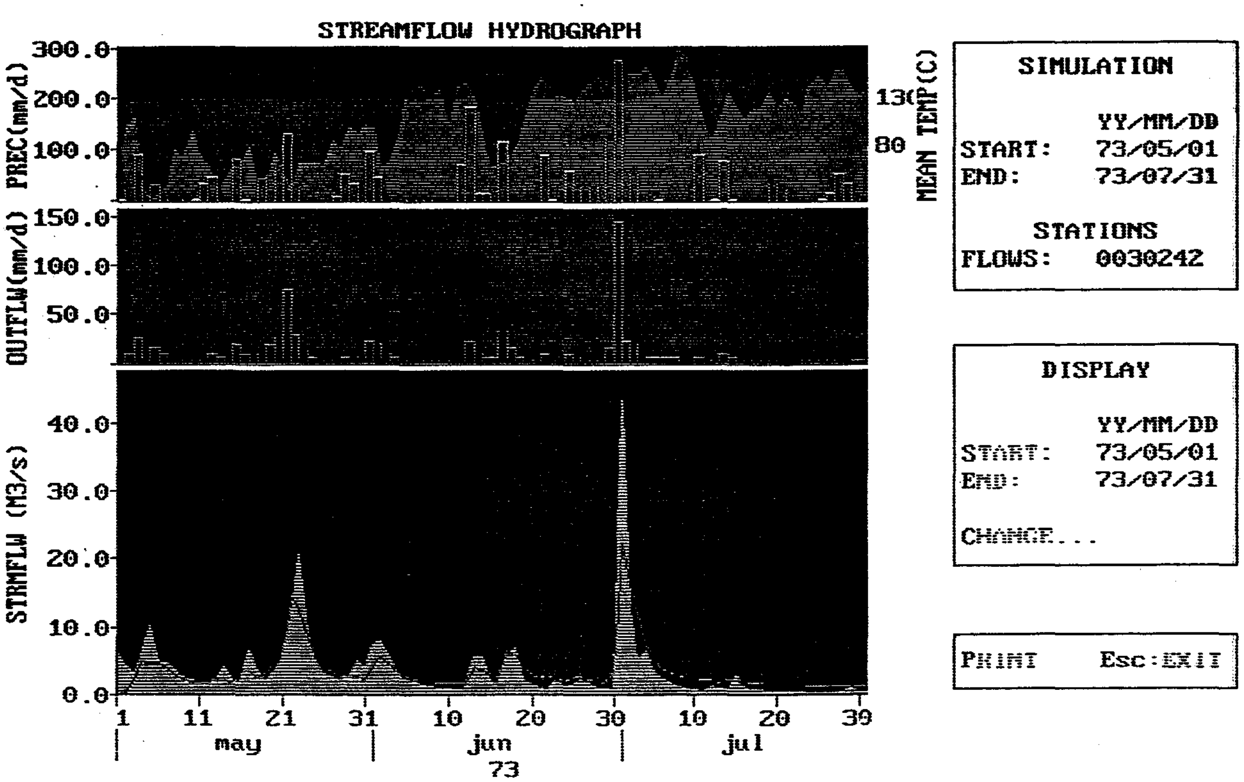


FIGURE 2.85 Streamflow hydrograph.

The display is divided into four windows (figure 2.85). 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 central window. In the lower window, measured streamflows are displayed (light color against a dark background) together with simulated streamflow (solid line).

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

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

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

  1. Move the cursor to the day(s) or year(s) to be modified.
  2. Press 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. Press the "ENTER" key. The new window is then displayed.

- Modification of the position or size of the display window

  1. Move the cursor to "window" and press the "ENTER" key to activate this mode.
  2. Using the arrows it is possible to displace the display window towards the beginning or end of the simulation period. Pressing the "+" key will increase the display window (max: 365 values), whereas pressing 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, press the "ENTER" key again.
4. Move the cursor to "display new window" and press the "ENTER" key. The window is then displayed.

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

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

Note that there is a time delay before printing starts.

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

Statistics on the simulation can be looked at when option 3 is selected. Read section 2.4.1.1 for a description of the criteria and other statistics in figure 2.86.

Statistics on the simulation can be looked at when option 3 is selected. Read section 2.4.1.1 for a description of the criteria and other statistics in figure 2.86.

HYDROTEL

1._ Simulation parameters;

STATISTICS

Measured and estimated runoff (monthly values):

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.0	0.0	0.0	0.0	64.0	30.5	20.6	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	54.2	43.8	30.7	0.0	0.0	0.0	0.0	0.0

Measured and estimated runoff (total):
115.1
128.8

$\Sigma (Q_o - Q_c)^2$: 18.06
Nash-Sutclif: 0.34

FIGURE 2.86 Statistics on the simulation.

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 is also included in HYDROTEL 2.1, together with 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, visual comparison of simulated and measured streamflows can be used to help in the calibration of model parameters. However, as shown in figure 2.86, streamflow statistics and numerical criteria are also available to help in the calibration. More specifically, simulated and measured monthly and annual (or total) runoff values are computed and displayed for comparison, upon request.

If total simulated and measured runoff values are close, the water budget is respected over the simulation period. Monthly values are used to verify if the distribution of runoff over time is also respected.

Also computed are two goodness-of-fit criteria:

$$Fc_1 = \Sigma \; (Q_o - Q_c)^2$$

and

$$Fc_2 = 1 - \frac{\Sigma \; (Q_c - Q_o)^2}{\Sigma \; (Q_o - \overline{Q}_o)^2}$$

where:

Q_o = measured streamflow at time t (m^3s^{-1});
Q_c = simulated streamflow at time t (m^3s^{-1});
$\overline{Q}_o$ = mean streamflow over the simulated period.

Fc_1 is used in the objective optimization process. The smaller the value of Fc_1, the better the result. Comparisons are easy to make between simulation results, if the same period is used for a number of simulations. However, as Fc_1 depends on the actual values taken by Q_o and Q_c, it will changes as a function of simulation period and watershed.

Fc_2, as seen by the formulation, is the NTD criteria used by the World Meteorological Organization for the intercomparison of hydrological models. This criteria was originally suggested by Nash. A perfect fit is obtained when Fc_2 is equal to one. As the difference between simulated and measured streamflows becomes larger and larger, Fc_2 falls down to zero and even to negative values. If Fc_2 is negative, this means that the mean measured streamflow $\overline{Q}_o$ would be a better estimator of Q_o than Q_c, on the average. One should be aware that if the maximum amplitude (Q_o - $\overline{Q}_o$) is relatively small, Fc_2 may become over sensitived to the difference Q_o - Q_c, resulting in values of Fc_2 not close to 1, whereas, as seen on the hydrograph, Q_c and Q_o may be relatively close to one another.

Also, as both simulated and measured streamflows are available on files, the user has the possibility of using its own criteria to find the best parameter values.

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 Calibration strategy

The following applies primarily for sujective calibration, but could also be used in the case of objective 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.

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.

In the pre-calibration sensitivity analysis you may have found out that changing the value of a particular parameter affects the simulated streamflows much more than a similar change in another parameter. This is the reason why it can be worthwhile to optimize parameters in a certain order.

In practice, the experienced user will without any doubt, develop his own calibration strategy. A strategy, based on our experience, and easy to follow step by step is still suggested:

Step 1: Total streamflow

Try first to obtain similar total simulated and measured streamflows over the period. In other words, the total water budget must be respected. Measured precipitations (as well as their spatial distribution) must be representative of the true areal precipitation on the watershed. Actual evapotranspiration should also be looked at and adjusted if needed. The vertical water budget could also affect total streamflows, but it should normally not be the case, unless a very large storage capacity is available and the water stored at the end of the period is much larger than that at the beginning.

Step 2: Monthly distribution of streamflows

It is normal to notice that simulated values are higher than measured values for a particular month and lower for another month, specially if that variation is small and random. If, in summer, the simulated streamflows are systematically smaller than measured streamflows, that may results from an erroneous repartition between surface (and interflow) and base flow or from high values of actual evapotranspiration, compensated in fall by low values. So, look at the parameters that affect the repartition between the various flows in the vertical water budget sub-model and check the evapotranspiration distribution in time.

In spring, high melt rates will give an early flood. Check the streamflows in the melt period to verify if melt rate are too high (snowmelt sub-model). This will be the case, for instance, if the spring flood is over two months and the simulated streamflows in the first month are higher than the measured streamflows, whereas they are lower in the following month.

Step 3: Flood volumes

Once the monthly distribution of streamflows is good, it is possible to look at individual flood volumes. Again, measured precipitations at stations, even if they are representative on the average, may underestimate or overestimate a particular precipitation event. It is normal to notice simulated flood volumes over or under measured flood volumes, provided this is not systematic.

Overestimation or underestimation of flood volumes may come, in spring, from melt rates or the remaining water equivalent of the snowpack (wrong estimation of solid precipitation). For instance if the estimated water equivalent is lower than it should be, the simulated flood volumes at the end of the melt period can be much lower than the measured volumes.

At this step, it might be a good move to "fine tune" the parameters responsible for the vertical distribution of the water profile and the outflow (surface and inter-flow) in the vertical water budget sub-model, as well as the melt parameters in the snowmelt sub-model.

Step 4: Peak flows and hydrograph shape

A fine adjustment of the outflow parameters in the vertical water budget sub-model, together with adjustment of the parameters controling surface and sub-surface runoff as well as channel routing should be done at this step. The parameter(s) responsible for interflow in the vertical water budget sub-model will affect the slope of the recession portion of the flood hydrograph, whereas the slope of the streamflows between flood events depend on the recession coefficient of the saturated part of the vertical water profile.

More informations on the effects of various parameters on the simulated hydrographs will be given in Part 3 of this user's guide, together with the descriptions of the main equations programmed in HYDROTEL 2.1.

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

2.4.1.4 Objective calibration

Objective calibration of specific model parameters is available with HYDROTEL 2.1. The approach favored in the development of the objective optimization process is the following:

- optimization of coefficients multiplying parameter or estimated variable values, rather than direct optimization of parameter or variable values. Optimization of parameter or variable values in user's defined options is made easier, since only those coefficients are transfered to the optimization sub-program;

- multiplication by a specific optimization coefficient of a group of parameters (e.g.: the three melt factors in the snowmelt sub-model) which may also be modified independently manually if needed. This simplifies the optimization process;

- possible use of the optimization coefficients for subjective calibration of parameter or variable values.

The procedure to follow for a calibration run is described next.

All coefficients can be optimized at the same time, but following the strategy suggested in 2.4.1.3 could give better results. The optimization algorithm is the one developed by Powell and described by Press et al. (1988). With that algorithm, at each iteration, the value of each coefficient is optimized one after the other. The program go to the next coefficient, when the difference between two successive evaluations of the coefficient is less than a tolerance threshold. At the end of each iteration the objective function is evaluated. The optimization process stop when the change between two successive values of the objective function at the end of each Powell iteraction is less than a predetermined tolerance threshold.

In order to optimize a coefficient, its "state" should be "ON". The default initial value is "1", meaning that the starting value is that given in input or resulting from a computation (evapotranspiration). Another initial value can be given if it is believed that it would be better. The range is also given. Default values are "0" for the minimum value and "100" for the maximum value. Those values can also be changed, according to the user's expectations. The minimum and maximum values taken by the coefficients have to be related to the expected range of the values taken by the parameter or variable they multiply.

Once all variables to be optimized have been selected, the optimization process itself has to be activated. This is done in sub-menu #2.0. Do as explained in section 2.3.4.

At the end of an optimization run, the optimized coefficients will be saved for later use.

The procedure to follow to use optimized coefficients for a normal simulation run or for subjective calibration is now described.

First, the optimization process must of course be "OFF" in sub-menu #2.0.

It should be noted here that the coefficients are always multiplying the variables to which they are assigned. If the optimized (or modified) value of a specific coefficient is not wanted, its value must be returned to "1".

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 purposes, 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. No matter which model is used, it is easier to start the simulation when only base flow is contributing, that is one or two days after the last rainfall.

Two sub-models are available with HYDROTEL 2.1.

2.4.2.1.1 *CEQUEAU (modified)*

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

A few days after the last rainfall, the actual water level in the unsaturated reservoir should be below the threshold level for sub-surface runoff. Moreover, if the threshold level for percolation to the saturated zone reservoir is identical to that for sub-surface runoff, then the water level in that reservoir is equal to these thresholds at the end of the flood and decreases only by evapotranspiration. It is then only necessary to estimate total actual evapotranspiration since the water 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 cells or HHU's, if sub-menu #4.4.1.5 is used to do so. It is also possible to give individual values to cells or HHU's using sub-menu #3.2.2.

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

$$H = \frac{86.4\ Q_o}{A \bullet C} \tag{2.1}$$

where:

H = water level in saturated zone reservoir (mm);
Q_o = 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 section 2.4.2.2.1.

The third state variable for which an initial value has to be given is the level in the PONDS and MARSHES reservoir of each square. Unless ponds 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 ponds and marshes is important and it is felt by comparison of simulated and measured streamflows that changing the initial value would help. It is suggested to test the sensitivity of changes in that reservoir.

2.4.2.1.2 *BV3C*

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

Again, a few days after the last rainfall, in the surface layer, θ_1 should be close to θcc, the water content at field capacity, maybe a little below.

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

The value of θ_3 should be determined with relation to streamflow, as for the saturated zone reservoir of the CEQUEAU model, knowing that the product $Z_{33}\theta_3$ in equation 3.22 is equivalent to H in equation 2.1. Since layer 3 is, in the actual case, the only layer providing water for streamflow, θ_3 must be greater than θ_{cc}.

More accurate values will be obtained if total actual evapotranspiration at the end of drainage is estimated and distributed between the three layers.

2.4.2.2 Water in transit

At any time, water is in transit to the outlet of the basin, over the cells or HHU's or in the reaches. This also has to be initialized.

2.4.2.2.1 *First simulation on a new basin*

As the saturated zone reservoir in CEQUEAU and layer 3 in BV3C have similar behaviour, the method can be used to obtain initial values of water in transit from both sub-models.

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 cells or HHU's) in the saturated zone reservoir corresponding to the measured streamflow Q_O.

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

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

where:

H_{t-n} and H_t = water level in saturated zone reservoir at time (t-n) and time t, respectively, t being the time corresponding to "start of simulation" in sub-menu #1.2;

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 (CEQUEAU) or layer 3 (BV3C). To stop water from going out of other reservoirs or layers, utilize the following values or similar ones:

- Sub-menu #1.2:

  - end of simulation: 30 days or more after the beginning of the simulation.

For CEQUEAU:

- Sub-menu #4.4.1.1:

  - depth threshold for surface runoff (mm): 100.

- Sub-menu #4.4.1.2:

  - capacity of the reservoir (mm): 500;
  - runoff coefficient: 0.0;
  - percolation coefficient: 0.0.

  Leave other parameters with default values.

- Sub-menu #4.4.1.3:

  - type your own values or use default values. Remember that the outflow coefficient is used in equations (2.1) and (2.2).

- Sub-menu #4.4.1.4:

  - outflow coefficient: 0.0.

  Leave the other parameter with its default value.

- Sub-menu #4.4.1.5:

- saturated zone (mm): value of the water level at H_{t-n} as estimated above by equation (2.2).

For BV3C:

- Sub-menu #4.4.2.2:

  Initial water content θ/θ_s of each layer:

  - layers 1 and 2: 0.01 or other low value;
  - layer 3: weighted value derived from 2.2, recalling that $Z_{33}\theta_3 \equiv H$ (eq. 2.1) and that many soil types may exist in the basin with various water content θ_{cc} at field capacity.

  Bottom of each layer:

  - layer 1: 1.5 m or other large value;
  - layer 2: 3 m or other large value;
  - layer 3: bottom depth Z_3 so that $Z_{33} = Z_3 - Z_2$ has the required value (see above) and corresponds to the thickness estimated for that layer.

    In other words, layers 1 and 2 are made very thick to absorb all infiltrated rain during the initialization period.

- Sub-menu "OPTIMIZATION PARAMETERS" corresponding to chosen evapotranspiration option:

  - state: ON;
  - initial: 0.01.

  The setting of the coefficient multiplying all evapotranspiration values to a very low values will allow to have negligeable AET values for the initialization process of the water in transit.

First initialization simulation

River network without lakes or reservoirs

Make a first initialization simulation and save the intermediate streamflow results. 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.

River network with lakes and/or reservoirs

Flood hydrographs are damped by lakes and reservoirs. If those are relatively large, they will control most of the flow variation in recession periods. Known water levels above the threshold level of the control section of each lake would be important. If they are not known, proceed to a serie of simulations, as explained above. The first of these simulations could be done with a water level a little over the threshold level. If the streamflows are too low, the water levels in lakes could be rised slowly.

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 over the cells or HHU's and in the reaches 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 over the cells or HHU's and in the reaches, on a particular basin, they can be used for later simulations, provided the initial streamflow is relatively close to that corresponding to data on the files.

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

2.5 USING HYDROTEL 2.1 FOR FORECASTING

An updating routine is not incorporated to HYDROTEL 2.1 for forecasting purposes. However, it is possible to use HYDROTEL 2.1 for that purpose, to a certain extent.

If HYDROTEL 2.1 is used in a forecasting mode, the state variables can be saved on the last time step with measured input data and not on the last time step of the simulation. In practice, the time step at which data will be saved is asked for in the program. It should be understood that the other input data used for streamflow forecasting are also forecasted data, which are changed at each forecast. The updating procedure, if needed, has to be carried out outside of HYDROTEL 2.1. Updating of state variables can be done as a result of such a procedure or from a more subjective decision process based on the comments made in Part 3 of this manual on the effects of the various hydrological processes on the streamflows.

PART 3

MAIN SIMULATION EQUATIONS AND FLOW CHARTS

PART 3 MAIN SIMULATION EQUATIONS AND FLOW CHARTS

3.1 INTRODUCTION

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

3.2 SPATIAL DISTRIBUTION OF PRECIPITATION

Two 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 Estimation of precipitation on individual cells

3.2.1.1 <u>Thiessen polygons</u>

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

3.2.1.2 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 cell. The weights are inversely proportional to the distance and their sum must equal one.

3.2.2 Estimation of precipitation on homogeneous hydrological units

If homogeneous hydrological units are used, weights are first computed for each cell identified to a particular HHU, using one of the methods presented above. The weights are subsequently summed up for all cells identified to a HHU and the total weight for each station is equal to the total weight for that station divided by the sum of the weights for all stations, so that the final sum of the weight is again equal to one.

So, more than one station may be used to estimate the precipitation on a HHU, with Thiessen polygons, and more than three stations in the second case.

3.2.3 Effect on streamflows

Remember that no matter what hydrological model is used, it is impossible to obtain good results if the available stations are not representative of the precipitation regime over a watershed. Make sure your meteorological data are representative of all parts of a watershed before even thinking of applying a model on a watershed.

Problems will normally be encountered if all stations are located in valleys. Also, do not be surprised if a flood is missed from time to time. That may come from occasional lack of representativeness.

3.3 SNOW COVER SIMULATION AND MELTING

Only a modified degree-day method is available with HYDROTEL 2.1.

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 cell or HHU, depending on its mean altitude.

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

If the simulation time step (hours) is 24 hours and there is no hourly data available, then all precipitation is considered as solid if the maximum air temperature $T_x \leq T_{th}$. When $T_x > T_{th}$, the fraction of precipitation W considered as rain is equal to $(T_x - T_{th})/(T_x - T_n)$, T_n being the minimum air temperature. The fraction of precipitation considered as snow is 1 - W.

When the time step is less than 24 hours, hourly values are assumed to be available and the hourly precipitation is added to either the rain or the snowfall total depending on $T_a - T_{th}$, where T_a is the air temperature at hour h.

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.

$$\rho_s = 151 + 10.63\ T_a + 0.2767\ T_a^2 \tag{3.1}$$

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):

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

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 (Frank and Lee, 1966);
R_h = radiation index for a horizontal surface;
T_a = air temperature (°C);
T_s = threshold temperature (assumed to be 0°C by Riley et al. (1972));
A = albedo of snow;
R = rainfall (mm).

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

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

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

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

3.3.3 Input variables

Values of input variables are assumed to be identical for each cell or HHU 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} $^{\circ}C^{-1}$): melt factors for coniferous forests, deciduous forests and open areas respectively. Effective cover should be taken into account when choosing a particular value. The smallest value should be given to CFR and the greatest to CFD. Actual values usually range between 2 and 5 mm d^{-1} $^{\circ}C^{-1}$;

- DSNGX (kg m^{-3}): maximum density of snowpack (usually at the end of the season). A value of DSNGX ranging approximately from 450 to 600 km m^{-3} could be assumed. It is suggested to look at past snowcover records in the region under study to decide upon a value;

- FONSFOL (mm d^{-1}): melt rate at the snow-ground interface. That value should be relatively low, taking into account the actual ground condition in the basin. For instance, Riley et al. (1972) assumes 0.5 mm d^{-1}. It is suggested to define such a value with an equation based on the average thermal gradient in the upper layer of the ground. Other values cited in the literature are close to that used by Riley et al. (1972);

- TS (°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.

3.3.4 Effect on streamflows

The first effect comes effectively from the estimation of precipitation and more precisely of solid precipitations on the watershed. If solid precipitations are overestimated, the spring flood will be overestimated.

If floods are missed at temperatures around 0°C, this might be due to the threshold temperature for the transformation of rain into snow which is too high.

If the spring flood is in advance, the melt factors are too high.

3.4 EVAPOTRANSPIRATION

3.4.1 Potential evapotranspiration

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

3.4.1.1 Thornthwaite potential evapotranspiration

3.4.1.1.1 *The equation*

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

The equation is:

$$E_{th} = \frac{16.2}{30.4} \left[\frac{10\ T_a}{X_1} \right]^{X_2} C_1 * 10^{-3} \qquad (3.3)$$

where:

E_{th} = Thornthwaite potential evapotranspiration (m d^{-1});
T_a = mean daily air temperature (°C);
X_1 = Thornthwaite's thermal index;
X_2 = exponent derived from X_1;
C_1 = adjustment factor for latitude and day length.

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

3.4.1.1.2 *Input data*

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

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

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

- L_a: mean latitude of the basin (degrees and hundredth of a degree);

- J_{sol}: temporal shift parameter for the estimation of C_1. Usually, J_{sol} should be set to 80, to obtained the maximum day length at the end of June.

3.4.1.2 Linacre potential evapotranspiration

3.4.1.2.1 *The equation*

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

The equation is:

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

where:

$E_{lin(l)}$ = Linacre potential evapotranspiration for land-use classe l (md^{-1});
Δ = slope of saturation vapor pressure at temperature T_a (mb °C^{-1});

γ = psychrometric constant (mb °C^{-1});
A = albedo of land-use class I;
T_a = mean daily air temperature (°C);
T_M = sea-level equivalent of the measured mean temperature T_a
$T_M = T_a + 0.006\ h_a$;
T_d = dew point temperature;
h_a = altitude (m);
L_a = mean latitude of the basin (degrees and hundredth of a degree).

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

$$\frac{\Delta}{\Delta+\gamma} = C + D\ T_a \tag{3.5}$$

where:

C = intersect for T_a = 0°C;
D = slope (°C^{-1}).

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

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

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

where:

T_{JX} and T_{JN} = maximum and minimum daily air temperatures (°C);
T_{MX} and T_{MN} = mean air temperature of the warwest and coldest months, respectively (°C).

3.4.1.2.2 *Input data*

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

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

- T_d = dew point temperature at climatological stations;
- L_a = mean latitude of the basin (degrees and hundredths of a degree);
- C and D = the constants for the linear approximation to $\Delta/(\Delta + \gamma)$.

Also, if T_d values are not available, then proper values for the following variables should be read:

- T_{MX} = mean air temperature of warmest month (°C);
- T_{MN} = mean air temperature of coldest month (°C).

3.4.1.3 Monteith - Penman potential evapotranspiration

3.4.1.3.1 *The equation*

Two formulations of the original Penman equation are available.

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

The second one keeps Penman's empirical wind function.

The general formulation of the equation is:

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

with, in either case:

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

If R_g is not measured then:

$$R_g = Ig_a\ (A + B\ h/H) \tag{3.9}$$

and for option 1: (more theoretical wind function)

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

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

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

where:

E_p	=	Penman potential evapotranspiration (m d^{-1});
Δ	=	slope of the saturation vapor pressure at temperature Ta (mb k^{-1});
R_n	=	net solar radiation (J m^{-2} d^{-1});
E_a	=	term representing the "drying power of the air" (Jm^{-2} d^{-1} mb k^{-1});
γ	=	psychrometric constant (0.6638 mb k^{-1});
L_e	=	latent heat of vaporization (2.466 X 10^6 J kg^{-1});
A(I)	=	albedo of land-use class I on day d;
R_g	=	global daily solar radiation (J m^{-2} d^{-1});
σ	=	Stefan-Boltzman constant (4.8986 X 10^{-3} Jm^{-2} k^{-1} d^{-1});
T_a	=	mean daily air temperature (K);
h_r	=	relative humidity (%);
e_s	=	saturation vapor pressure for water at temperature Ta (mb);
h	=	hours of bright sunshine on day d (h);
H	=	day length on day d (h);
ρ	=	air density (1.2923 kg m^{-3});
c_p	=	specific heat of air (1005 J kg^{-1} k^{-1});
k	=	von Karman constant (0.4);
u_1	=	wind speed at height Z_1 (ms^{-1});
Z_1	=	height at which wind measurements are taken (m);
d(I)	=	zero plane displacement height (0.7 h_{veg}) (m);
h_{veg}(I)	=	height of vegetation land-use classe I on day d (m);
Z_o(I)	=	roughness length for momentum transport (0.13 (h_{veg}(I)-d(I))) (m);
Z_{ov}(I)	=	roughness length for water vapor transport (Z_o(I)/5) (m);
Ig_a	=	daily extraterrestrial solar radiation (Jm^{-2} d^{-1});
A and B	=	constants.

3.4.1.3.2 *Input data*

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

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

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

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

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

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

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

3.4.1.4 Priestley-Taylor potential evapotranspiration

3.4.1.4.1 *The equation*

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

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

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

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

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

$$E_{pt} = \alpha \, E_e \tag{3.13}$$

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

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

3.4.1.4.2 *Input data*

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

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

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

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

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

3.4.2 Actual evapotranspiration

No equation has been programmed for the estimation of actual evapotranspiration for HYDROTEL 2.1. However, it is possible to use AET values computed elsewhere or from a user's defined sub-program, as seen in menu #4.3.2.

The AET values should correspond to that of each land-use class. They will be distributed between the three layers in the vertical water profile simulated by BV3C, and summed up as shown in equations 3.26 to 3.36.

It is not possible to use the CEQUEAU vertical water budget in this case.

3.4.3 Effect on streamflows

Evapotranspiration has an effect on monthly or seasonal mean flow values, rather that on individual flood events. So, it has been found more appropriate, if needed, to correct evapotranspiration values, no matter what equation is used, by an (optimized) coefficient. The result is to get lower or higher evapotranspiration values leading to a better water budget over the simulation period. Of course, it is possible to make modification directly on the input values, if the user knows what should be changed in the particular equation he is using.

3.5 VERTICAL WATER BUDGET

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

3.5.1 CEQUEAU (modified)

3.5.1.1 Description of the function

In the CEQUEAU model (Morin et al., 1981) the vertical water budget on each of the cell is simulated with the help of three reservoirs (figure 3.1). The water budget on the fraction of the cell 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, or 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 cell, 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 cell.

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

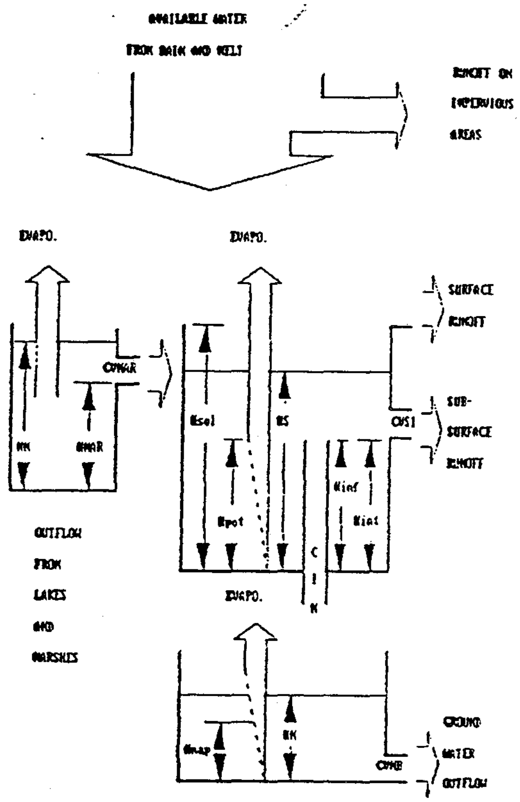


FIGURE 3.1 Vertical water budget adapted from the CEQUEAU model.

Evapotranspiration is satisfied using both reservoirs. A fraction of potential evapotranspiration is first taken out from the saturated zone reservoir. This fraction varies with HN, being greater if HN > HNAP and smaller if HN < HNAP. The remaining portion of the potential evapotranspiration, usually the greatest part of it, is taken from the unsaturated zone reservoir, at potential rate, if HS > HPOT and at a reduced rate if HS < HPOT.

The damping effect of lakes and reservoirs on the river network is simulated in the routing process, but in HYDROTEL 2.1, the water budget in the lakes and reservoirs is still simulated by the lake and marshes reservoir of the CEQUEAU model in the same way as the previous reservoirs.

So, at each time step, water becomes available on each cell of HHU as runoff from impervious areas, surface runoff, sub-surface runoff and ground water outflow from the land portion, and as outflow from lakes and marshes.

3.5.1.2 Input data

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

. Runoff on impervious areas:

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

. Unsaturated zone reservoir:

  - HSOL (mm): maximum depth of water which can be stored in the reservoir (capacity of the reservoir). This value corresponds to saturated conditions. It can be determined with reference to porosity and the mean thickness of the unsaturated zone in the basin;

- HINT (mm): threshold level for sub-surface runoff. This value, as that of HINF and HPOT below, should be estimated with reference to the field capacity of the unsaturated zone in the basin. It is suggested to give identical or nearly identical values to HINT, HINF and HPOT;

- CVSI: runoff coefficient. This parameter should be adjusted by looking at the volume of the flood and the shape of the recession part of the hydrograph, assuming simulation of channel flow is good;

- HINF (mm): threshold level for percolation from the unsaturated zone to the saturated zone;

- CIN: percolation coefficient. This parameter controls partly the distribution of infiltrated water between the unsaturated and saturated zone and thus between the volume of the floods and the base flow;

- X_{infma} (mm d^{-1}): maximum amount of percolation water at each time step;

- HPOT (mm): threshold level for evapotranspiration to occur at potential rate.

. Saturated zone reservoir:

- CVNB: outflow coefficient. The value of CVNB should be adjusted so that simulated streamflow decreases at the same rate as measured streamflow in low flow periods;

- EVNAP: reference fraction of evapotranspiration satisfied from water in the saturated zone. It is suggested to give a relatively low value to EVNAP (.10 for instance), unless the water table is usually high in the basin and water is effectively taken from the saturated zone by the roots;

- HNAP (mm): reference level over which the effective fraction of evapotranspiration taken from the reservoir is greater than EVNAP and under which it is smaller. The variation is linear.

. Lakes and marshes:

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

- CVMAR: outflow coefficient.

. Initial levels in the reservoirs:

- HS (mm): initial water level in the unsaturated zone reservoir. It should be noticed that HS decreases only by evapotranspiration below HINT HPOT and HINF, and is close to HINT at the end of a flood;

- HN (mm): initial water level in the saturated reservoir. The value of HN can be estimated with reference to base flow, when the value of CVNB is already optimized;

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

3.5.1.3 Effect on streamflows

The effects of the coefficient CVSI, CIN and CVNB on various characteristics of the hydrographs are mentionned in section 3.5.1.2. Other parameters also have effects. For instance if HSOL is too small, the unsaturated reservoir will be full rapidly resulting in surface runoff and quick floods. More generally, HSOL, HINT, HINF and HNAP are related to the storage capacity of the soil column. The threshold levels must also be related to field capacity. They control the speed with which the flow ceases after a rain event. Also, the difference between HINT and HSOL may be estimated with reference to saturation and field capacity for a soil column of a specific thickness.

3.5.2 BV3C

3.5.2.1 Description of the function

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

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

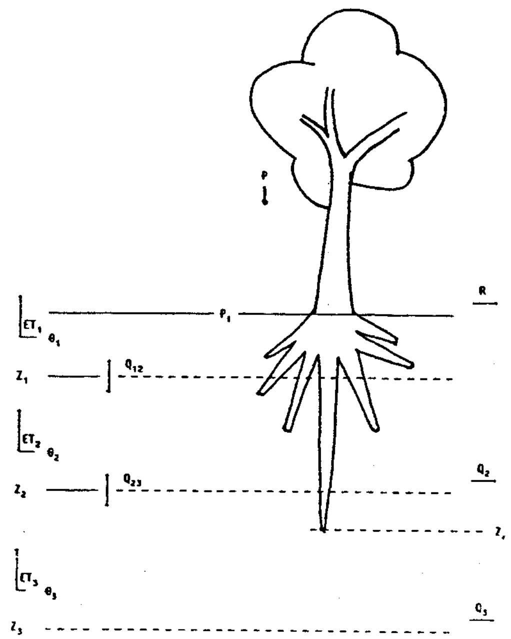


FIGURE 3.2 Vertical water budget in BV3C.

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

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

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

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

<u>All these values</u> Z_1, Z_2 <u>and</u> Z_3, <u>are assumed identical for all cells or HHU's within a particular basin</u>.

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

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

The following computations are done for each cell or HHU at each time step.

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

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

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

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

where:

K (θ_j) = hydraulic conductivity at water content θ_j in layer j (m h^{-1});
K_s = hydraulic conductivity at saturation for soil type k (m h^{-1});
θ_s = water content at saturation for soil type k;
b = $^1/\lambda$, λ being the pore size distribution for soil type k.

Next, the matrix potentials ψ (θ_j) are computed from an equation suggested by Clapp and Hornberger (1978) as a modification to Campbell's equation for ψ (θ):

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

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

with:

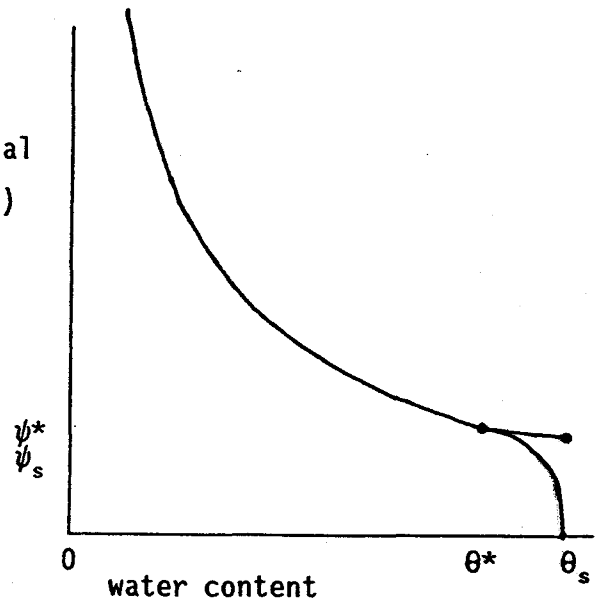
$$\theta^* = \theta_s \frac{1 + 2b}{2 + 2b}$$

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

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

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

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



(after Clapp and Hornberger)

FIGURE 3.3 Variation of the matrix potential with θ.

where:

$\psi(\theta_j)$ = matrix potential at water content θ_j (m);
ψ_s = matrix potential at θ_s (m);
and all other variables are defined above.

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

The vertical hydraulic conductivities between adjacent layers are estimated according to Mahrt and Pan (1984):

$$K_{12} = \max\left(K(\theta_1), K(\theta_2)\right) \tag{3.17}$$

and:

$$K_{23} = \max\left(K(\theta_2), K(\theta_3)\right) \tag{3.18}$$

where:

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

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

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

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

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

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

where:

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

The flow Q_2 out of layer 2 is:

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

where:

S (m,n) = slope of cell or HHU m,n (m/m).

Finally, the outflow Q_3 from layer 3 is:

$$Q_3 = K_r\ Z_{33}\ \theta_3 \tag{3.22}$$

where:

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

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

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

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

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

where:

Δt_c = actual time step used in the compulation (h);
ETR_1, ETR_2 and ETR_3 = actual evapotranspiration from layers 1, 2 and 3 respectively.

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

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

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

Evaporation E_s from bare soil is first estimated by:

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

where:

E_p = potential evapotranspiration (m d^{-1});
D = extinction coefficient;
LAI(I,t) = leaf area index for land-use classe I at time t;
Δt = time step (h).

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

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

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

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

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

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

where:

$\alpha(k)$ = coefficient depending on soil type k;
θ_{r1} = relative water content in the surface layer.

The actual bare soil evaporation is then:

$$E_r = C_s\ E_s \tag{3.29}$$

Next, transpiration has to be estimated for all three layers and each land-use class.

A mean water content $\bar{\theta}$ at time t for the soil profile influenced by a particular land-use class with root depth Z(I) at time t, is first computed as follows.

If $Z(I) \leq Z1$ (bottom depth of layer 1):

$$\bar{\theta}(I) = \theta_1 \tag{3.30a}$$

If $Z1 < Z(I) \leq Z2$ (bottom depth of layer 2):

$$\bar{\theta}(I) = (\theta_1 * Z1 + \theta_2 * (Z(I) - Z1)) / Z(I) \tag{3.30b}$$

If Z2 < Z(I) ≤ Z3 (bottom depth of layer 3):

$$\bar{\theta}(I) = (\theta_1 * Z1 + \theta_2 * (Z2 - Z1) + \theta_3 \, (Z(I) - Z_2)) \,/\, Z(I) \tag{3.30c}$$

Note that if Z(I) > Z3, it is set equal to Z3.

Then, the dryness coefficient $C_t(I)$ of land-use class I at time t is:

$$C_t(I) = \frac{1 - e^{-\alpha(k)\,\bar{\theta}(I)}}{1 - 2e^{-2^{\alpha(k)}} + e^{-\alpha(k)\,\bar{\theta}(I)}} \tag{3.31}$$

The mean actual transpiration $T_p(I)$ over the soil profile affected by land-use class I is then:

$$T_p(I) = C_t(I) \left[(E_p - E_s) \, (\beta + (1 - \beta \frac{E_r}{E_s} \right] \tag{3.32}$$

where:

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

$T_p(I)$ is next distributed over the soil profile affected by land-use class I to obtain actual evapotranspiration AET for each of the three soil layers.

For $Z(I) \leq Z1$:

$$AET_1(I) = E_r + T_p(I) \tag{3.33a}$$

$$AET_2(I) = AET_3(I) = 0 \tag{3.33b and c}$$

For $Z1 < Z(I) \leq Z2$:

$$AET_1(I) = E_r + T_p(I)\ [(\theta_1\ Z1) / (\bar{\theta}(I)\ Z(I))] \tag{3.34a}$$

$$AET_2(I) = T_p(I)\ [\theta_2\ (Z(I) - Z1) / (\bar{\theta}(I)\ Z(I))] \tag{3.34b}$$

$$AET_3(I) = 0 \tag{3.34c}$$

For $Z2 < Z(I) \leq Z3$:

$$AET_1(I) = E_r + T_p(I)\ [(\theta_1\ Z1) / (\bar{\theta}(I)\ Z(I))] \tag{3.35a}$$

$$AET_2(I) = T_p(I)\ [(\theta_2\ (Z2 - Z1)) / (\bar{\theta}(I)\ Z(I))] \tag{3.35b}$$

$$AET_3(I) = T_p(I)\ [(\theta_3\ (Z(I) - Z2)) / (\theta(I)\ Z(I))] \tag{3.35c}$$

And the actual evapotranspiration for each soil layer, weighted over all land-use classes is:

$$AET_1 = \sum_I P_A(I)\ AET_1(I) \tag{3.36a}$$

$$AET_2 = \sum_I P_A(I)\ AET_2(I) \tag{3.36b}$$

$$AET_3 = \sum_I P_A(I)\ AET_3(I) \tag{3.36c}$$

where:

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

If actual evapotranspiration $E_A(I)$ for each land-use class is available instead of potential evapotranspiration, the same procedure is used to distribute $E_A(I)$ between the three layers, starting at equation 3.26. The essential difference is that no reduction from $E_p(I)$ to $E_a(I)$ is made through the dryness coefficient for transpiration $C_t(I)$. This is equivalent to putting $C_t(I) = 0$ in equation 3.31.

3.5.2.2 Input variables

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

First, characterics of land-use classes have to be available. One variable is considered constant in time:

- ZP(I): maximum depth of the root system at maturity for land-use class I. We must have ZP < Z_3, the maximum depth of soil layer 3.

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

Those are:

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

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

In order to characterize each soil type k, values of θ_s, θ_{cc}, θ_{pf}, K_s, ψ_s, λ and α have also to be available. Values suggested by Rawls and Brakensiek (1989) (with the exception of α) are used as default values in the model (table 3.2 in section 3.9). If the user has better values, he may change the default values. Values for α are taken from Patoine (1988) and vary from 10 for sand to 0.5 for clay.

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

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

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

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

3.5.2.3 Effect on streamflows

Comments given in 3.5.1.3 generally apply to BV3C, if the change of variable is made. For instance, the outflow coefficients do have an effect similar to the hydraulic conductivities, HSOL corresponds to $Z_{ii}\theta_i$, and CVNB to K_r. The correct soil types should be chosen as representative of a cell or HHU because storage and outflow characteristics are related to soil type in BV3C.

The characteristics of the root system of each land-use class may also affect the hydrograph. For instance, on a cell or HHU where only bare soil or shallow root vegetation is observed, actual evapotranspiration will be taken out only from the layer 1 or layer 1 and 2. Layer 3 will be left more saturated. Base flow will be more sustained.

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

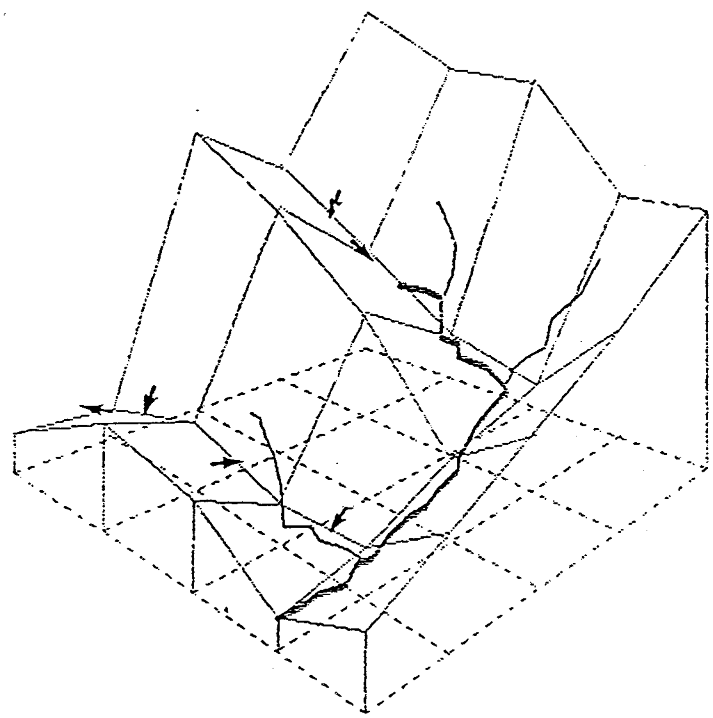


FIGURE 3.4 Surface and sub-surface runoff and channel flow.

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 cell are the following:
(continuity equation)

$$\frac{\partial R}{\partial x} + \frac{\partial h}{\partial t} = i \qquad (3.37)$$

(kinematic equation)

$$h = cR^d \qquad (3.38)$$

where:

R = surface runoff ($m^2\ s^{-1}$);
h = flow depth (m);
i = water available for runoff from the vertical water budget function ($m\ s^{-1}$);

$$C = \left(\frac{n}{1.49\ 1\sqrt{S_o}}\right)^{3/5};$$

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 Adaptation of surface and sub-surface runoff to homogeneous hydrological units

When HHU's are chosen as the simulation unit for the vertical water budget, the characteristics of the drainage network within these HHU's have to be taken into account. A procedure has been developped to do so, which starts from the cells from which the HHU's are made up. At the beginning of the simulation, a reference runoff equal for all cells and corresponding to one time step is made available for drainage from cell to cell within each particular HHU (using the kinematic wave equations as with a normal simulation with cells only) and flows down to its outlet, where the streamflows are stored as a function of time, until the volume corresponding to the reference runoff is completely evacuated. This distribution a streamflows constitutes a lag function characterizing the HHU. Thus, after that process, each HHU is characterized by a specific lag function.

During the simulation at each time step, and for each HHU (since the vertical budget is then computed for HHU's), the ratio of the actual runoff over the reference runoff is distributed in time using that lag function. The resulting streamflow becomes lateral flow to a river reach, since the outlet of a HHU must be to a river reach and not to another HHU.

3.6.3 Input data

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

- altitude (m): mean altitude of each cell;

- basin mask: binary matrix identifying the order in which cells within the basin are evaluated;

- slope ($m\ m^{-1}$): determined from the difference in altitude between contiguous cells;

- aspect: determined to eight directions from the difference in altitude between contiguous cells, by a steepest descent algorithm. Slope and aspect for each cell 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

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.

When HHU's are used, informations have to be given on:

HHU's: identification of the HHU' to which each cell belongs;
HHU's outlet: identification, for each cell in a particular HHU of the downstream HHU.

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.

Then one may 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. 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. A modified set of kinematic wave equations, permitting a larger range of applications has been programmed and is available in HYDROTEL 2.1, as is the approach using the diffusive wave equations.

3.7.1 Modified kinematic wave equations

3.7.1.1 Theory

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

- continuity equation

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q \tag{3.39}$$

- dynamic equation

$$\frac{\partial h}{\partial x} = S_o - S_f \tag{3.40}$$

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

- cross-section-discharge relationship

$$A = \alpha\, Q^{\beta}\; S_f^{-\beta/2} \tag{3.41}$$

- depth-discharge relationship

$$h = rQ^s \tag{3.42}$$

where:

Q = streamflow ($m^3\ s^{-1}$);
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 . $\alpha^* = \left(\frac{n}{1.49} B^{2/3}\right)^{0.6}$;

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.

3.7.1.2 Input data

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

For each reach end:

- identification number;
- UTM coordinates (m);

- altitude (m);
- channel width (m).

For each reach:

- identification number for lower end;
- identification number for higher end;
- Manning's roughness coefficient n;
- reach length (m).

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

3.7.2 Diffusive wave equation

3.7.2.1 Theory

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

$$\frac{\partial Q}{\partial t} = -C\frac{\partial Q}{\partial x} + \frac{\sigma}{C^2}\frac{\partial^2 Q}{\partial t^2} + \frac{2\sigma^2}{C^3}\frac{\partial^3 Q}{\partial x \partial t^2} \tag{3.43}$$

where:

Q = streamflow (m^3s^{-1});
C = celerity (ms^{-1});
σ = diffusion (m^2s^{-1});
t = time (s);
x = distance (m).

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

$$p^1Q(j-1,i-1) + q^1Q(j-1,i) + r^1Q(j-1,i+1) = pQ(j,i-1) + qQ(j,i) + rQ(j,i+1) \tag{3.44}$$

with:

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

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

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

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

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

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

and:

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

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

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

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

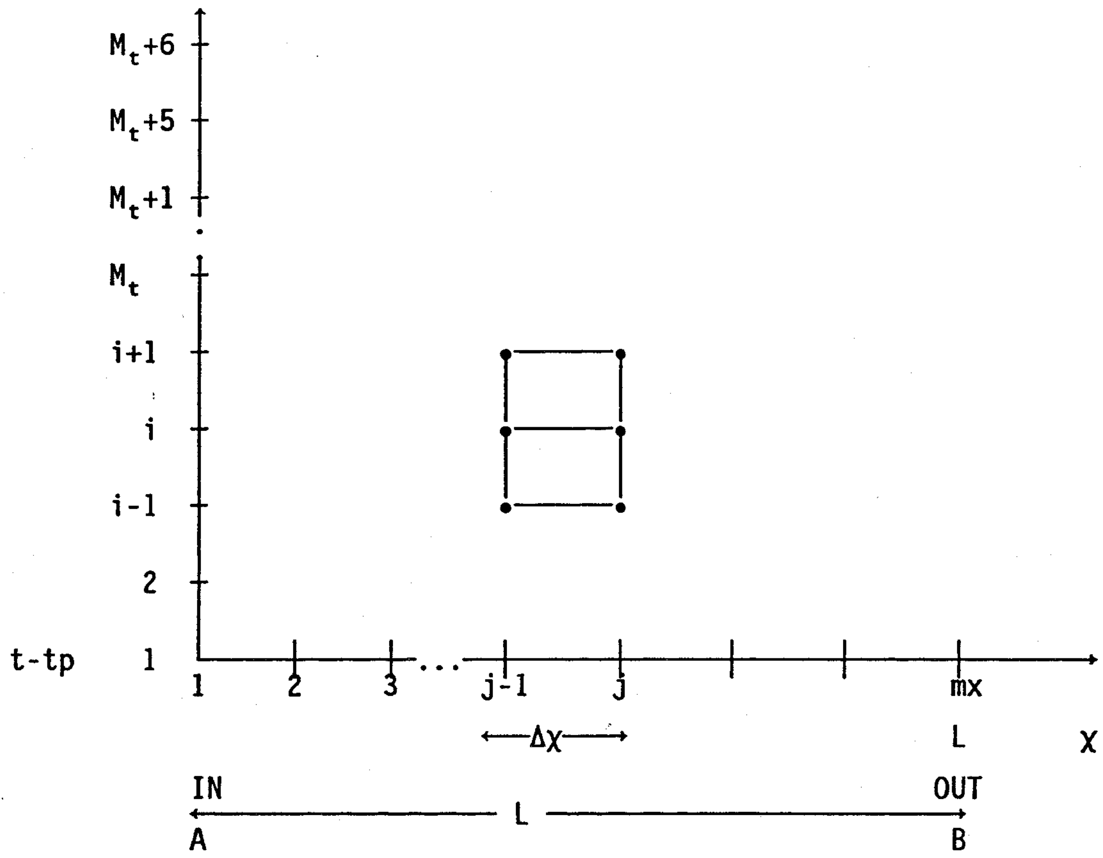


FIGURE 3.5 Finite difference scheme for the solution of the diffusive wave equation.

3.7.2.2 Input data

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

For each reach end:

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

For each reach:

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

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

3.7.3 Effect of channel routing on streamflows

When the river network consists only of river reaches without lakes or reservoirs, its mean effect is on the flood peak and the lag time between the simulated and measured peak. It also affects the shape of the hydrograph, but to a lesser extent.

Of course, the more reaches are used to represent the river network and the shorter they are, the more time is taken for the simulation of channel routing. Knowing that the celerity C of a wave is approximately 1 to 2 ms^{-1}, and with a reach lengths L a computation time Δt must chosen (by the program) to respect the following inequality:

$$C < L / \Delta t \qquad (3.45)$$

That time step will be shorter than the simulation time step, specially if the latter is 24 hours. More reaches and more time steps means more time to simulate river routing.

3.8 LAKE AND RESERVOIR ROUTING

3.8.1 Theory

With HYDROTEL 2.1, it is possible to include natural lakes and man-made reservoirs in the river network. The damping effect of lakes and reservoirs is simulated in the usual manner:

$$A(h_{t+\Delta t} - h_t) = \left[\frac{Q_{i_t} + Q_{i_{t+\Delta t}}}{2} \right]^{\Delta t} - \left[\frac{Q_{o_t} + Q_{o_{t+\Delta t}}}{2} \right]^{\Delta t} + \left[\frac{q_t + q_{t+\Delta t}}{2} \right]^{\Delta t} \tag{3.46}$$

where:

A = lake or reservoir surface (m^2);

h_t and $h_{t+\Delta t}$ = stage level of lake at time t and t+Δt respectively;

Q_{i_t} and $Q_{i_{t+\Delta t}}$ = input streamflows at time t and t+Dt (m^3s^{-1});

Q_{o_t} and $Q_{o_{t+\Delta t}}$ = input streamflows at time t and t+Δt (m^3s^{-1});

q_t and $q_{t+\Delta t}$ = lateral inflows at time t and t+Δt (m^3s^{-1}).

Since $Q_o = f(h)$, solving equation (3.46) is not straighforward, but is facilitated by the use of a stage-discharge relation of the form:

$$Q_o = C\ h^k \tag{3.47}$$

where:

C = $\sqrt{g} * L$ (for a rectangular section);
g = 9,8 ms^{-1};

L = width at the outlet of the lake;
k = 1,5.

It is possible to read the C and k values as inputs if other values should be use to describe the stage-discharge relationship.

In practice, the Newton-Raphson method is used to solve equation (3.46), a first estimation on $ht+\Delta t$, being obtained by assuming constant outflow Q_{ot} over the time step Δt.

3.8.2 Input data

The following informations must be input.

At each end of the lake or reservoir (as for channel reaches):

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

For each lake or reservoir:

- identification number for lower end;
- identification number for higher end;
- lake or reservoir area (km^2) (converted to m^2 by the program).

3.8.3 Effect on streamfloms

Depending on their location in the river network, relative to the outlet and their area, lakes and reservoir may have quite different effects. A large lake controling most of the watershed will have a very important damping effect on the peak flows at the outlet of the watershed. Also, small private reservoirs located on small watersheds may be the cause of unexpected flood waves impossible to simulate, or, on the contrary, their owner will store the flood volume, while the model will assume there is no storage.

If you have reasons to believe that a number of small reservoirs may affect the streamflow regime, be careful.

3.9 LAND-USE CLASSIFICATION

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

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

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

1. bare fields;
2. crops and pasture 1;
3. crops and pasture 2;
4. extractive areas (gravel, sand pits, ...);
5. forested areas 1 (coniferous);
6. forested areas 2 (deciduous);

7. highways and other impervious areas;
8. surface waters 1 (large streams, rivers and lakes);
9. surface waters 2 (narrow streams);
10. urban areas;
11. waste lands and bushes;
12. wetlands, marshes.

These classes should be considered as preliminary. More meaningful and appropriate classes should be obtained from the first applications to particular basins and new simulation equations. One has probably noted that the general classes "crops and pasture", "forested areas" and "surface waters" are already divided into two sub-classes. The idea is to facilitate classification and, at the same time, be ready as much as possible for the introduction of new equations. 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.

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

- albedo;
- leaf area index;
- height;
- maximum root depth;
- actual depth of the root system on day d.

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

The next two variables describe the root system. The first one is constant in time, and the last one can vary in the same way as the other variables.

Default values for all those variables are given in the files accompanying this program. It is important to repeat that the 12 land-use classes listed above are not absolutely necessary to run the model. As a matter of facts, for various historic reasons, most models do not differentiate between land-use classes, or use only a few broad classes, namely forested areas, agricultural areas, urban areas, (sometimes assimilated to impervious areas), and water surfaces.

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

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

3.10 SOIL TYPES AND HYDRAULIC CHARACTERISTICS

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

Variables representing hydraulic properties of soil types are used in BV3C, one of the available options for the simulation of the vertical water budget. The values appearing in Table 3.2 come from Rawls and Brakensied (1989) with the exception of α which comes from Patoine (1988).

Those values should be seen as initial values that can be given to the variables, which can be changed by the user. The actual values for a particular soil type and basin may differ, but at least, the values in Table 3.2 should represent, in the average, good initial values.

The proportions of sand, silt and clay appearing for each soil type are not used in the model. They are included in Table 3.2 only to help the user in the selection of a soil type, if such information is available.

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

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

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

TABLE 3.2 Soil hydraulic properties classified by soil texture.

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APPENDIX A

INTERNAL STRUCTURE OF THE PROGRAM

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HYDROTEL's goal is to simulate streamflows, to achieve this goal, the simulation process has been divided into six parts:

- interpolation of meteorological data;
- snow melting;
- real and potential evapotranspiration;
- vertical water budget;
- surface and sub-surface runoff;
- channel routing.

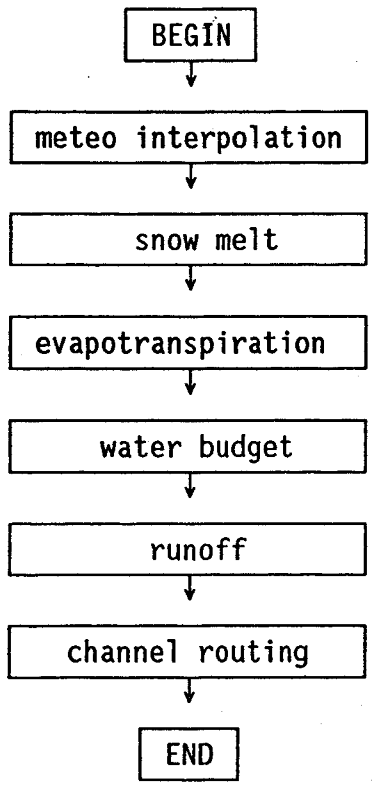

FIGURE 1 The sub-process sequential evaluation.

Each of these sub-processes has been sub-divided into three steps: initialization, modelisation and conclusion.

During the initialization step, the initialization functions are called in the order given above, once for each sub-process. At this step, the program allocates space and initializes variables, opens files and prepares them for further readings or makes time invariant computations.

In the modelisation step, as in the initialization step, each of the sub-models are called in the same order as above, once for each sub-process and repeated for each time step. At each call, a sub-process must do the computations for all the basin cells (HHU's) or all the river reaches and store the results in the appropriate global variable.

Finally, during the conclusion step, each of the sub-processes is called once to deallocate space, close open files and so on.

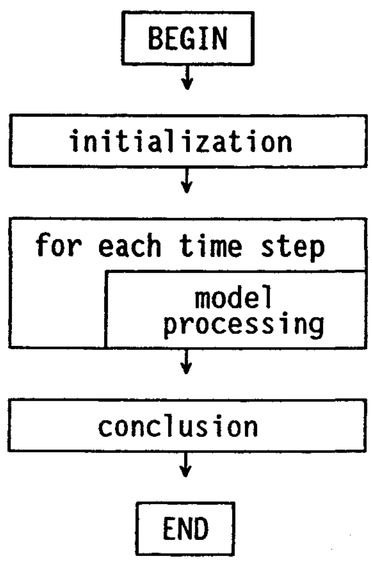

FIGURE 2 The three steps of the simulation.

To navigate through all those processes, we have defined a naming convention for the sub-processes. Each of the sub-processes has its specific radix:

pr	->	interpolation of meteorological data;
fo	->	snow melting;
et	->	potential evapotranspiration;
bv	->	vertical water budget;
ru	->	surface and sub-surface runoff;
tr	->	channel routing.

For each of the simulation step we give the prefix as follows:

init_	->	initialization step;
(nil)	->	modelisation step;
term_	->	conclusion step.

Finally, for each of the specific sub-models we add a meaningful suffix with few letters. Here are some examples:

_opt	->	user's defined function;
_lect	->	read function for intermediate results;
_thies	->	interpolation method using thiessen polygons;
_moyp	->	interpolation method using weighted mean of nearest three stations;
...	...	
_ocm	->	modified kinematic wave equation;
_od	->	diffusive wave equation.

A function name is made out of a prefix (optional), a radix (always) and a suffix (optional). If the suffix is missing the name will designate an interface function. An interface function is one doing calculation common to all sub-models and then calling a specific sub-models. If the prefix is missing the name designates either a function or a file containing the functions. Here are some examples:

pr -> specific interface function for the meteorological interpolation method. It is also the name of the file containing the interface function;

init_pr_thies -> initialization function for the interpolation method using thiessen polygons;

term_tr_ocm -> conclusion of the kinematic wave channel routing sub-model;

pr_opt -> user's defined meteorological interpolation sub-model.

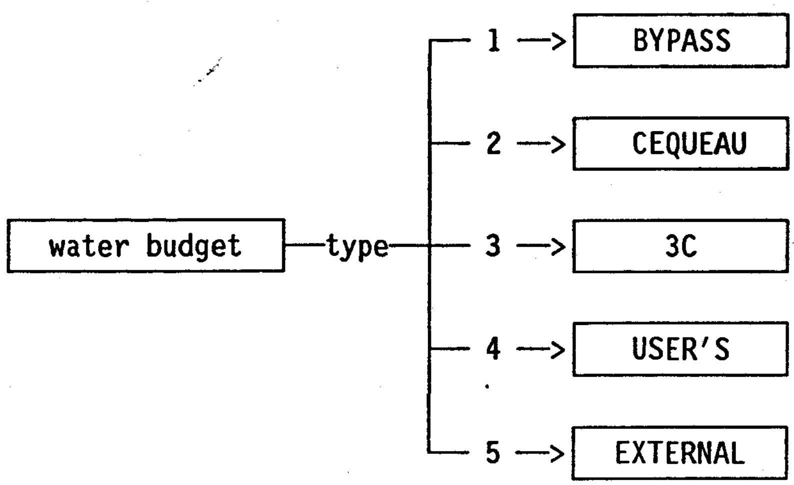

FIGURE 3 Example of interface function.

As we seen, each of the sub-model depends on the results coming out of the preceding sub-models. They also depend on the context of the simulation and on computations made on previous time steps.

Computations made on previous time steps are lost, so the sub-models using them must allocate the space to save them between the time steps and free the space after the simulation.

Context related data are read at the beginning of the program and kept until the user changes the simulation period or makes a simulation on another basin. These data are stored in global variables visible for all functions in the program. They are grouped in three data structures: the cells or HHU's in the structure "zones", the stream nodes in "noeuds" and the reaches in "troncons".

The data structure "zones" is an array of elements of type "ZONE": ZONE *zones. The elements of type "ZONE" groups the physiographic data and the intermediate results on one zone of the basin. The index of the structure "zones" begins at zero. The number of cells or HHU's in a watershed is given by the variable nbzones. HHU's are a generalization of the concept of squares used in previous versions of HYDROTEL. A HHU is simply a group of squares, and a group of one square is a cell. So, it will be possible to use either cells or HHU's. Data will continue to be exchanged at the cell level and the same data files can be read. All we need is to have a relation between cells and HHU's. The matrix "grille" gives, for each cell, the index of the corresponding HHU. The number of lines of that matrix is given by the variable "nblin", and the number of columns by the variable "nbcol". The element [0,0] of the matrix correspond to the upper left corner of the grid. The elements of the matrix are allocated when the file *.REL is read. The cells outside of the watershed have no corresponding HHU and the elements of the matrix have a zero value.

ZONE

Field	Format	Description
id	short	Identification of a HHU;
zn_aval	short	Downstream HHU index in "zones[]";
tr_aval	short	Downstream reach Index in "troncons[]";
ori	short	Mean aspect of the HHU;
pte	float	Mean slope of the HHU;
alt	float	Mean altitude of the HHU;
cot[MCL]	short	Land-use for each class (%*FAC_COT);
tmin	float	Minimum daily air temperature (C);
tmax	float	Maximum daily air temperature (C);
pluie	float	Liquid precipitation on the zone (mm);
neige	float	Snow precipitation on the zone (m);
stock	float	Snow pack (water equivalent) (mm);
apport	float	Precipitation and snow melt (mm);
evp[MCL]	float	Potential evapotranspiration for each land-use class (mm);
prod	float	Water budget outflow (m);
ruis	float	Runoff on the zone (m^2/s).

The data structure "noeuds" is a array of elements of type "NOEUD": NOEUD *noeuds. Each element groups physiographic data on a particular node of the river. The array is allocated when the data are read. The index begins at zero. The number of nodes is given by the variable "nbnoeud".

NOEUD

Field	Format	Description
id	short	Node identification;
east	long	UTM coordinate (x) of the node;
north	long	UTM coordinate (y) of the node;
alt	short	Altitude of the node (m);
lrg	float	Width of the river at the node (m).

Finally the structure "troncons" is an array of elements of type "TRONCON": TRONCON *troncons. The elements of the type "TRONCON" regroup the physiographic data and the intermediate results on the reach. The array is allocated when the physiographic data are read. The indices begin at zero. The number of reaches is given by the variable "nbnoeud".

The reaches need not be ordered from upstream to downstream, but an index is provided ordering them. This index is "it" and has as much elements as "troncons". The n^{th} element of the array "it" gives the index of the n^{th} element in "troncons" from upstream: troncons[it[n]]->id.

TRONCON

Field	Format	Description
id	short	Reach identification;
tr_aval	short	Upstream reach index in "troncons[]";
nd_amont	short	Upstream node index in "noeuds[]";
nd_aval	short	Downstream node index in "noeuds[]";
lrg	float	Mean width of the reach (m);
lng	float	Reach length (m);
pte	float	Reach slope (m/m);
man	float	Reach roughness coefficient;
Qamont	float	Upstream flow (m^3/s);
Qaval	float	Downstream flow (m^3/s);
apport	float	HHU contribution (m^3/s).

APPENDIX B

DEFINITION OF CONFIGURATION FILE

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DEFINITION OF CONFIGURATION FILE

The configuration file contains the state of the program at the end of last work session. The configuration file is read at the beginning of the program and saved at the end, except if you leave the program with the "Esc" key or if the program terminates abnormally. The configuration file is also saved before a call to an external program. The external program can then read (or modify) the configuration file.

The configuration file contains a variable number of lines, depending on the chosen sub-models. Almost every line refers to a menu of HYDROTEL, you can refer to the section describing the menus for more information. Each line begins with a six character code, identifying the type of information on the line. There can be only one line with a given code in the file. The code can also be used to quickly retrieve an information from the file. The file is read in free format, so the only restriction is to separate each field by a blank character (space, tab or return).

Each field has a format specifier, valid formats are: "char", "string", "line", "short", "long" and "float". The "char" format is the format used to specify only one character in the data field. The "string" format refers to groups of characters, excluding blank characters. The "line" format refers to groups of strings, including blank characters, beginning after a "carriage return" and up to the next one. A "short" format is used to describe an integer coded over two bytes, giving a range of -32768 to 32767. A "long" format is used to describe an integer coded over four bytes, giving a range of -2147483648 to 2147483647. Finally a "float" format is used to specify a real value coded over four bytes, giving a range of 1.17549e-38 to 3.40282e+38.

PATH TO FILES

Format	Description
string	MN0;
string	Name of the directory where the data files can be found;
string	Name of basin, used to construct names of data files.

TEMPORAL PARAMETERS

Format	Description
string	MN1;
short	Start of the simulation (year);
short	Start of the simulation (julian day);
short	End of the simulation (year);
short	End of the simulation (julian day);
short	Time step of the simulation (hours).

SPATIAL PARAMETERS

Format	Description
string	MN2;
short	UTM zone;
long	UTM coordinate (x axis) of the upper left corner;
long	UTM coordinate (y axis) of the upper left corner;
long	UTM coordinate (x axis) of the lower left corner;
long	UTM coordinate (y axis) of the lower left corner;
short	Resolution (m).

OPTIMIZATION PARAMETERS

Format	Description
string	MN3;
short	Maximum number of function calls;
short	Maximum number of powell iterations;
float	Tolerance on optimization of each coefficient;
float	Tolerance threshold on powell iteration.

METEOROLOGICAL AND HYDROLOGICAL DATA

Format	Description
string	Line **code**;
short	**Format** of the file;

Code	Description
MN4	Temperature and precipitation;
MN5	Wind speed;
MN6	Relative humidity;
MN7	Sunshine;
MN8	Global solar radiation;
MN9	Streamflows;

Format	Description
0	INRS format;
1	Environment Canada format;
2	User's defined format;

BASIN DATA

Format	Description
string	**Line code**
string	Filename;
short	**Format** of the file;

Code	Description
MN10	Meteo station id;
MN11	Streamflows station id;
MN12	Basin mask;
MN13	Altitude;
MN14	Aspect;
MN15	Slope;
MN16	Land-use classes;
MN17	Reach ends;
MN18	Reaches;

Format	Description
0	INRS format;
1	Environment Canada format;
2	User's defined format.

INITIAL SETTINGS

Format	Description
string	Line **code**;
string	Filename;
short	**Format** of the file;

Code	Description
MN19	Snow melt model initial setting;
MN20	Water budget model initial setting;
MN21	Runoff model initial setting;
MN22	Streamflows model initial setting;

Format	Description
0	INRS format;
1	Environment Canada format;
2	User's defined format.

INTERMEDIATE RESULTS

Format	Description
string	Line **code**;
string	Filename;
short	**Format** of the file;

Code	Description
MN23	Minimum temperature;
MN24	Maximum temperature;
MN25	Rain precipitation;
MN25a	Snow precipitation;
MN26	Snow melt;
MN27	Evapotranspiration;
MN28	Water budget outflow;
MN29	Runoff;
MN30	Streamflows;

Format	Description
0	INRS format;
1	Environment Canada format;
2	User's defined format.

SAVING OF RESULTS

Format	Description
string	MN31
long	Intermediate results code;
long	Final settings code;

Each bit in the code represents a type of results or settings to save at the end of the simulation. Every bit can be set independantly.

Code	Description
0x00010000L	Save Temperature;
0x00020000L	Save Precipitation;
0x00040000L	Save Snow melt;
0x00080000L	Save Evapotranspiration;
0x00100000L	Save Water budget;
0x00200000L	Save Runoff;
0x00400000L	Save Channel routing;
0x00001000L	Save final snowpack state variables;
0x00002000L	Save final water budget state variables;
0x00004000L	Save final runoff state variables;
0x00008000L	Save final channel routing state variables.

MODELS FOR INTERPOLATION OF PRECIPITATIONS

Format	Description
string	PR0;
short	**Code** for the model;
short	Number of lines specifying the model;

Code	Description
1	Bypass;
2	Read meteo data from disk;
3	Thiessen polygons;
4	Weighted mean of nearest three stations;
5	User's defined interpolation;
6	Stand alone program.

1) **Bypass:** (no lines)

2) **Read meteo data from disk:** (no lines)

3) **Thiessen polygons:**

Format	Description
string	PR1;
float	Precipitation vertical gradient (%/100 m);
float	Temperature lapse rate (C/100 m).

4) Weighted mean of nearest three stations:

Format	Description
string	PR1;
float	Precipitation vertical gradient (%/100 m);
float	Temperature lapse rate (C/100 m).

5) User's defined interpolation: (no lines)

6) Stand alone program: (no lines)

SNOWMELT MODELS

Format	Description
string	FN0;
short	**Code** for the model;
short	Number of lines specifying the model;

Code	Description
1	Bypass;
2	Read snowmelt from disk;
3	Modified degree/day method;
4	User's defined snow melt;
5	Stand alone program.

1) Bypass: (no lines)

2) Read snow melt from disk: (no lines)

3) Modified degree/day method:

Snow melt model parameters

Format	Description
string	FN1;
float	Threshold temperature for transformation of rain into snow (C);
float	Melt factor (coniferous forest) (mm/dC);
float	Melt factor (deciduous forest) (mm/dC);
float	Melt factor (open areas) (mm/dC);
float	Threshold temperature for melt (C);
float	Melt rate at snow/ground interface (mm/d);
float	Maximum density of snow pack (Kg/m^3);
float	Settlement constant.

Land-use codes

Format	Description
string	FN2;
short	Code for coniferous forest
short	Code for deciduous forest.

Optimization coefficient

Format	Description
string	FN3;
short	State (0:OFF|1:OPTIMIZE);
float	Minimum coefficient value;
float	Maximum coefficient value;
float	Current coefficient value.

4) User's defined snow melt:

Optimization coefficient

Format	Description
string	Line code;
short	State (0:OFF|1:OPTIMIZE);
float	Minimum coefficient value;
float	Maximum coefficient value;
float	Current coefficient value;

Code	Description
FN1	First coefficient;
FN2	Second coefficient;
FN3	Third coefficient.

5) Stand alone program:

Optimization coefficient

Format	Description
string	Line **code**;
short	State (0:OFF | 1:OPTIMIZE);
float	Minimum coefficient value;
float	Maximum coefficient value;
float	Current coefficient value;

Code	Description
FN1	First coefficient;
FN2	Second coefficient;
FN3	Third coefficient.

POTENTIAL EVAPOTRANSPIRATION MODELS

Format	Description
string	ET0;
short	**Code** for the model;
short	Number of lines specifying the model;

Code	Description
1	Bypass;
2	Read potential evapotranspiration data from disk;
3	THORNTHWAITE potential evapotranspiration;
4	LINACRE potential evapotranspiration;
5	PENMAN potential evapotranspiration;
6	PRIESTLEY_TAYLOR potential evapotranspiration;
7	User's defined potential evapotranspiration;
8	Stand alone program.

1) Bypass: (no lines)

2) Read potential evapotranspiration data from disk (no lines)

3) THORNTHWAITE potential evapotranspiration:

Simulation parameters

Format	Description
string	ETP1;
float	THORNTHWAITE thermal index;
float	Mean latitude of the basin (degrees);
short	Temporal shift parameter (day).

Optimization coefficient

Format	Description
string	ETP2;
short	State (0:OFF | 1:OPTIMIZE);
float	Minimum coefficient value;
float	Maximum coefficient value;
float	Current coefficient value.

4) LINACRE potential evapotranspiration:

Simulation parameters

Format	Description
string	ETP1;
string	File name of albedo values;
float	Mean latitude of the basin (degrees)
float	Intersect of the linear approximation;
float	Slope of the linear approximation (C^{-1});
float	Mean temperature of the coldest month (C);
float	Mean temperature of the warmest month (C).

Optimization coefficient

Format	Description
string	ETP2;
short	State (0:OFF | 1:OPTIMIZE);
float	Minimum coefficient value;
float	Maximum coefficient value;
float	Current coefficient value.

5) PENMAN potential evapotranspiration:

Simulation parameters

Format	Description
string	ETP1;
float	Parameter A of "RG= IGA(A+B*h/H)";
float	Parameter B of "RG= IGA(A+B*h/H)";
float	Height of wind observation (m);
short	Code for wind function;
string	File name of albedo values;
string	File name of land-use heights.

Code	Description
0	Aerodynamic resistance;
1	Empirical wind function.

Optimization coefficient

Format	Description
string	ETP2;
short	State (0:OFF | 1:OPTIMIZE);
float	Minimum coefficient value;
float	Maximum coefficient value;
float	Current coefficient value.

6) PRIESTLEY_TAYLOR potential evapotranspiration:

Simulation parameters

Format	Description
string	ETP1;
string	File name of albedo values;
float	Parameter A in "RG= IGA(A+B*h/H)";
float	Parameter B in "RG= IGA(A+B*h/H)";
float	Parameter ALPHA in "ETP= alpha*Eeq".

Optimization coefficient

Format	Description
string	ETP2;
short	State (0:OFF|1:OPTIMIZE);
float	Minimum coefficient value;
float	Maximum coefficient value;
float	Current coefficient value.

7) User's defined potential evapotranspiration:

Optimization coefficient

Format	Description
string	Line code;
short	State (0:OFF | 1:OPTIMIZE);
float	Minimum coefficient value;
float	Maximum coefficient value;
float	Current coefficient value;

Code	Description
ETP1	Potential evapotranspiration;
ETP2	Second coefficient;
ETP3	Third coefficient.

8) Stand alone program:

Optimization coefficient

Format	Description
string	Line code;
short	State (0:OFF | 1:OPTIMIZE);
float	Minimum coefficient value;
float	Maximum coefficient value;
float	Current coefficient value;

Code	Description
ETP1	Potential evapotranspiration;
ETP2	Second coefficient;
ETP3	Third coefficient.

ACTUAL EVAPOTRANSPIRATION MODELS

Format	Description
string	ET0;
short	**Code** for the model;
short	Number of line specifying the model;

Code	Description
1	Bypass;
2	Read actual evapotranspiration data from disk;
3	User's defined actual evapotranspiration;
4	Stand alone program.

1) Bypass: (no lines)

2) Read actual evapotranspiration data from disk (no lines)

3) User's defined actual evapotranspiration:

Optimization coefficient

Format	Description
string	Line **code**;
short	State (0:OFF | 1:OPTIMIZE);
float	Minimum coefficient value;
float	Maximum coefficient value;
float	Current coefficient value;

Code	Description
ETR1	Actual evapotranspiration;
ETR2	Second coefficient;
ETR3	Third coefficient.

4) Stand alone program:

Optimization coefficient

Format	Description
string	Line code;
short	State (0:OFF | 1:OPTIMIZE);
float	Minimum coefficient value;
float	Maximum coefficient value;
float	Current coefficient value;

Code	Description
ETR1	Actual evapotranspiration;
ETR2	Second coefficient;
ETR3	Third coefficient.

WATER BUDGET MODELS

Format	Description
string	BV0;
short	**Code** for the model;
short	Number of lines specifying the model;

Code	Description
1	Bypass;
2	Read outflow data from disk;
3	CEQUEAU (modified);
4	BV3C;
5	User's defined function;
6	Stand alone program.

1) Bypass: (no lines)

2) Read outflow data from disk: (no lines)

3) CEQUEAU (modified):

Surface runoff parameters

Format	Description
string	BV1;
float	Depth threshold for surface runoff (mm).

Unsaturated zone reservoir parameters

Format	Description
string	BV2;
float	Capacity of the reservoir (mm);
float	Threshold for sub-surface runoff (mm);
float	Runoff coefficient;
float	Threshold for percolation (mm);
float	Percolation coefficient;
float	Maximum rate of percolated water (mm/d);
float	Threshold for PET (mm).

Saturated zone reservoir parameters

Format	Description
string	BV3;
float	Outflow coefficient;
float	Fraction of PET taken in sat. zone;
float	Reference level for fraction of PET (mm).

Lakes and marshes parameters

Format	Description
string	BV4;
float	Threshold for outflow (mm);
float	Outflow coefficient.

Initial levels in reservoirs

Format	Description
string	BV5;
float	Unsaturated zone (mm);
float	Saturated zone (mm);
float	Lakes and marshes (mm).

Land-use codes

Format	Description
string	BV6;
short	**Code** for water;
short	**Code** for impervious area;
short	**Code** for forest;

Bit code	Description
1	First land-use class;
2	Second land-use class;
...	...
$2^{nbcla-1}$	Last land-use class;

The bit code are summed to give the **code.**

Optimization coefficient

Format	Description
string	Line code;
short	State (0:OFF | 1:OPTIMIZE);
float	Minimum coefficient value;
float	Maximum coefficient value;
float	Current coefficient value;

Code	Description
BV7	Threshold for PET;
BV8	Capacity of unsaturated zone reservoir;
BV9	Outflow coefficient of the saturated zone reservoir;
BV10	Runoff coefficient.

4) BV3C:

Soil and land-use files

Format	Description
string	Line code;
string	File name;

Code	Description
BV2	Leaf area index on day D;
BV3	Root depth on day D;
BV4	Hydraulic properties of soil types;
BV5	Spatial distribution of soil types.

Parameters characterizing layers

Format	Description
string	BV6
float	Relative initial water contents of layer 1 (θ/θ_s);
float	Relative initial water contents of layer 2 (θ/θ_s);
float	Relative initial water contents of layer 3 (θ/θ_s);
float	Bottom of layer 1 (m);
float	Bottom of layer 2 (m);
float	Bottom of layer 3 (m).

General parameters

Format	Description
string	BV7;
float	Extinction coefficient DES;
float	Recession coefficient;
float	Maximum variation of θ/time step.

Land-use codes

Format	Description
string	BV8;
short	**Code** for water;
short	**Code** for impervious ares.

Bit code	Description
1	First land-use class;
2	Second land-use class;
...	...
$2^{nbcla-1}$	Last land-use class;

The bit codes are summed to give the **code.**

Optimization coefficient

Format	Description
string	Line **code**;
short	State (0:OFF | 1:OPTIMIZE);
float	Minimum coefficient value;
float	Maximum coefficient value;
float	Current coefficient value;

Code	Description
BV9	Soil class;
BV10	Reduction factor for PET --> AET;
BV11	Depth of layers 2 and 3;
BV12	Extinction coefficient.

5) User's defined function:

Optimization coefficient

Format	Description
string	Line code;
short	State (0:OFF | 1:OPTIMIZE);
float	Minimum coefficient value;
float	Maximum coefficient value;
float	Current coefficient value;

Code	Description
BV13	First coefficient;
BV14	Second coefficient;
BV15	Third coefficient.

6) Stand alone program:

Optimization coefficient

Format	Description
string	Line code;
short	State (0:OFF | 1:OPTIMIZE);
float	Minimum coefficient value;
float	Maximum coefficient value;
float	Current coefficient value;

Code	Description
BV1	First coefficient;
BV2	Second coefficient;
BV3	Third coefficient,

SURFACE AND SUB-SURFACE RUNOFF MODELS

Format	Description
string	RU0;
short	**Code** for the model;
short	Number of lines specifying the model;

Code	Description
1	Bypass;
2	Read runoff data from disk;
3	Kinematic wave equation;
4	User's defined runoff function;
5	Stand alone program.

1) **Bypass:** (no lines)

2) **Read runoff data from disk:** (no lines)

3) Kinematic wave equation:

Land-use codes

Format	Description
string	RU1;
short	**Code** for forest;

Bit code	Description
1	First land-use class;
2	Second land-use class;
...	...
$2^{nbcla-1}$	Last land-use class;

The bit coded are summed to give the **code.**

Optimization coefficient

Format	Description
string	RU2;
short	State (0:OFF | 1:OPTIMIZE);
float	Minimum coefficient value;
float	Maximum coefficient value;
float	Current coefficient value.

4) User's defined runoff function:

Optimization coefficient

Format	Description
string	Line **code**;
short	State (0:OFF | 1:OPTIMIZE);
float	Minimum coefficient value;
float	Maximum coefficient value;
float	Current coefficient value;

Code	Description
RU1	First coefficient;
RU2	Second coefficient;
RU3	Third coefficient.

5) Stand alone program:

Optimization coefficient

Format	Description
string	Line **code**;
short	State (0:OFF | 1:OPTIMIZE);
float	Minimum coefficient value;
float	Maximum coefficient value;
float	Current coefficient value;

Code	Description
RU1	First coefficient;
RU2	Second coefficient;
RU3	Third coefficient.

CHANNEL ROUTING MODELS

Format	Description
string	TR0;
short	Code for the model;
short	Number of lines specifying the model;

Code	Description
1	Bypass;
2	Read streamflow data from disk;
3	Modified kinematic wave equation;
4	Diffusive wave equation;
5	User's defined channel routing function;
6	Stand alone program.

1) Bypass: (no lines)

2) Read streamflow data from disk: (no lines)

3) Modified kinematic wave equation:

Optimization coefficient

Format	Description
string	Line code;
short	State (0:OFF | 1:OPTIMIZE);
float	Minimum coefficient value;
float	Maximum coefficient value;
float	Current coefficient value;

Code	Description
TR1	Roughness coefficient;
TR2	Reach width.

4) Diffusive wave equation:

Optimization coefficient

Format	Description
string	Line code;
short	State (0:OFF | 1:OPTIMIZE);
float	Minimum coefficient value;
float	Maximum coefficient value;
float	Current coefficient value;

Code	Description
TR1	Roughness coefficient;
TR2	Reach width.

5) User's defined channel routing function:

Optimization coefficient

Format	Description
string	Line code;
short	State (0:OFF | 1:OPTIMIZE);
float	Minimum coefficient value;
float	Maximum coefficient value;
float	Current coefficient value;

Code	Description
TR1	First coefficient;
TR2	Second coefficient;
TR3	Third coefficient.

6) Stand alone program:

Optimization coefficient

Format	Description
string	Line **code**;
short	State (0:OFF | 1:OPTIMIZE);
float	Minimum coefficient value;
float	Maximum coefficient value;
float	Current coefficient value;

Code	Description
TR1	First coefficient;
TR2	Second coefficient;
TR3	Third coefficient.

COLOR CODE MAPS

Format	Description
string	CC0;
short	Index of the current variable (0 to NB_CC_VAR).

SCALE FOR MAPS

Format	Description
string	Line code;
short	Type of scale;
float	Origin of the scale;
float	???

Code	Description
CC1	
CC2	
...	...
CC16	

Type	Description
...	...

APPENDIX C

DATA FILES

APPENDIX C

DATA FILES

The data files are structured in two parts, header and data. The header contains information related to the file and the simulation. The data section contains individual values for each time step on each cell of the grid or on each reach of the river. The file is in standard Ascii format, and can be read or modified with a text editor. The file is read in free format, so the only restriction is to separate each field by a blank character (space, tab or return).

Each field has a format specifier. Valid formats are: "char", "string", "line", "short", "long" and "float". The "char" format is the format to specify only one character in the data field. The "string" format refers to groups of characters, excluding blank characters. The "line" format refers to groups of strings, including blank characters, beginning after a "carriage return" and up to the next one. A "short" format is used to describe an integer coded over two bytes, giving a range of -32768 to 32767. "Long" format describe an integer coded over four bytes, giving a range of -2147483648 to 2147483647. Finally a "float" format is used to specify a real value coded over four bytes, giving a range of 1.17549e-38 to 3.40282e+38.

A filename is made up of four parts: the drive designator, the directory, the name and the extension. The name given to the file is arbitrary but HYDROTEL uses a convention: the name part of the filename corresponds to the name of the watershed and the extension to the type of data contained in the file. If you stick to the convention you will never have to enter a filename for data file.

TOPOGRAPHIC DATA

Topographic data files contain the time invariant variables describing the watershed. The data are related to two main data structures: a grid over the watershed and the reaches composing the drainage network of the watershed. We also use an intermediate data structure to describe the reach ends. So we use three different types of files: one for the data on the grid, one for the data on the reaches and one for the data on the reach ends. **Homogeneous hydrological units (HHU's) are simply considered as aggregates of grid cells. To specify a characteristic of a HHU you must give a value to each of the grid cells.**

Grid data are spread over 7 files (*.MSK, *.ZON, *.ORI, *.REL, *.ALT and *.PTE) and two formats. The MSK extension is for the basin mask, each cell of the grid with a zero value is outside the basin. For cells within the basin, the value represents the order in which each cell is evaluated. The ZON extension is for the definition of the HHU mask, each cell of a HHU must have the same value and the value gives the order of evaluation of each HHU. The ALT extension is for an altitude data file. That file must contain mean altitudes for each cell of the grid; the altitude for a HHU is the mean of the mean altitude for the cells belonging to this HHU. The ORI extension is for an aspect data file. That file contains the aspect of each cell to eight points of the compass, identified 1 to 8 counterclockwise from East (East = 1). Aspect data files are not relevant for HHU's, we use REL data files containing for each cell of a HHU the id of the downstream HHU. The PTE extension is for slope data on each cell, the slope of a HHU is the mean of the slopes on the cells.

If the number of HHU's, as summed up by the program, is equal to the cells, this means that the simulation is made on cells.

File structure for *.ALT, *.MSK, *.ORI, *.PTE, *.REL and *.ZON:

Line	Format	Description
#1	short	File type (always 1);
#2	short short	Number of lines of the grid; Number of columns of the grid;
#3	long long short	Coordinate (x) of the upper left corner (UTM); Coordinate (y) of the upper left corner (UTM); Grid resolution (m);
#4	line	Comment describing the file;
for every cell of the grid:		
#5...	float	Value.

The cells are read beginning with the upper left cell to the lower right cell, line by line and from left to right.

The data related to the hydrographic network is split in two types of data, one on reaches and one on reach ends. The topology of the hydrographic network is determined by reach ends data. Each reach is specified by its ends, and two connected reaches have one common node. The hydrological behavior is determined by reach data and node data. Files with the extension NDS contains nodes or reach end data. Files with the extension TRO contain reach related data.

File structure for *.NDS:

Line	Format	Description
#1	short	File type (always 1);
#2	short	Number of reach ends;
#3	line	Comment describing the file;
for every reach ends of the stream:		
#4...	short	Identification number;
	long	Easting (UTM);
	long	Northing (UTM);
	float	Altitude (m);
	float	Channel width (m);

File structure for *.TRO:

Line	Format	Description
#1	short	File type (always 1);
#2	short	Number of reaches (number of reach ends - 1);
#3	line	Comment describing the file;
for every reach of the stream:		
#4...	short	Identification number of downstream end;
	short	Identification number of upstream end;
	short	Reach **type** (0:RIVER,1:LAKE);
for reach type 0 (RIVER):		
	float	Estimated reach lenght (m);
	float	Manning's roughness coefficient.
for reach type 1 (LAKE):		
	float	Estimated surface (km^2);
	float	first parameter c of the relation $Q= cH^k$.
	float	second parameter k of the relation $Q= cH^k$.

If a zero is entered as the estimated reach lenght, it is assumed that the reach lenght can be considered as equal to the straight line joining the ends of the reach and the zero value is changed for that of the straight line.

LAND-USE DATA

Land-use data are related to the grid data structure. The first file (*.CLA) describes the land-use of each grid cell. The other files characterize each land-use class. Some characteristics of land-uses can vary over one year. The files Albedo.YY, hau_veg.YY, Pro_rac.YY and Ind_fol.YY contain discrete values taken on specific dates by the variable identified by the filename. The value for a particular day is interpolated linearly from the two nearest day available.

File structure for *.CLA:

Line	Format	Description
#1	short	File type (always 1);
#2	short short short	Number of lines of the grid; Number of columns of the grid; Number of classes;
#3	line	Land-use class identifier. Each column must be identified by a name. That name will be used in HYDROTEL to refer to the class in that column. You can use as many classes as you want. Classes can be combined in HYDROTEL;
for every cell of the grid:		
#4...	long	Easting coordinate of the lower left corner of the cell (UTM);
	long	Northing coordinate of the lower left corner of the cell (UTM);
for every classes:		
	short	Number of pixels belonging to that class;
	short	Total number of pixels for that cell.

The cells are read beginning with the upper left cell and ending with the lower right cell, line by line and from left to right, one cell per line.

Suggested codes and class identification*:

■"champ"	bare fields;
■"herbe"	crops and pasture 1;
■"paill"	crops and pasture 2;
■"gravi"	extracting areas;
■"resin"	forested areas 1 (coniferous);
■"feuil"	forested areas 2 (deciduous);
■"route"	highways and other impervious areas;
■"eau1"	surface waters 1;
■"eau2"	surface waters 2;
■"urb"	urban areas;
■"frich"	waste lands and bushes;
■"mar"	wet lands and marshes.

* Remember that classes may be aggregated by HYDROTEL into groups changing from sub-model to sub-model depending on their ability to differentiate between land-use classes. Also, any class code can be given to a land-use class.

So, it is only necessary to have a number of classes sufficient to fill the minimum requirements of the model.

File structure for Albedo.YY, hau_veg.YY, Pro_rac.YY, Ind_fol.YY:

Line	Format	Description
#1	short	File type (always 2);
#2	short short short	Number of land-use classes, Number of days for which values are available Year;
#3	line	Title or comment identifying the file.
#4	string	"Day";
for every classes:		
	string	Land-use code for that class.

The order is not important, but he code names must be the same as those given in the file *.CLA.

for every day for which values are available:		
#5...	short	Day;
for every classes:		
	float	Actual value for that land-use class;

SOIL DATA

File structure for *.TSO:

Line	Format	Description
#1	short	File type (always 4);
#2	short short	Number of lines; Number of columns;
#3	long long short	Easting; Northing; Spatial resolution (m);
#4	line	Title or comment identifying the file;

for every cell of the grid:

#5...	short	Soil type.

The cells are read beginning with the upper left cell and ending with right the lower right cell, line by line and from the left to the right.

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

File structure for *.SOL:

Line	Format	Description
#1	short	File type (always 3);
#2	short short	Number of soil types; Number of characteristics for each soil type;
#3	line	Comment describing the file;
#4	line	"Name Thetas Thetacc Thetaph KS PSIS Lambda Alpha".

This line is considered as a comment. It is there only to help in the identification of the values below. The user can change the wording, but not the order.

for every soil type:

#5...	string	Code name for that soil type;
	float	Water content at saturation (m^3m^{-3});
	float	Water content at field capacity (m^3m^{-3});
	float	Water content at the permanent wilting point (m^3m^{-3});
	float	Hydraulic conductivity (mh^{-1});
	float	Matrix potential at θs (m);
	float	Pore size distribution;
	float	Coefficient in eq. 3.28.

STREAMFLOW AND METEOROLOGICAL DATA

Streamflow and meteorological data are related to a point structure called STATION. The files *.STM and *.STH give the name and position of meteorological and streamflow stations, respectively. The data files can be in two formats, INRS or ENVCAN. The two formats are described below.

File structure for *.STM and *.STH:

Line	Format	Description
#1	short	File type (always 1);
#2	short	Number of stations;
#3	line	Title or comment identifying the file.
for every station:		
#4...	string	Identification numbe r;
	float	Longitude (degrees.minutes);
	float	Latitude (degrees.minutes);
	float	Altitude (m).

INRS data formats

File structure for stream flow data (H*.YY):

Line	Format	Description
#1	string	Station identification;
	short	Year
	short	Number of valid values;
For each day of the year (366), 24 values per line:		
#2...	float	Daily streamflows. Missing data: -1000.

File structure for meteorological data (M*.YY):

Line	Format	Description
#1	string	Station identification;
	short	Year;
	short	Number of valid data for maximum temperature;
	short	Number of valid data for minimum temperature;
	short	Number of valid data for rain;
	short	Number of valid data for snow;
	float	Latitude (degrees.minutes);
	float	Longitude (degrees.minutes);
	short	Altitude (m);
	string	Station identification;
for each day of the year (366), 24 value per line:		
#2...	float	Maximum temperature (°C), missing data: -99;
#18...	float	Minimum temperature (°C), missing data: -99;
#34...	float	Rainfall values (10^{-1}mm), missing data: -1;
#50...	float	Snowfall values (10^{-1}cm), missing data: -1.

Environment Canada data formats

Format for streamflow data, hourly values:

Line	Format	Description
#1...	char	Code for type of data and units (column 1). Q: discharges in m^3/s;
	string	Station number, e.g. 08AA023 (column 2-8)
	short	Year, e.g. "68" for 1968 (column 9-10)
	short	Month, e.g. "06" for June (column 11-12)
	short	Day (column 13-14)
	short	Card number, (column 15-16) 1: for hours 1 to 6 2: for hours 7 to 12 3: for hours 13 to 18 4: for hours 19 to 24
	float	Data fields (column 17-80), six field of data of 10 positions;

Format for streamflow data, daily values:

Line	Format	Description
#1...	char	Code for type of data and units (column 1). Q: Daily discharges in cubic meters per second;
	string	Station number, e.g. 08AA023 (column 2-8)
	short	Year, e.g. "968" for 1968 (column 9-11)
	string	Month, e.g. "b7" for July (column 12-13)
	char	Code for time interval (column 14) 1: daily figures from day 1 to day 10 2: daily figures from day 11 to day 20 3: daily figures from day 21 to day 31
	float	Data fields (column 15-80), ten values to eleven values;

Comments:

- Daily discharges for each month are stored on three 80 column lines.
- Each data field has six positions.
- The first five positions contain daily discharge data, right justified with a decimal point if necessary; the sixth position contains a symbol.
- Whenever data are missing the value "-9999" is entered in positions 1-5 and position 6 contains a blank.
- The first line contains 10 days from day 1 to 10; columns 75-78 are not used; the number of days in the month, e.g. "30" for November, is typed in columns 79-80.
- The second line contains 10 days from day 11 to 20; columns 75-80 are not used.
- The third line contains 11 days from day 21 to 31; the figure "-1111" is written in the appropriate field for days that do not apply to the months e.g. 30 and 31 for February 1968, and position 6 contains a blank.

Reference:

- Environment Canada card format 79-041 daily discharges.

Format for meteorological data

Daily values:

Line	Format	Description
#1...	string	Sstation identification (column 1-7);
	short	Year, e.g. "973" for 1973 (column 8-10)
	short	Month, e.g. 01 = JAN. (column 11-12)
	short	Elements number (column 13-15)
	float	31 7-character groups structured as follows:
		1st character: "-" = negative
		"0" = positive
		2nd to 6th character: data value (numeric)
		7th character: Flag (alphanumeric)

File content (depending on element number):

The following elements are read and used in HYDROTEL 2.1:

- maximum temperature: 001 (.1°c);
- minimum temperature: 002 (.1°c);
- total precipitation: 012 (.1mm).

Hourly values:

Line	Format	Description
#1...	string	Station identification (column 1-7);
	short	Year, e.g. "973" for 1973 (column 8-10)
	short	Month, e.g. 01 = JAN. (column 11-12)
	short	Day (column 13-14)
	short	Elements number (column 15-17)
	float	24 7-character groups structured as follows: 1st character: "-" = negative "0" = positive 2nd to 6th character: data value (numeric) 7th character: Flag (alphanumeric)

File content (depending on element number):

The following elements are read and used in HYDROTEL 2.1:

- global solar radiation: 061 (.001 = MJ/m^2);
- wind: 076 (km h^{-1});
- relative humidity: 080 (%);
- precipitation: 123 (10^{-1}m/h);
- bright sunshine: 133 (10^{-1}h);
- dry bulb temperature: 0.78 (.1°C).

Reference:

- Format documentation for the digital archive of Canadian climatological data.

INITIAL SETTINGS OF STATE VARIABLES

Initials setting files are provided to initialize state variables of specific sub-models. Each model uses its proper initialization file, that it must create and read. Usually, initialization files cannot be shared among sub-models.

Initial settings for modified degree/day method (file *.SIS)

Line	Format	Description
#1	short	File type: 1 (integer)
#2	short short	Number of lines; Number of columns;
#3	long long short	Easting of upper left corner (UTM); Northing of upper left corner (UTM); Grid size (m);
#4	line	Title or comment identifying the file;

for every cell of the grid:

#5...	float	Snow pack water equivalent values in deciduous forest;
	float	Snow pack water equivalent values in coniferous forest;
	float	Snow pack water equivalent values in open areas;
	float	Snow pack depth values in deciduous forest;
	float	Snow pack depth values in coniferous forest;
	float	Snow pack depth values in open areas forest.

The cells are read beginning with the upper left cell and ending with the lower right cell, line by line and from left to right.

CEQUEAU vertical water budget (*.PIS):

Line	Format	Description
#1	short	File type: 1 (integer)
#2	short	Number of lines;
	short	Number of columns;
#3	long	Easting of upper left corner (UTM);
	long	Northing of upper left corner (UTM);
	short	Grid size (m);
#4	line	Title or comment identifying the file;

for every cell of the grid:

#5...	float	Water levels in the soil reservoir;
	float	Water levels in ground water reservoir;
	float	Water levels in lakes and marshes reservoir.

The cells are read beginning with the upper left cell and ending with the lower right cell, line by line and from left to right.

BV3C vertical water budget (*.PIS):

Line	Format	Description
#1	short	File type: 1 (integer)
#2	short short	Number of lines; Number of columns;
#3	long long short	Easting of upper left corner (UTM); Northing of upper left corner (UTM); Grid size (m);
#4	line	Title or comment identifying the file;

for every cell of the grid:

#5...	float	Water contents in layer 1 (θ/θ^s);
	float	Water contents in layer 2 (θ/θ^s);
	float	Water contents in layer 3 (θ/θ^s).

The cells are read beginning with the upper left cell and ending with the lower right cell, line by line and from left to right.

Initial settings for kinematic wave equation applied for surface and sub-surface runoff (file *.RIS)

Line	Format	Description
#1	short	File type: 1 (integer)
#2	short short	Number of lines; Number of columns;
#3	long long short	Easting of upper left corner (UTM); Northing of upper left corner (UTM); Grid size (m);
#4	line	Title or comment identifying the file;
for every cell:		
#5...	float	Runoff values.

The cells are read beginning with the upper left cell and ending with the lower right cell, line by line and from left to right.

Initial settings for kinematic or diffusive wave equation applied in reaches (file *.CIS)

Line	Format	Description
#1	short	File type: 1 (integer)
#2	short	Number of reaches;
#3	line	Title or comment identifying the file;
for every reach:		
#5...	short	Index number for downstream end (different from identification number);
	short	Index number for upstream flow;
	float	Index number for downstream flow;
	float	Upstream flow;
	float	Lateral inflow.

INTERMEDIATE RESULTS FILES

Intermediate result files serve two purposes: store simulation results at each time step and read results at each time step.

Intermediate result files are created when asked by the user. The format of the intermediate files is not intended to save space on disk, a long simulation can therefore take a huge amount of disk space.

Intermediate result files can be used to bypass unnecessary calculation. As an example, if somebody always uses the same basin, the same period of simulation and the same interpolation method, he can save the interpolation of meteorological data and read them directly at subsequent simulations. The option "Bypass" in the sub-model menus serves that purpose.

Intermediate result files are also used to communicate with the external programs. When the option "stand alone program" is chosen in the sub-model menus, HYDROTEL saves intermediate results of the simulation in progress before the external call, and read the results in intermediate results files.

Intermediate results on the grid (*.TMX, *.TMN, *.PLU, *.NEI, *.FON, *.EVP, *.PRO and *.RUI)

Line	Format	Description
#1	short	File type (always 1);
#2	short	Number of lines of the grid;
	short	Number of columns of the grid;
	long	Coordinate (x) of the upper left corner (UTM);
	long	Coordinate (y) of the upper left corner (UTM);
	short	Grid resolution (m);
#3	short	First year of simulation;
	short	First day of simulation (julian day);
	short	Length of the simulation (day);
#4	line	Comment describing the file;

for every simulation day:

#5...	short	Year;
	short	Julian day;
	short	Hour;

for every cell of the grid:

	float	Value.

The cells are read beginning with the upper left cell and ending with the lower right cell, line by line and from left to right.

Intermediate results on the drainage network

Line	Format	Description
#1	short	File type (always 1);
#2	short	Number of reaches;
#3	short short short	First year of simulation; First day of simulation (julian day); Length of the simulation (day);
#4	line	Comment describing the file;
for every simulation day:		
#5...	short	Number of days since the beginning of the simulation;
for every reach:		
	float	Value.

APPENDIX D

USER'S DEFINED FUNCTIONS

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USER'S DEFINED FUNCTIONS

As seen in Appendix A, the simulation process is split into six sub-processes: interpolation of meteorological data, snow melting, potential evapotranspiration, vertical water budget, surface and sub-surface runoff and channel routing. Each of these processes sub-divided into three steps: initialization, modelisation and conclusion.

Each of these sub-processes and each step in it corresponds to a 'C' function. The naming convention is described in Appendix A. The user can provide his own 'C' functions, by replacing the dummy functions present in the code. The dummy functions are the ones with the suffix "_opt". In the source code of the HYDROTEL 2.1 these functions show only how to call a FORTRAN function, if FORTRAN is used instead of "C". Each of these functions has a particular task that is described next.

The initialization step is intended to allocate memory and initialize local variables, to read initial settings of state variables or open files and prepare them for reading. By local variables we mean variables declared outside all functions with the "static" storage-class specifier. This kind of variable is visible everywhere in the user's defined source sub-program in which it appears and do not conflict with variables having the same name in other source files. Local variables must be used to store state values of sub-processes not stored elsewhere or to make time invariant computations once and for all. Use dynamic memory allocation as much as you can, that allows sharing memory with other processes.

During the modelisation step, the functions corresponding to the sub-models are called once for each time step. They must do the computations for every cell (HHU) in the basin or every reach of the river. The results must be place in the structure "zones" for the cells or HHU's and in the structure "troncons" for the reaches. The sub-processes are evaluated sequentially so that the input values of a sub-process are the output of the previously executed sub-process.

The interpolation process is the first in the chain. It must calculate the minimum daily air temperature, the maximum daily air temperature, the liquid precipitation and the snow precipitation on every cell. The results must be placed in the fields "tmin", "tmax", "pluie" and "neige" of the data structure ZONE. The data structures are described in details in Appendix A. It does not depends on previous sub-process.

The second process calculates the water available at the surface of the ground on each cell or HHU, from snow melt and/or liquid precipitation. The result must be placed in the field "apport" of the data structure ZONE. The process must also keep track of the accumulated snow. This process depends on the interpolation process.

The evapotranspiration process calculates the potential or actual evapotranspiration on each cell or HHU as a function of each land-use class. The result must be placed in the field "etp" of the data structure ZONE. That field is an array, the first element corresponding to the potential or actual evapotranspiration for the first land-use class read in the file *.cla, and so on. This process depends on the meteorological interpolation process.

The water budget process calculates the surface and sub-surface outflow from the vertical water profile in the soil of each cell or HHU. The model must keep track of the amount of water in that profile. The result is place in the field "prod" of the data structure ZONE. This process depends on all the preceding processes.

The runoff process transfers water from cell to cell until it finds a reach. When the process gets to a cell with a reach passing trough, the result is added to the value in the field "apport" of the data structure TRONCON, if not the result is added to the value in the field "ruis" of the data structure ZONE. The function must keep track of the water flowing on the cells at preceding time steps because the fields "apport" and "ruis" are set to zero at the beginning of each time step. This process depends on the output from the water budget process.

The last process calculates the downstream flow for each reach, transferring water from reach to reach. The result for one reach must be placed in the field "Qaval" of the structure TRONCON and added to the value in the field "Qamont" of the downstream reach. The downstream and the upstream flows are reset to zero at the beginning of each time step. This process depends on the runoff process output.

ZONE		Subprocess
...	...	
tmin	Minimum temperature	Meteo interpolation
tmax	Maximum temperature	
pluie	Liquid precipitation	
neige	Snow precipitation	
stock	Snow cover	Snowmelt
apport	Precipitation and snowmelt	
evp[]	Pot. or act. evapotranspiration	Evapotranspiration
prod	Outflow	Water budget
ruis	Runoff	Runoff

FIGURE 1 Sub-processes and ZONE data structure.

TRONCON		Subprocess
...	...	
apport	Cell contribution	Runoff
Qamont	Upstream flow	Channel routing
Qaval	Downstream flow	

FIGURE 2 Sub-processes and TRONCON data structure.

The last step of the simulation process is used to free allocated space, close files and write final settings of state variables, like snow density or flows in the river. Be sure to free all dynamically allocated memory.

Once you have modified the three functions corresponding to the sub-model that you want to add to HYDROTEL, compile it first and then link it to the rest of the HYDROTEL program.

To compile all the modules of HYDROTEL we use MICROSOFT C compiler version 5.1, and try to be as close as possible of the proposed ANSI standard. We also use a graphic library from Graphic Solution Systems (GSS). That graphic library is an implementation of the graphic standard GKS and must available in a *.lib file when the modified modules are recompiled.

After compilation and before execution all object modules must be linked together. The linker provided with MICROSOFT C does not allow nested overlay, so we used PLINK + from POLYTRON software. The nested overlays are needed because of the limited memory available within DOS operating system. Memory is allocated to a program when loaded, some parts of that memory can be shared by modules of the program that are mutually exclusive. An overlay is that part of memory shared by many modules. We can also reserve some space in an overlay for mutually exclusive sub-modules: this is nested overlay. The use of overlays permit to reduce the amount of memory needed at execution time. Note that other solutions are available now to break the 640 K barrier.

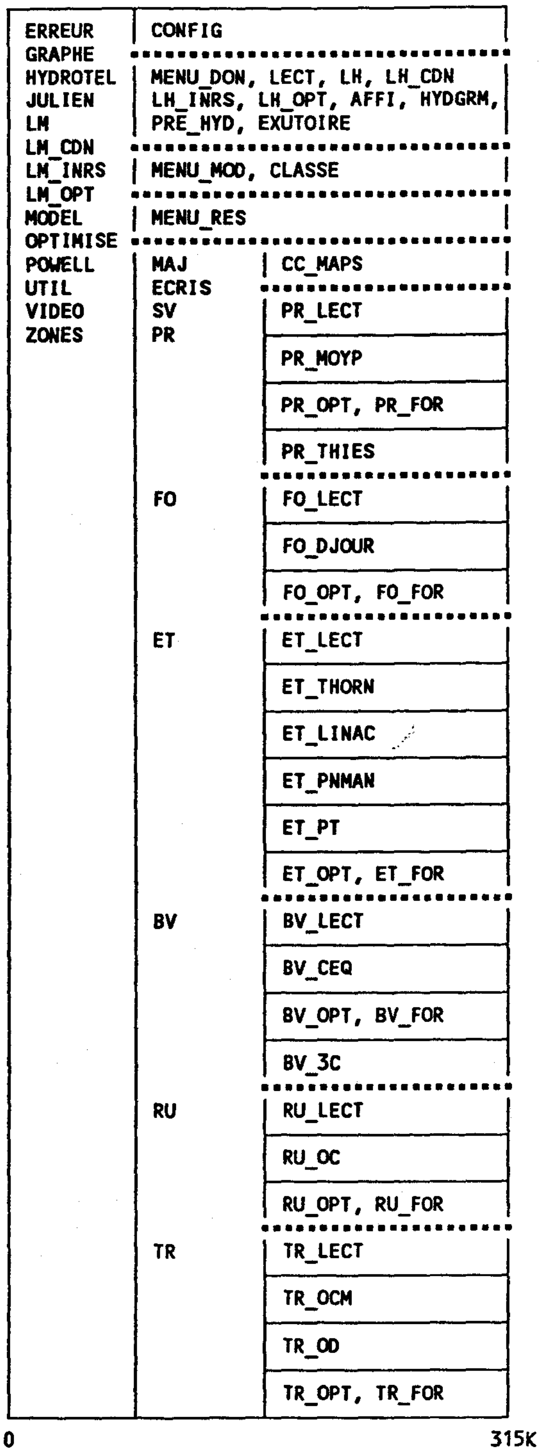

FIGURE 3 Memory map of the loaded program.

To ease the compilation and linkage processes we have included with the compiled module a make file (hydrotel.mak). This file is used with the utility **make** to automatically compile and link modified files. To build the program, enter at the DOS prompt, the command "make hydrotel.mak".

APPENDIX E

STAND-ALONE PROGRAM

APPENDIX E

STAND-ALONE PROGRAM

Stand-alone programs are programs that can be executed independently at the DOS prompt. HYDROTEL can make a request to the operating system to execute the external program. When such a request is made, HYDROTEL remains in memory while the external program is executed and then resumes its execution when the external program terminates. If the stand-alone program is too big, the request can fail and abort the simulation in HYDROTEL. The external program must be as small as possible.

The main advantages of that option are that you do not have to recompile HYDROTEL and that you can use the language of your choice. On the other hand the integration with HYDROTEL is minimal and the DOS must load your program from disk at each time step, slowing the simulation.

In HYDROTEL when the option "stand-alone program" is chosen in one of the sub-model menu, a variable is set to save the intermediate results most likely needed by the external program. That choice of intermediate results can be modified by the user in the corresponding menu.

During the initialization step, HYDROTEL saves the current state of the program in the configuration file (*.cfg). HYDROTEL also saves, in a file called 'HYDROTEL.tmp', the name of the configuration file and a negative number identifying the initialization step. After these settings, the external program is called for the first time. The name of the external program is determined by the sub-process type (PR|FO|ET|BV|RU|TR) and the suffix '_ext':

ex: ET_EXT --> external program computing the potential evapotranspiration.

During the modelisation step, HYDROTEL saves again the temporary file with the name of the configuration file and the number of days elapsed since the beginning of the simulation. Then the external program is called. The results of the call are assumed to be in the corresponding intermediate result file format.

Finally, during the conclusion step, the temporary file is saved with the name of the configuration file and a number equal to the Julian day corresponding to the last day of the simulation plus one (1). No results are needed at conclusion step.

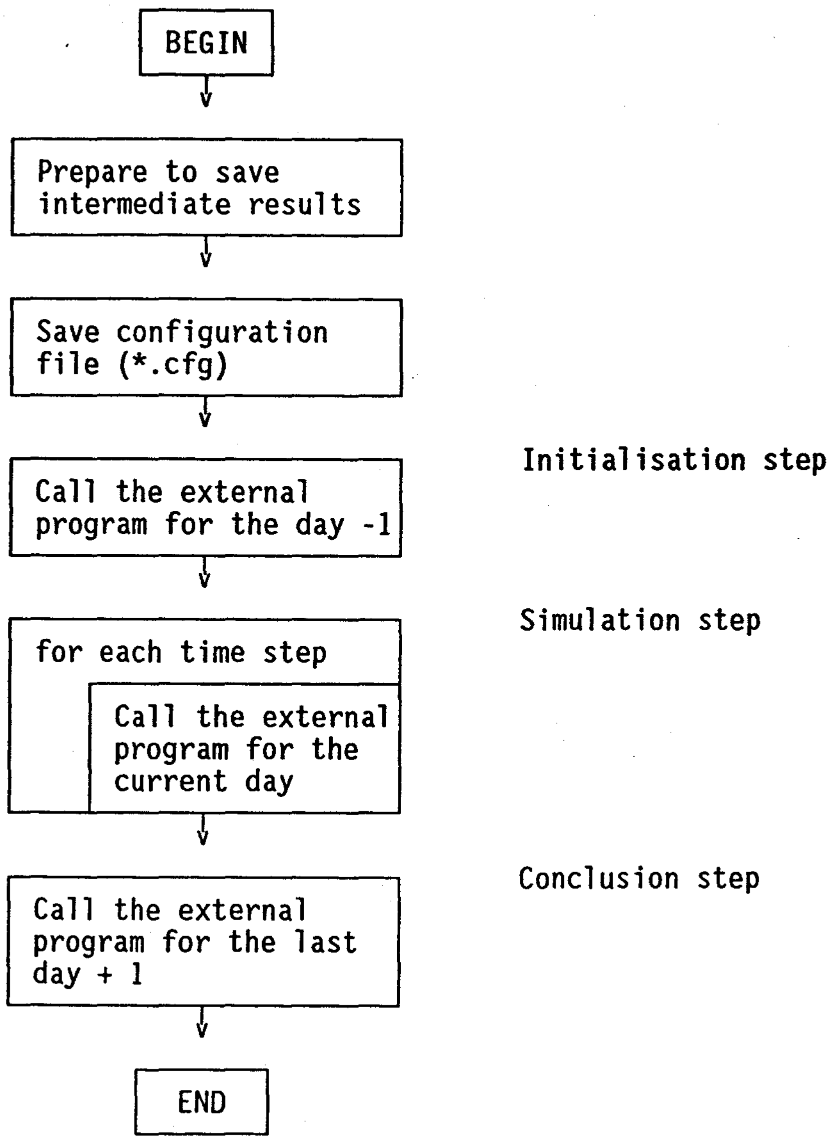

FIGURE 1 Calls to the external program in HYDROTEL.

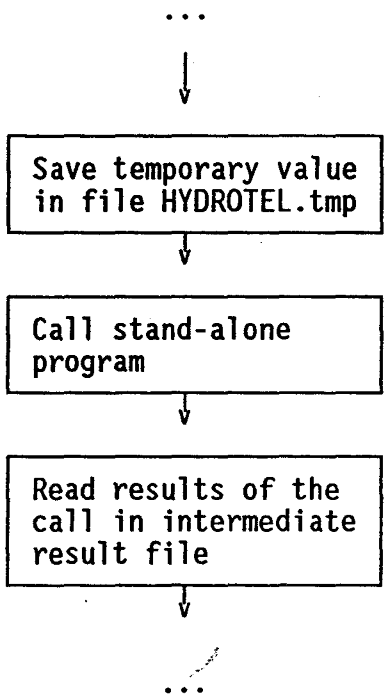

FIGURE 2 Details of a call to an external program.

The external program is assumed to do certain tasks. First, it must read the temporary file to get the name of the configuration file and the current time step of the simulation. Then, it must read the corresponding configuration file (described in Appendix B) to get the parameters of the simulation. The same program is called at the three steps of the simulation. No results are needed at the initialization or conclusion step. At the modelisation step, the program must append the results of its computations to the corresponding intermediate results. Results needed from a sub-process are described in Appendix D. The program is then terminated, removed from active memory and execution resumes in HYDROTEL.

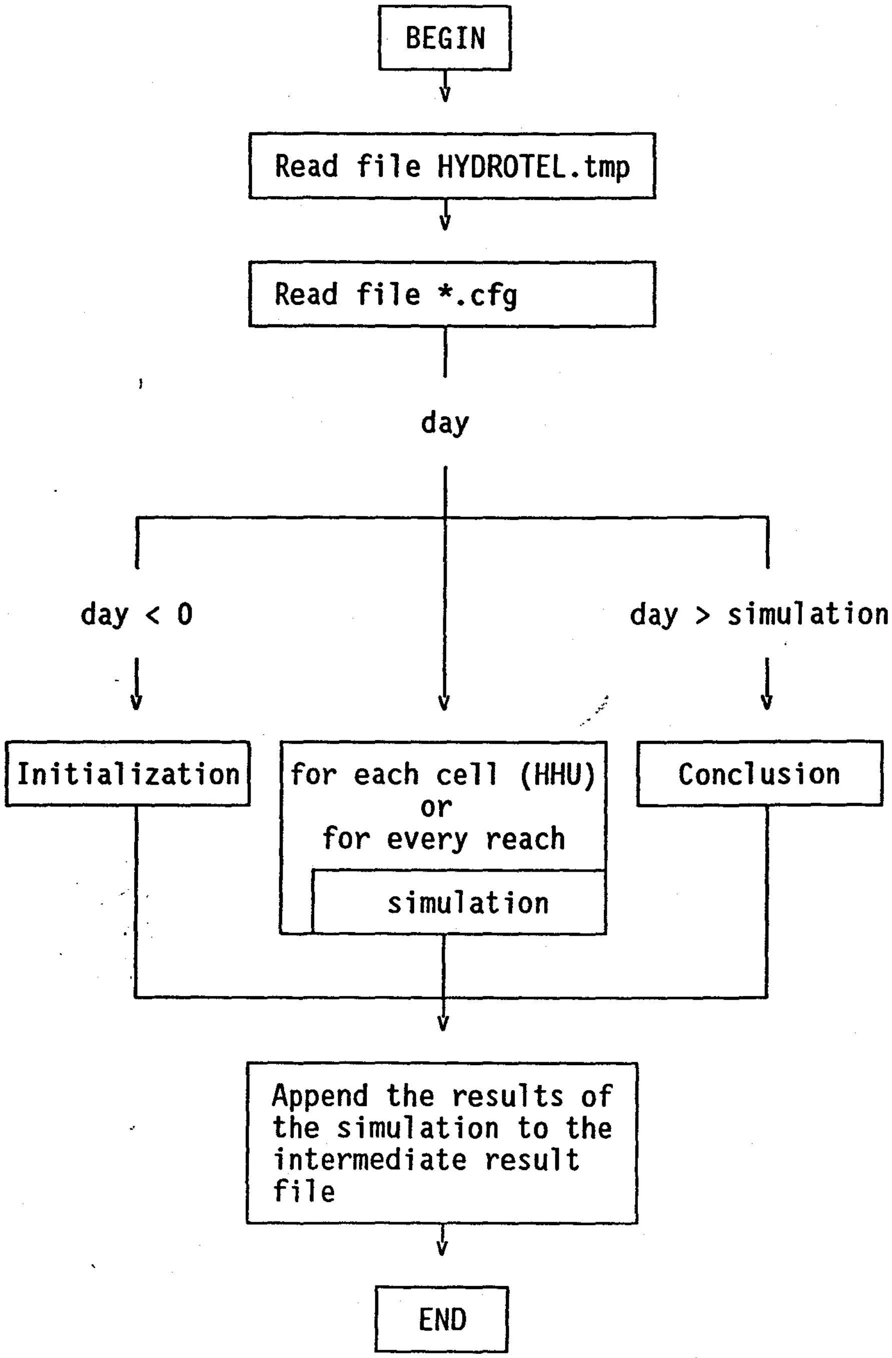

FIGURE 3 Stand alone program.