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HYDROTEL 1.0

USER'S GUIDE

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PART 1

GENERAL INFORMATION

PART 1 GENERAL INFORMATION

1.1 SOFTWARE MAIN CHARACTERISTICS AND HARDWARE REQUIREMENTS

Name: HYDROTEL 1.0

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

Programming languages: Mostly MS "C". The "precipitation module" is temporary written in BASIC.

Type of microcomputer: IBM PC/XT or AT and compatibles.

Memory requirements: 640K.

Written by: Claude Blanchette, Denis Isabel, Jean-Pierre Fortin and Hilaire Proulx.

1.2 INTRODUCTION

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

At the beginning, the model was seen as one program allowing determination of basin topography from DEM, land-use determination from the analysis of remotely sensed images and hydrological simulation and forecasting. As seen in figure 1.1, it was thought later on that the large number of tasks would be handled more easily by three interrelated software packages instead of one.

The HYDROTEL package will be devoted to hydrological simulation and forecasting. As such, it will receive input data in the proper format from PHYSITEL (topography) and IMATEL (land-use and daily operational data (surface temperature, albedo, ...)).

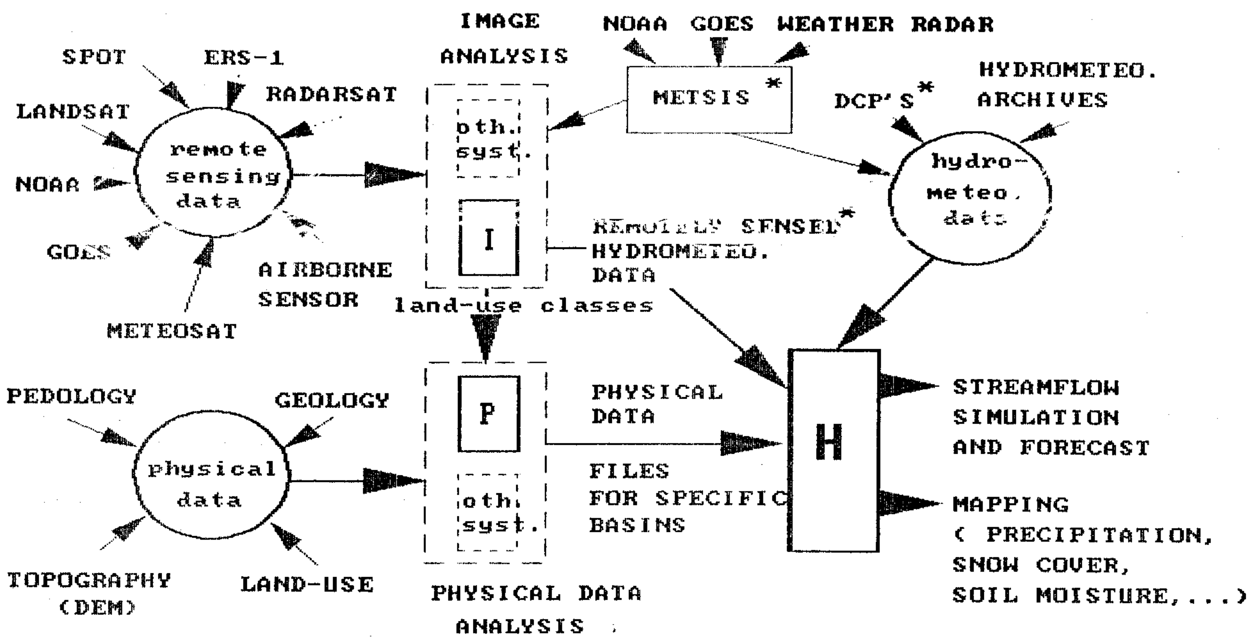

Figure 1.1 Integrated analysis of physical, remotely sensed and meteorological data for steamflow simulation and forecasting by PHYSITEL, IMATEL and HYDROTEL.

Writing of the HYDROTEL main program itself began only a few months ago. As seen by INRS-Eau the status of the current HYDROTEL version is the following:

- HYDROTEL 1.0 structure has been conceived and programmed to facilitate the gradual addition of all wanted options to a fully "à la carte" model, as well as the input and output of G.I.S. and time dependent data;

- HYDROTEL 1.0 is considered as a first working prototype, with a minimum of options and should be regarded as only a step in the development of the model originally conceived;

- HYDROTEL 1.0 can already make use of topography and land-use information;

- HYDROTEL 1.0 should not be compared to any fully developed model;

- HYDROTEL 1.0 should be used mainly to get acquainted with the model and suggest what options should be added in the following versions.

INRS-Eau will try to make development versions (1.nn) available to those participating in the tests whenever the addition of new options well make it worthwhile.

1.3 ORGANIZATION OF THE MANUAL

Part "ONE" of the manual contents general information on HYDROTEL 1.0.

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

A description of the main simulation methods available with HYDROTEL 1.00 is finally given in part "THREE", together with hints on how to select values for model parameters.

1.4 SOFTWARE AVAILABILITY AND INFORMATION

The current version (1.0) of HYDROTEL is available only to CCRS and Environment Canada personnel participating in the testing of that version, to help defining the options that should be available in HYDROTEL (2.nn).

Agreements with other agencies is also possible.

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PART 2

THE HYDROTEL PROGRAM (1.0)

PART 2 THE HYDROTEL PROGRAM (1.0)

2.1 GENERAL MODEL STRUCTURE

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

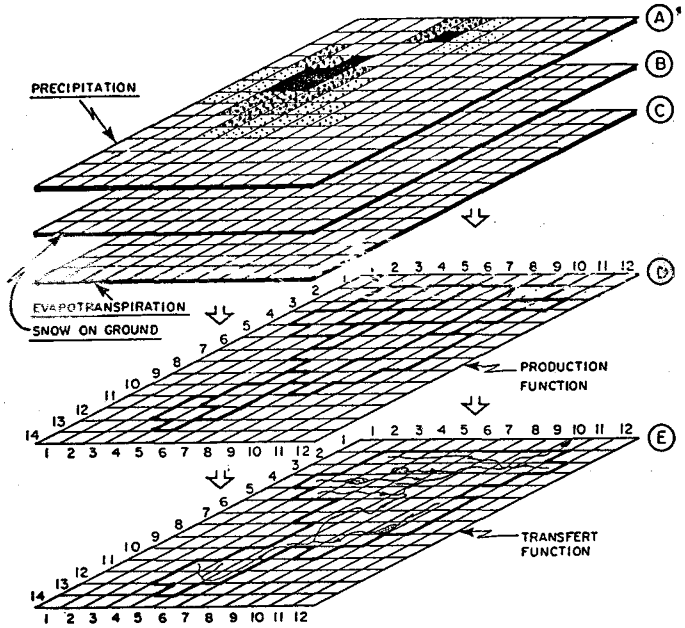

Figure 2.1 Spatial structure of the model.

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

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

- EVAPOTRANSPIRATION (estimation of potential evapotranspiration);

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

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

- MAIN (management of all tasks).

A third characteristic of HYDROTEL is the possibility for the user to incorporate its own simulation options to those already available in the model. This characteristic should be very interesting for specific applications. This means that, if a user has developed a program for the simulation of a particular part of the hydrologic cycle, it could be possible for him to integrate it in the HYDROTEL program as a new user's defined option. This option will be somewhat restricted with HYDROTEL 1.0, but will be made easier to implement in the next versions.

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 diskettes

Diskette 1	PREMOD.ENM	PREMOD.EXE	PREMOD.EXE	
Diskette 2	CLIFTON.ALT	CLIFTON.PTE	M7023312.73	M7024624.74
	CLIFTON.CLA	CLIFTON.STN	M7023312.74	M7027802.73
	CLIFTON.ICR	CLIFTON.TRO	M7027372.73	M7027802.74
	CLIFTON.IRO	M7020885.73	M7027372.74	M7028124.73
	CLIFTON.MSK	M7020885.74	M7027520.73	M7028124.74
	CLIFTON.NDS	M7022280.73	M7027520.74	M7028906.73
	CLIFTON.ORI	M7022280.74	M7024263.73	M7028906.74
	CLIFTON.PCP	M7022306.73	M7024263.74	H0030242.73
		M7022306.74	M7024624.73	H0030242.74

2.2.2 Installing HYDROTEL 1.0

Since paths to files are asked for in the menu, the user may copy the files in any directory or subdirectory.

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

1. create a new directory (or subdirectory) HYDROTEL, using the MS-DOS command MD;
2. change from the current directory (or subdirectory) to the new directory HYDROTEL, using the MS-DOS command CD;
3. when in the HYDROTEL directory, make a subdirectory MODEL;
4. change to that subdirectory. You should now have c:\HYDROTEL\MODEL;
5. copy all model files to that subdirectory;
6. change back to the HYDROTEL directory;
7. make a second subdirectory BASINS;
8. change to that subdirectory;
9. while in the subdirectory BASINS, make a specific subdirectory CLIFTON to contain all test data. Later on you could do the same for all basins for which you would like to run the program;
10. change to that last subdirectory;
11. copy all test data files to that subdirectory.

You should now be ready to start the program.

2.2.3 Test data and structure of data files

In order to familiarize the user with HYDROTEL 1.0, a data set is included with the program. At the same time, it should be looked at as an example, for the preparation of other data sets.

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

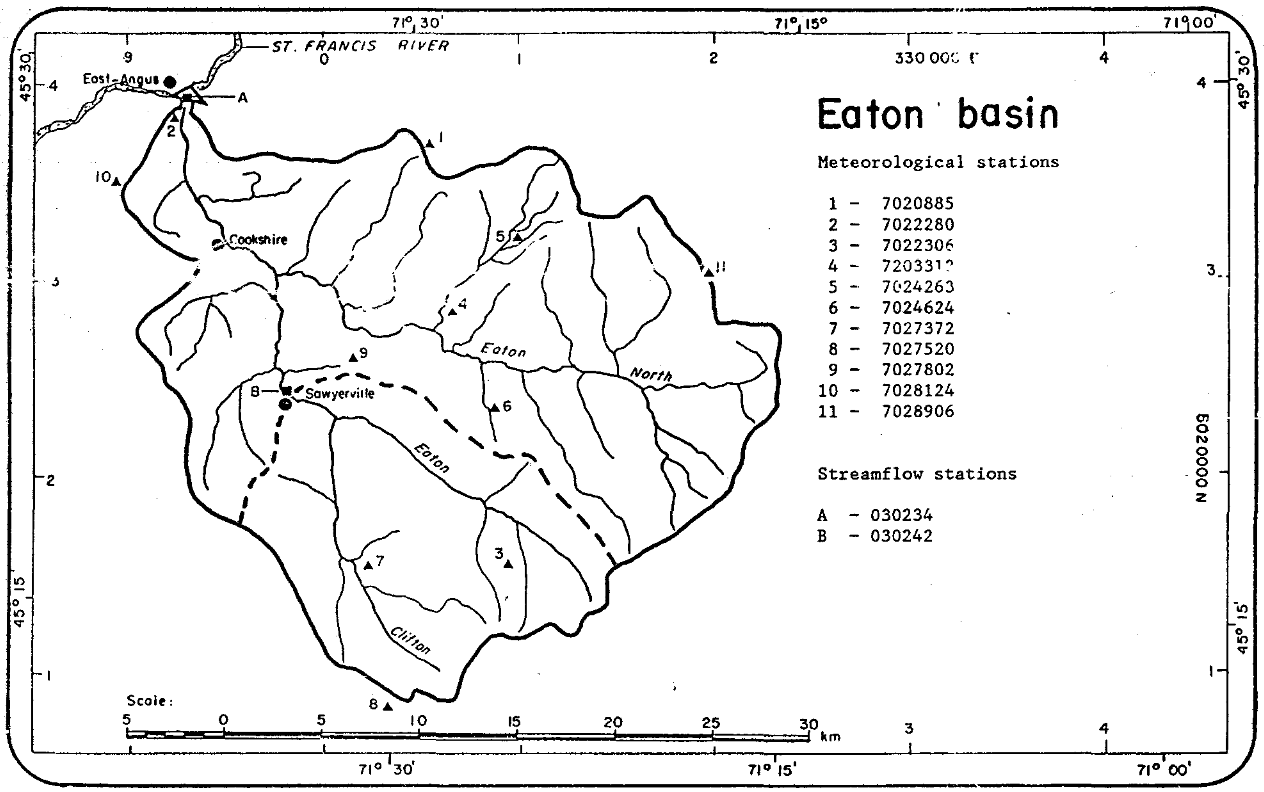

Figure 2.2 Streamflow and climatological stations on the Eaton basin.

Are included in the data set:

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

- File structure for *.TRO:

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

- land-use data for each square:

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

  - class identification and codes:

    - bare fields: "champ";
    - crops and pasture 1: "herbe";
    - crops and pasture 2: "paill";
    - extracting areas: "gravi";
    - forested areas 1 (coniferous): "resin";
    - forested areas 2 (deciduous): "feuil";
    - highways and other impervious areas: "route";
    - surface waters 1: "eau1";
    - surface waters 2: "eau2";
    - urban areas: "urb" (not in use);
    - waste lands and bushes: "frich" and "coupe";
    - wet lands and marshes: "MAR" (not in use).

- identification of streamflow and meteorological stations available for use in the simulation:

  - file name: Clifton.STN:
  - file structure:
    - record #1: file type: 1.;
    - record #2: number of streamflow stations, number of meteorological stations;
    - record #3: title or comment identifying the file;
    - record #4: identification numbers for streamflow stations;
    - record #5: identification numbers for meteorological stations.

- streamflow data (ms^{-1}) at streamgauge station 030242 for 1973 and 1974, beginning on the 1st of January of each year;

  - file name: H030242.YY (H station identification.year):

    - file structure:

      - record #1: station identification, year, number of valid values;
      - record #2 to 32: 366 daily streamflows. Missing data (including February 29): -1000.

- meteorological data (maximum daily air temperature, minimum daily air temperature, rainfall, snowfall), for 1973 and 1974, beginning on the 1st of January of each year, at the following stations:

  - 7020885 Bury;
  - 7022280 East-Angus;
  - 7022306 Eaton 2nd Branch;
  - 7023312 Island Brook;
  - 7024263 Lawrence;
  - 7024624 Maple Leaf East;
  - 7027372 St-Isidore d'Auckland;
  - 7027520 St-Malo d'Auckland;

- 7027802 Sawyerville Nord;
- 7028124 Sherbrooke A;
- 7028906 West Ditton.

- file name: M7020885.YY (M station identification.year):

  - file structure:

    - record #1: station identification, year, numbers (4) of valid data for maximum temperature, minimum temperature, rain and snow respectively, latitude in degrees and minutes, longitude in degrees and minutes, altitude (m), station identification;
    - record #2 to 17: 366 maximum temperature (°C);
    - record #18 to 33: 366 minimum temperature (°C);
    - record #34 to 49: 366 rainfall values (10^{-1} mm);
    - record #50 to 65: 366 snowfall values (10^{-1} cm).

  - missing data:

    - temperatures: -99;
    - rainfall or snowfall: -1.

2.3 USING HYDROTEL (1.0)

2.3.1 Starting HYDROTEL 1.0

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

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

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

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

2.3.2 Main menu

The main menu contains 6 options (figure 2.3). You have to go through options 1 to 4, before choosing option 5 "RUN" to execute the program with the chosen options. To choose an option, first go to that option using the arrows on the keyboard. Then, push the "ENTER" key. The sub-menu needed to define that option will appear.

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

```
MAIN MENU

1._ Input of simulation parameters;
2._ Input of physiographic data files;
3._ Sub-models;
4._ Output options;
5._ Run;
0._ End of simulation.
```

Figure 2.3 Main menu.

2.3.3 Sub-menu #1.0: input of simulation parameters

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

```
MAIN MENU

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

Figure 2.4   Sub-menu #1.0: input of simulation parameters.

2.3.3.1 Sub-menu #1.1: paths to files

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

```
MAIN MENU

1._ SIMULATION PARAMETERS        ;
2._
3._ 1._ PATH TO FILES
4._ 2._
5._ 3._ ...Path to system files: c:\hydrotel\model\
0._ 0._ ...Path to data files:   c:\hydrotel\basins\
        ...Basin filename:       clifton

        F10: Accept                          Esc: Quit
```

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

- path to system files: system files contain menus and programs. You should type HYDROTEL\MODEL, if you have followed instructions given in section 2.2.2;
- path to data files: it has been suggested in section 2.2 to group data files in a particular sub-directory. The path to files in that sub-directory should be given here;
- basin filename: this is the name under which all data files for a particular basin will be identified. As an example, the general name for all data in the set furnished with the program is "CLIFTON". Particular files are identified by "CLIFTON.***", with the stars corresponding to letters and/or numbers identifying the specific file.

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

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

2.3.3.2 Sub-menu #1.2: temporal parameters

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

- start of simulation (YYDDD): the year (last two digits) and day (1 to 366 (table 2.1)) of the first day of the simulation;
- duration (NN): the number of consecutive days in the simulation;
- time step (days): only one time step is allowed with HYDROTEL 1.0: <u>1 day</u>.

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.

```
MAIN MENU

1._ SIMULATION PARAMETERS          ;
2._                                les;
3._ 1._
4._ 2._ TEMPORAL PARAMETERS
5._ 3._
0._ 0._ ...Start of simulation (YYDDD): 73  152
        ...Duration (days):             30
        ...Time step (days):            1

        F10: Accept                   Esc: Quit
```

Figure 2.6 Sub-menu #1.2: temporal parameters.

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".

2.3.3.3 Sub-menu #1.3: spatial parameters

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

- upper left corner (UTM): enter the upper left corner of the rectangular grid containing the basin, in UTM coordinates. Note: this will be changed in later versions of HYDROTEL to use other coordinate systems more suitable to large basins;

- lower right corner (UTM): enter the lower right corner of the rectangular grid containing the basin, in UTM coordinates;

```
MAIN MENU

1._ SIMULATION PARAMETERS        ;
2._                              les;
3._ 1._ Path to files;
4._ 2._
5._ 3._ SPATIAL PARAMETERS
0._ 0._
        ...Upper left corner (UTM):  295000   5026000
        ...Lower right corner (UTM): 316000   5007000
        ...Resolution (m):           1000

        F10: Accept                           Esc: Quit
```

Figure 2.7 Sub-menu #1.3: spatial parameters.

- resolution (m): enter grid size in meters. No more than 40 squares are allowed in either direction, N-S or E-W, leading to a 40 x 40 matrix, of which only 900 squares can be within the basin. This number is much larger than needed.

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

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

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

2.3.4 Sub-menu #2.0: input of physiography data files

All first seven options (figure 2.8) have to be selected, sequentially by moving to each of these options and pressing "ENTER".

```
MAIN MENU

1._
2._ INPUT OF PHYSIOGRAPHIC DATA FILES;
3._
4._ 1._ Basin mask;
5._ 2._ Altitude of each square;
0._ 3._ Aspect of each square;
    4._ Slope of each square;
    5._ Land uses classes for each square;
    6._ Data on reach ends;
    7._ Data on reaches;
    8._ Clear memory;
    0._ Return to previous menu.
```

Figure 2.8   Sub-menu #2.0: input of physiography data files.

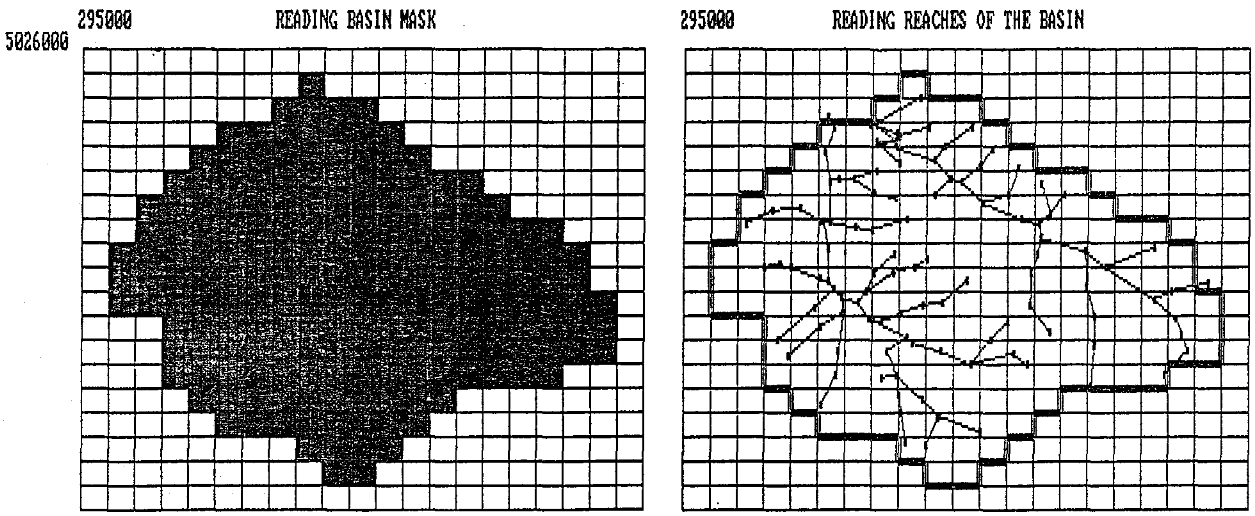

Figure 2.9   Monitoring of file input a) options 1 to 5 b) option 7.

The sub-menu is then replaced by a discretized map of the basin (figure 2.9a) monitoring the reading of the file corresponding to the chosen option. For options 1 to 5 each square is put "ON" when the value corresponding to that particular square is read. If a square within the basin limits remains "OFF", that means that no value has been read for that square.

For option 6 (data on reach extremities), the pixels corresponding to all reach extremities in the basin are put "ON".

For option 7 (data on reaches) all pixels corresponding to reaches are put "ON" (figure 2.9b). It is then possible to check if all reaches are connected.

To come back to sub-menu #2.0, when you have checked that everything seems right, just press any key.

Option 8 "clear memory" allows clearing of the memory if considered necessary for a new simulation on another basin or sub-basin.

After completing operations of options 1 to 7, return to the "main menu" by selecting option "0" and pressing "ENTER".

2.3.5 Sub-menu #3.0: sub-models

```
MAIN MENU

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

Figure 2.10 Sub-menu #3.0: sub-models.

All options (figure 2.10) 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".

2.3.5.1 Sub-menu #3.1: interpolation of precipitation

See section 3.2 for more informations.

```
MAIN MENU

1._ Input of simulation parameters;
2._
3._ SUB-MODELS
4._
5._ 1._ INTERPOLATION OF PRECIPITATIONS
0._ 2._
    3._ 1._ Thiessen polygons;                         ✓
    4._ 2._ Weighted mean of nearest three stations;
    5._ 3._ Arithmetic mean of nearest three stations;
    6._ 4._ User's define interpolation;
    0._ 0._ Return to previous menu.
```

Figure 2.11 Sub-menu #3.1: interpolation of precipitation.

Three options are available for the interpolation of precipitations (figure 2.11). Select one of those and press "ENTER". After typing input values in sub-menus 3.1.1, 3.1.2 or 3.1.3, return to "sub-menu 3.0" by selecting option "0" and pressing "ENTER".

It is possible to write a user's define interpolation function with HYDROTEL 1.0, but that would require writing also a snow melt subprogram. Separate and simplified programming of both tasks (interpolation and snowmelt) will be available in the next version of HYDROTEL. Please contact us, should it be necessary to write such a program before we make it available.

2.3.5.1.1 <u>Sub-menu #3.1.1: Thiessen polygons (figure 2.12)</u>

```
MAIN MENU

1._ Input of simulation parameters;
2._
3._ SUB-MODELS
4._
5._ 1._ INTERPOLATION OF PRECIPITATIONS
0._ 2._
    3._ 1._ THIESSEN POLYGONS
    4._ 2._
    5._ 3._ ...Precipitation vert. grad. (%/100m): 0.
    6._ 4._ ...Temperature lapse rate (C/100m):    0.
    0._ 0._
            F10: Accept                        Esc: Quit
```

Figure 2.12 Sub-menu #3.1.1: Thiessen polygons.

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

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

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

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

```
MAIN MENU

1._ Input of simulation parameters;
2._
3._ SUB-MODELS
4._
5._ 1._ INTERPOLATION OF PRECIPITATIONS
0._ 2._
    3._ 1._
    4._ 2._ WEIGHTED MEAN OF NEAREST THREE STATIONS
    5._ 3._
    6._ 4._ ...Precipitation vert. grad. (%/100m): 0.
    0._ 0._ ...Temperature lapse rate (C/100m):    0.

            F10: Accept                          Esc: Quit
```

Figure 2.13 Sub-menu #3.1.2: weighted mean of nearest three stations.

As seen in figure 2.13, this sub-menu is similar to 3.1.1. The information given is 2.3.5.1.1 applies.

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

```
MAIN MENU

1._ Input of simulation parameters;
2._
3._ SUB-MODELS
4._
5._ 1._ INTERPOLATION OF PRECIPITATIONS
0._ 2._
    3._ 1._ Thiessen polygons;
    4._ 2._
    5._ 3._ ARITHMETIC MEAN OF NEAREST THREE STATIONS
    6._ 4._
    0._ 0._ ...Precipitation vert. grad. (%/100m): 0.
            ...Temperature lapse rate (C/100m):    0.

            F10: Accept                          Esc: Quit
```

Figure 2.14 Sub-menu #3.1.3: arithmetic mean of nearest three stations.

As seen in figure 2.14, this sub-menu is similar to 3.1.1. The information given in 2.3.5.1.1 applies.

2.3.5.2 Sub-menu #3.2: snowmelt

```
MAIN MENU

1._ Input of simulation parameters;
2._
3._ SUB-MODELS
4._
5._ 1._
0._ 2._ SNOWMELT
    3._
    4._ 1._ Modified degree/day method;  ✓
    5._ 2._ User's defined snowmelt;
    6._ 0._ Return to previous menu.
    0._
```

Figure 2.15 Sub-menu #3.2: snowmelt.

Only one option is currently available for snowcover simulation and melting (figure 2.15). Select it and press "ENTER". After typing input values in sub-menu 3.2.1 (figure 2.16), return to "sub-menu 3.0" by selecting option "0" and pressing "ENTER".

The same remarks as in 2.3.5.1 applies here, if a user decides to write his own program.

2.3.5.2.1 Sub-menu #3.2.1: modified degree-day method (figure 2.16)

```
MAIN MENU

1._ Input of simulation parameters;
2._
3._ SUB-MODELS
4._
5._ 1._
0._ 2._ SNOWMELT
    3._
    4._ 1._ MODIFIED DEGREE/DAY METHOD
    5._ 2._
    6._ 0._ ...Temp. for transf. of rain into snow (°C):   0.
    0._     ...Melt factor (coniferous forest) (mm/d°C):   2.
            ...Melt factor (deciduous forest) (mm/d°C):    3.
            ...Melt factor (open areas) (mm/d°C):          4.
            ...Treshold temp. for melt (°C):               0.
            ...Melt rate at snow/ground interface (mm/d):  0.5
            ...Maximum density of snowpack (hg/m3):        550
            ...Settlement constant:                        0.1
            ...Hour zone:                                  2

            F10: Accept                               Esc: Quit
```

Figure 2.16 Sub-menu #3.2.1: modified degree-day method.

See section 3.3 for more informations.

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

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

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

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

- Threshold temperature for melt (°C): type threshold temperature for melt, in degrees Celcius.

- Melt rate at snow/ground interface (mm/d): type estimated mean constant melt rate at snow/ground interface, in millimeters per day.

- Maximum density of snowpack (kg/m^3): type estimated maximum density of snowpack, in kilograms per cubic meters.

- Settlement constant: type the settlement constant (smaller than one).

- Hour zone: Atlantic (1);
  East (2);
  Center (3);
  Prairies (4);
  West (5).

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

2.3.5.3 Sub-menu #3.3: evapotranspiration

```
MAIN MENU

1._ Input of simulation parameters;
2._
3._ SUB-MODELS
4._
5._ 1._ Interpolation of precipitations;
0._ 2._
    3._ EVAPOTRANSPIRATION
    4._
    5._ 1._ THORNTHWAITE potential evapotranspiration;   ✓
    6._ 2._ User's defined potential evapotranspiration;
    0._ 0._ Return to previous menu.
```

Figure 2.17 Sub-menu #3.3: evapotranspiration.

Only one option is currently available for the estimation of potential evapotranspiration (figure 2.17). Select it and press "ENTER". After typing input values in sub-menu 3.3.1 (figure 2.18), return to "sub-menu 3.0" by selecting option "0" and pressing "ENTER".

It is possible to write a user's defined option. See section 2.5, and contact us, eventually.

2.3.5.3.1 <u>Sub-menu #3.3.1: input data for Thorthwaite PE (figure 2.18)</u>

```
MAIN MENU

1._ Input of simulation parameters;
2._
3._ SUB-MODELS
4._
5._ 1._ Interpolation of precipitations;
0._ 2._
    3._ EVAPOTRANSPIRATION
    4._
    5._ 1._ INPUT DATA FOR THORNTHWAITE PE
    6._ 2._
    0._ 0._ ...Thornthwaite thermal index:              30.
            ...Mean latitude of the basin (degrees): 45.25
            ...Temporal shift parameter:             80

            F10: Accept                            Esc: Quit
```

Figure 2.18 Sub-menu #3.3.1: input data for Thorthwaite PE.

See section 3.4.1 for more informations.

- Thorthwaite thermal index: type Thorthwaite thermal index.

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

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

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

2.3.5.4 Sub-menu #3.4: vertical water budget

```
MAIN MENU

1._ Input of simulation parameters;
2._
3._ SUB-MODELS
4._
5._ 1._ Interpolation of precipitations;
0._ 2._ Snowmelt;
    3._
    4._ VERTICAL WATER BUDGET
    5._
    6._ 1._ CEQUEAU (modified);          ✓
    0._ 2._ User's defined function;
        0._ Return to previous menu.
```

Figure 2.19 Sub-menu #3.4: vertical water budget.

Only one option is currently available for the estimation of the vertical water budget on each square (figure 2.19). Select it and press "ENTER". After typing input values in each of the derived sub-menus, return to "sub-menu 3.0" by selecting option "0" and pressing "ENTER".

It is possible to write a user's defined option. See section 2.5 and contact us, eventually.

2.3.5.4.1 Sub-menu #3.4.1: input data for CEQUEAU

```
MAIN MENU

1._ Input of simulation parameters;
2._
3._ SUB-MODELS
4._
5._ 1._ Interpolation of precipitations;
0._ 2._ Snowmelt;
    3._
    4._ VERTICAL WATER BUDGET
    5._
    6._ 1._ INPUT DATA FOR CEQUEAU
    0._ 2._
        0._ 1._ Runoff on impervious areas;
            2._ Unsaturated zone reservoir;
            3._ Saturated zone reservoir;
            4._ Lakes and marshes;
            5._ Initial levels in reservoir;
            0._ Return to previous menu.
```

Figure 2.20 Sub-menu #3.4.1: input data for CEQUEAU.

See section 3.5 for more information.

The usual separation of the terrestrial part of the hydrologic cycle into components has been used to group the parameters of the CEQUEAU function (figure 2.20). This should facilitate the identification of each parameter and the estimation of realistic values, based on the user's knowledge of the physical characteristics of the basin.

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

2.3.5.4.1.1 Sub-menu #3.4.1.1: runoff on impervious areas (figure 2.21)

```
MAIN MENU

1._ Input of simulation parameters;
2._
3._ SUB-MODELS
4._
5._ 1._ Interpolation of precipitations;
0._ 2._ Snowmelt;
    3._
    4._ VERTICAL WATER BUDGET
    5._
    6._ 1._ INPUT DATA FOR CEQUEAU
    0._ 2._
        0._ 1._ RUNOFF ON IMPERVIOUS AREAS;
            2._
            3._ ...Depth threshold for surface runoff (mm): 0.
            4._
            5._ F10: Accept                              Esc: Quit
            0._
```

Figure 2.21 Sub-menu #3.4.1.1: runoff on impervious areas.

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

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

2.3.5.4.1.2 Sub-menu #3.4.1.2: unsaturated zone reservoir (figure 2.22)

```
MAIN MENU

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

Figure 2.22 Sub-menu #3.4.1.2: unsaturated zone reservoir.

- Capacity of the reservoir (mm): type the maximum depth of water which can be stored in the reservoir (in millimeters).

- Threshold for sub-surface runoff (mm): type the threshold level water must reach before any surface runoff begin (in millimeters).

- Runoff coefficient: type the runoff coefficient.

- Threshold for percolation (mm): type the threshold level (in millimeters), water must reach before any percolation to the saturated zone reservoir occurs.

- Percolation coefficient: type the percolation coefficient.

- Maximum rate of percolated water (mm/d): type the maximum amount (millimeters) of percolated water allowed each day.

- Threshold for PET (mm): type the threshold level (millimiters) over which evapotranspiration occurs at potential rate.

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

2.3.5.4.1.3 Sub-menu #3.4.1.3: saturated zone reservoir (figure 2.23)

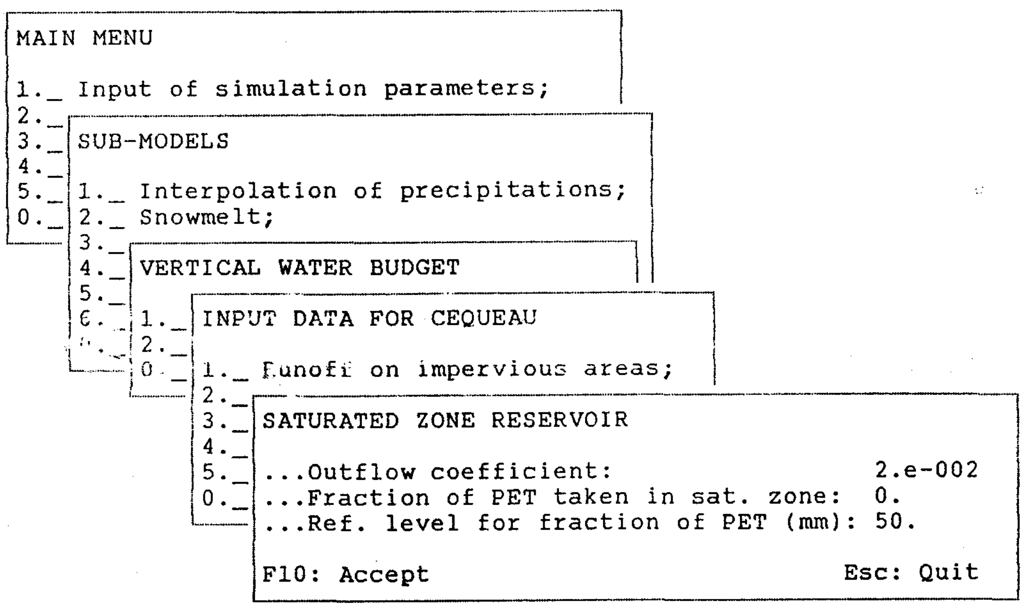

Figure 2.23 Sub-menu #3.4.1.3: saturated zone reservoir.

- Outflow coefficient: type the outflow coefficient.

- Fraction of PET taken in saturated zone: type the nominal fraction of potential evapotranspiration taken from the saturated zone.

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

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

2.3.5.4.1.4 Sub-menu #3.4.1.4: lakes and marshes (figure 2.24)

```
MAIN MENU

1._ Input of simulation parameters;
2._
3._ SUB-MODELS
4._
5._ 1._ Interpolation of precipitations;
0._ 2._ Snowmelt;
    3._
    4._ VERTICAL WATER BUDGET
    5._
    6._ 1._ INPUT DATA FOR CEQUEAU
    0._ 2._
        0._ 1._ Runoff on impervious areas;
            2._ Unsaturated zone reservoir;
            3._
            4._ LAKES AND MARSHES
            5._
            0._ ...Threshold for outflow (mm): 250
                ...Outflow coefficient:        2.5e-002

                F10: Accept                    Esc: Quit
```

Figure 2.24 Sub-menu #3.4.1.4: lakes and marshes.

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

- Outflow coefficient: type the outflow coefficient.

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

2.3.5.4.1.5 Sub-menu #3.4.1.5: initial levels in reservoirs (figure 2.25)

```
MAIN MENU

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

Figure 2.25 Sub-menu #3.4.1.5: initial levels in reservoirs.

- Unsaturated zone (mm): type the initial level of water (in millimeters) in the unsaturated zone reservoir.

- Saturated zone (mm): type the initial level of water (in millimeters) in the saturated zone reservoir.

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

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

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

```
MAIN MENU

1._ Input of simulation parameters;
2._
3._ SUB-MODELS
4._
5._ 1._ Interpolation of precipitations;
0._ 2._ Snowmelt;
    3._ Evapotranspiration;
    4._
    5._ SURFACE AND SUB-SURFACE RUNOFF;
    6._
    0._ 1._ Kinematic wave equation;        ✓
        2._ User's defined runoff function;
        0._ Return to previous menu.
```

Figure 2.26 Sub-menu #3.5: **surface and sub-surface runoff.**

See section 3.6 for more information.

Only one option is currently available for the simulation of surface and sub-surface runoff (figure 2.26). Select it and press "ENTER". A control "V" appears, confirming the selection.

After typing, in sub-menu 3.5.1, the "file name" in which initial values of water in transit are stored, return to sub-menu "3.0" by selecting option "0" and pressing "ENTER".

It is possible to write a user's defined option. See section 2.5 and contact us, eventually.

2.3.5.5.1 Sub-menu #3.5.1: kinematic wave equation (figure 2.27)

```
MAIN MENU

1._ Input of simulation parameters;
2._
3._ SUB-MODELS
4._
5._ 1._ Interpolation of precipitations;
0._ 2._ Snowmelt;
    3._ Evapotranspiration;
    4._
    5._ SURFACE AND SUB-SURFACE RUNOFF;
    6._
    0._ 1._ KINEMATIC WAVE
        2._
        0._ 1._ Read initial settings ;
            0._ Return to previous menu.
```

Figure 2.27 Sub-menu #3.5.1: **kinematic wave equations.**

See section 2.4.2.2 for more information. If you want to use a pre-computed initialization file select "Read initial settings" and press "ENTER". A control "V" will appear and the "file name" will be asked when the program is run. Otherwise, initial runoff values are initialized to "zero". Return to sub-menu 3.5 by selecting option "0" and pressing "ENTER".

2.3.5.6 Sub-menu #3.6: channel routing

```
MAIN MENU

1._ Input of simulation parameters;
2._
3._ SUB-MODELS
4._
5._ 1._ Interpolation of precipitations;
0._ 2._ Snowmelt;
    3._ Evapotranspiration;
    4._ Vertical water budget;
    5._
    6._ CHANNEL ROUTING
    0._
        1._ Modified kinematic wave equation;          ✓
        2._ User's defined channel routing function;
        0._ Return to previous menu.
```

Figure 2.28 Sub-menu #3.6: channel routing.

See section 3.7 for more information.

Only one option is currently available for the simulation of channel routing (figure 2.28). Select it and press "ENTER". A control "V" appears, confirming the selection.

After typing, in sub-menu 3.6.1, the "file name" in which initial values of channel water are stored, return to sub-menu "3.0" by selecting option "0" and pressing "ENTER".

It is possible to write a user's defined option. See section 2.5 and contact us, eventually.

2.3.5.6.1 Sub-menu #3.6.1: modified kinematic wave equation (figure 2.29)

```
MAIN MENU

1._ Input of simulation parameters;
2._
3._ SUB-MODELS
4._
5._ 1._ Interpolation of precipitations;
0._ 2._ Snowmelt;
    3._ Evapotranspiration;
    4._ Vertical water budget;
    5._
    6._ CHANNEL ROUTING
    0._
        1._ MODIFIED KINEMATIC WAVE          ;
        2._                                  unction;
        0._ 1._ Read initial settings ;
            0._ Return to previous menu.
```

Figure 2.29 Sub-menu #3.6.1: modified kinematic wave equations.

See section 2.4.2.2 for more information. If you want to use a pre-computed initialization file select "Read initial settings" and press "ENTER". A control "V" will appear and the "file name" will be asked when the program is run. Otherwise, initial runoff values are initialized to "zero". Return to sub-menu 3.6 by selecting option "0" and pressing "ENTER".

2.3.6 Sub-menu #4.0: output options

```
MAIN MENU

1._ Input of simulation parameters;
2._ Input of physiographic data files;
3._
4._ OUTPUT OPTIONS
5._
0._ 1._ Watch ;
    2._ Display ;
    3._ Save ;
    0._ Return to previous menu.
```

Figure 2.30 Sub-menu #4.0: output options.

Sub-menu 4.0 contains three options (figure 2.30). Any of them may be selected but do not have to be selected, depending on user's decision. When this is done, return to "main menu" by selecting option "0" and pressing "ENTER". Each of those options leads to a new sub-menu in which information has to be given to defined output more specifically.

2.3.6.1 Sub-menu #4.1: watch

```
MAIN MENU

1._ Input of simulation parameters;
2._ Input of physiographic data files;
3._
4._ OUTPUT OPTIONS
5._
0._ 1._ WATCH
    2._
    3._ 1._ Squares;
    0._ 2._ Reaches;
        3._ Reservoir;
        0._ Return to previous menu.
```

Figure 2.31 Sub-menu #4.1: watch.

Three options can be selected in sub-menu #4.1 (figure 2.31), but only one at the same time.

Select one option and press "ENTER". A control "V" appears, confirming the selection. Return to previous menu #4.0 by selecting "0" and pressing "ENTER".

No matter what option is chosen, a discretized map of the basin appears in the left portion of the screen (figures 2.32, 2.33 and 2.34). A rectangular cursor is "on" and can be moved from square to square or reach to reach, by the "arrows" on the keyboard. To the right of the map, tabular information is given relative to square, reaches and reservoirs, depending on the option.

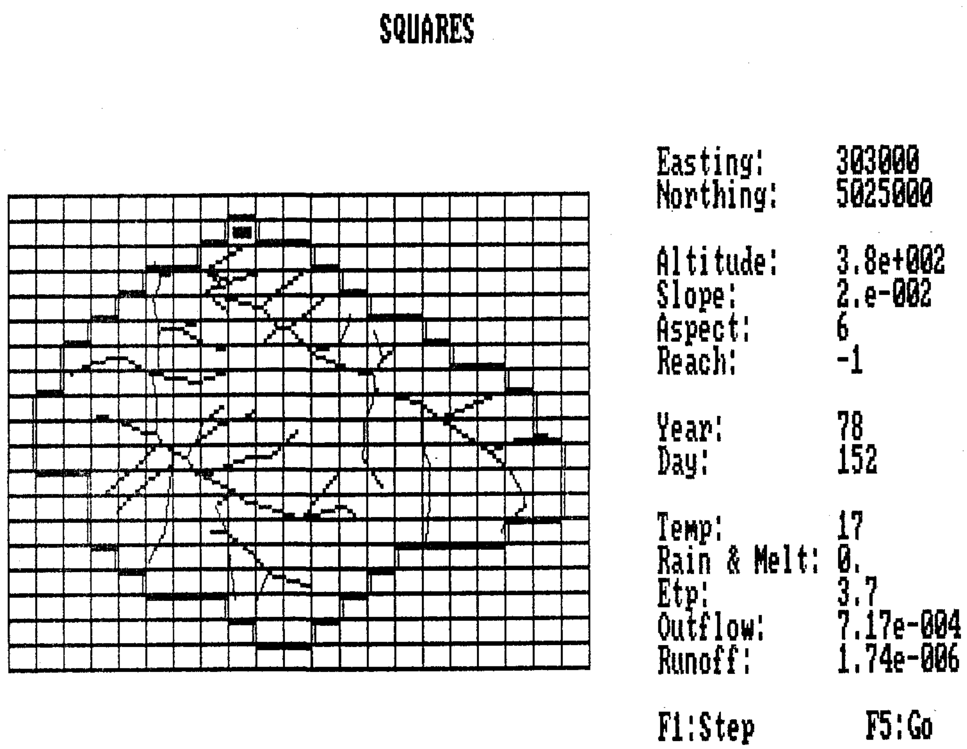

Figure 2.32 Tabular informations on variables related to squares.

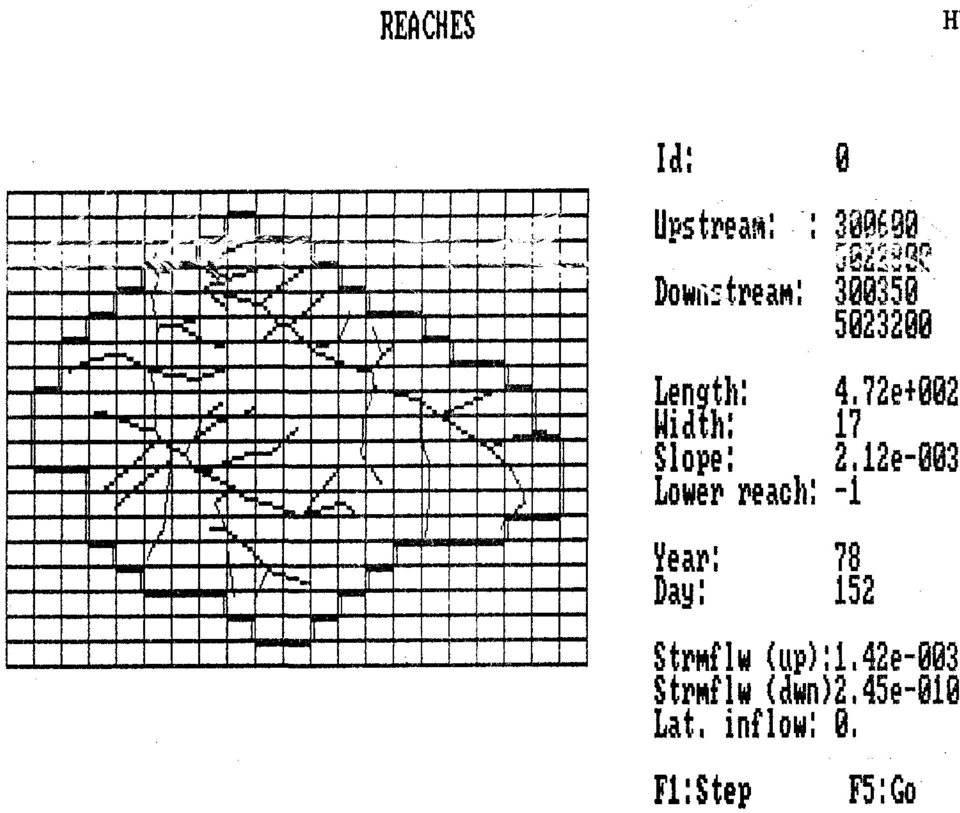

Figure 2.33 Tabular informations on variables related to reaches.

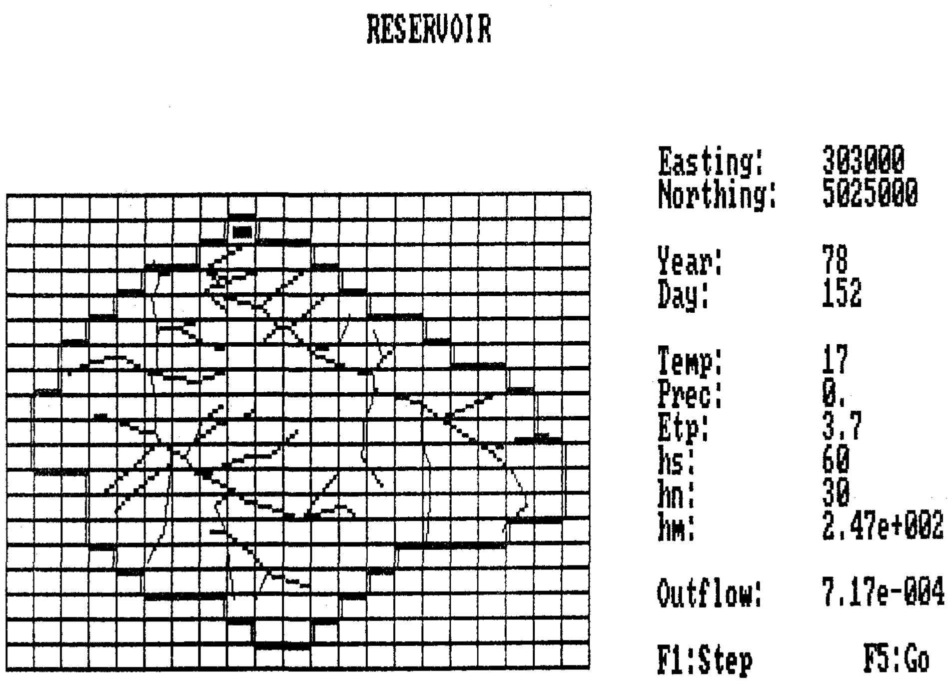

Figure 2.34 Tabular informations on variables related to vertical water budget.

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

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

2.3.6.2 Sub-menu #4.2: display

```
MAIN MENU

1._ Input of simulation parameters;
2._ Input of physiographic data files;
3._
4._ OUTPUT OPTIONS
5._
0._ 1._
    2._ DISPLAY
    3._
    0._ 1._ Streamflow hydrograph;
        0._ Return to previous menu.
```

Figure 2.35 Sub-menu #4.2: display.

Only one option is currently available in sub-menu #4.2 (figure 2.35). It allows tracing of both observed and simulated hydrographs (figure 2.36).

Press "ENTER". A control "V" appears, confirming the selection. Return to previous menu #4.0 by selecting "0" and pressing "ENTER".

The graph will appear automatically, at the end of the simulation. To print it press "PRINT SCREEN". To return to "main menu" after looking at the hydrographs, press any key. Note that GRAPHICS.COM must be run before running HYDROTEL if printing of graphs is required.

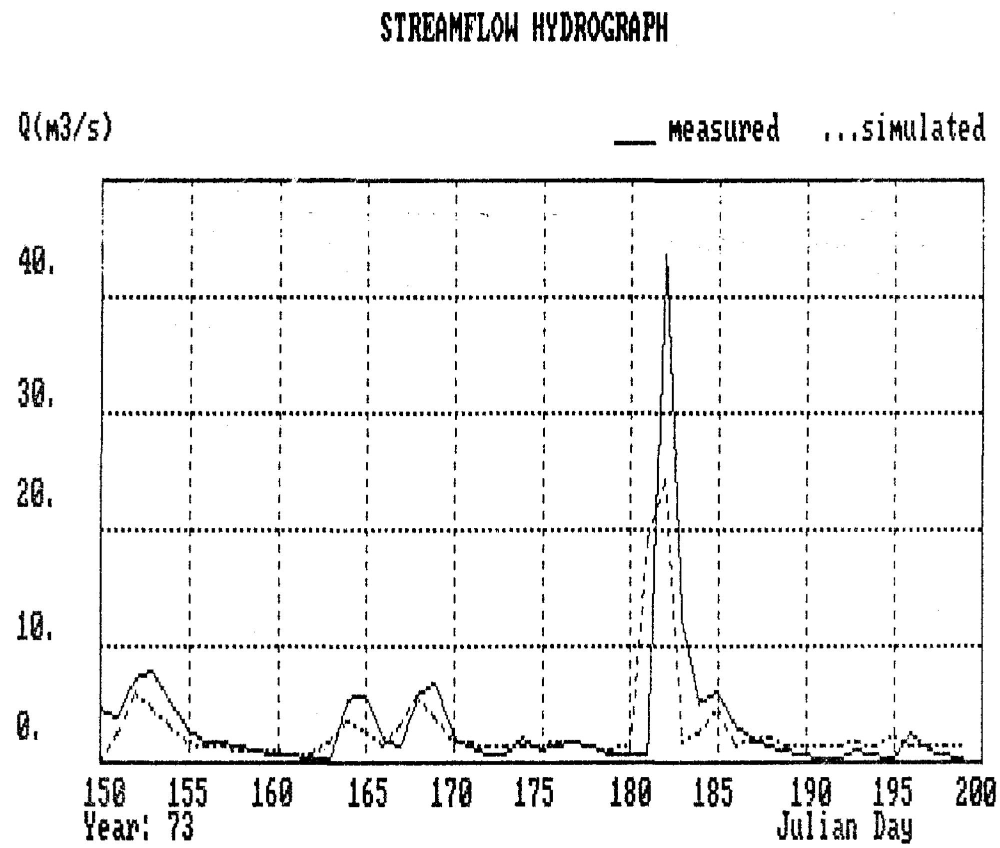

Figure 2.36 Streamflow hydrograph.

2.3.6.3 Sub-menu #4.3: save

```
MAIN MENU

1._ Input of simulation parameters;
2._ Input of physiographic data files;
3._
4._ OUTPUT OPTIONS
5._
0._ 1._ Watch ;
    2._
    3._ SAVE
    0._
        1._ Temperatures;
        2._ Rain and/or melt;
        3._ Potential evapotranspiration;
        4._ Outflow;
        5._ Runoff;
        6._ Streamflows;
        7._ Final runoff settings;
        8._ Final channel routing settings;
        0._ Return to previous menu.
```

Figure 2.37 Sub-menu #4.3: save.

It is possible to save values of all variables appearing in sub-menu #4.3 (figure 2.37).

To do that, move to the desired variable, and press "ENTER". A control "V" appears, confirming the selection. When all desired variables have been confirmed, return to previous sub-menu "4.0" by selection "0" and pressing "ENTER".

The variables will be saved as matrices corresponding to their own types of spatial distribution (figures 2.38 and 2.39), one per time step! This may take a lot of space on hard disk, so be careful.

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	14.5	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	14.5	14.5	14.5	15.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	14.5	14.5	14.5	14.5	14.5	14.5	14.5	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	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.5	14.5	14.5	14.5	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	15.5	15.5	15.5	14.5	14.5	0.0	0.0	0.0	0.0	0.0
0.0	0.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	15.5	15.5	15.5	15.5	15.5	14.5	14.5	0.0	0.0	0.0
0.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	0.0	0.0
0.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	0.0	0.0
0.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	0.0
0.0	0.0	0.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	0.0
0.0	0.0	0.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	0.0
0.0	0.0	0.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	15.5	15.5	15.5	15.5	15.5	15.5	15.5	0.0	0.0	0.0
0.0	0.0	0.0	0.0	14.0	14.0	14.0	14.0	13.5	13.5	13.5	15.5	15.5	15.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	13.5	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	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.5	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	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

2

Figure 2.38 Main daily temperature.

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 2.39 Available water from rain and/ or melt.

At the beginning of the simulation, the program will ask for file identification for each of the files it will create.

After the simulation is completed, it will be possible to look at them with any of the available tasks to look at and modify regular ASCII files. It will also be possible to process those files with other software programs, to get, for instance, maps, statistics or variations of a particular variable on a particular square as a function of time.

2.4 CALIBRATION OF MODEL PARAMETERS AND INITIALIZATION OF STATE VARIABLES

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

2.4.1 Calibration of model parameters

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

2.4.1.1 Control criteria

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

2.4.1.2 Pre-calibration sensitivity analysis

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

2.4.1.3 Subjective calibration

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

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

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

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

2.4.2 Initialization of state variables

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

2.4.2.1 Vertical water profile

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

In the case of the sub-model used in HYDROTEL 1.0 to simulate the vertical water budget, three state variables need be initialized (see also sections 2.3.5.4.1.5 and 3.5.1.2).

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

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

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

where:

H = water level in saturated zone reservoir (mm)
Q_0 = measured streamflow (m^3s^{-1})
86.4 = constant (conversion of units)
A = basin area (km^2)
C = outflow coefficient from the saturated zone reservoir (see sections 2.3.5.4.1.3 and 3.5.1.2).

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

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

2.4.2.2 Water in transit

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

2.4.2.2.1 <u>First simulation on a new basin</u>

The following method is suggested.

<u>Estimation of water level in the saturated zone reservoir for base flow simulation</u>

With equation (2.1), obtain a first estimate H of the water level (equal for all <u>square</u>) in the saturated zone reservoir corresponding to the measured streamflow Q_0.

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

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

where:

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

n = number of days (10 to 20)

C = outflow coefficient from the saturated zone reservoir.

Parameter values for base flow simulation

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

- Sub-menu 1.2:

  - number of days: 30 (or more);

- Sub-menu 3.4.1.1:

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

- Sub-menu 3.4.1.2:

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

Leave other parameters with default values.

- Sub-menu 3.4.1.3:

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

- Sub-menu 3.4.1.4:

  - outflow coefficient: 0.0;

Leave the other parameter with its default value.

- Sub-menu 3.4.1.5:

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

<u>First initialization simulation</u>

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

<u>Second initialization simulation</u>

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 <u>the last day</u> of the simulation. Run the program and <u>save</u> the values of water in transit from square to square and from reach to reach (sub-menus #3.5.1 and #3.6.1) for later use.

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

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

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

2.5 INTEGRATION OF USER'S DEVELOPED SUB-MODELS

Following June meeting in Ottawa, we have decided to postpone a detailed section on how to integrate to HYDROTEL 1.0 users' developed sub-models. Such a section should be available next fall with version 1.1 of HYDROTEL, integrating all options having a high priority for CCRS and Environment Canada. These options will likely include Environment Canada formats for streamflows and climatological data, more display options, precipitation module rewritten in "C". A special effort will be make to look of the possibility of integrating FORTRAN programs to HYDROTEL, as wished by attendees.

We assume that users will normally get acquainted with the model before deciding to integrate their own programs. By that time, we should have a detailed guide ready to help them do so. Otherwise, we could give them informations to do so.

HYDROTEL 1.0 already contains dummy sub-programs that will be used to implement new options. As long as the new option uses data already available and is written in "C", it should be easy to implement.

PART 3

MAIN SIMULATION EQUATIONS AND FLOW CHARTS

PART 3 MAIN SIMULATION EQUATIONS AND FLOW CHARTS

3.1 INTRODUCTION

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

Only main equations and flow charts will be briefly explained here. A more detailed chapter describing the model will be available starting with HYDROTEL 2.00. Of course, it will be assumed that the reader is already familiar with hydrological simulation and forecasting.

3.2 SPATIAL DISTRIBUTION OF PRECIPITATION

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

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

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

3.2.1 Thiessen polygons

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

3.2.2 <u>Weighted mean of nearest three stations</u>

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

3.2.3 <u>Arithmetic mean of nearest three stations</u>

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

3.3 SNOW COVER SIMULATION AND MELTING

Only a modified degree-day method is available with HYDROTEL 1.0. However, simulation of snowpack processes using an energy budget method is planned and will be added in further versions of the model.

3.3.1 <u>Transformation of rainfall into snowfall</u>

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

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

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

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

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

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

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

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;

R_h = radiation index for a horizontal surface;

T_a = air temperature (°C);

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

A = albedo of snow;

R = rainfall (mm).

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

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

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

3.3.3 Input variables

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

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

The following variables apply to the snowpack submodel exclusively:

- COMPAC: settlement constant. This constant is applied to the difference between the actual snow depth at density ρ_t corresponding to a particular water equivalent and the snow depth that would be observed at maximum density DSNGX. A value around 0.1 is suggested;

- CFR, CFF, CDF (mm d^{-1} $°C^{-1}$): melt factors for coniferous forests, deciduous forests and open areas respectively. Effective cover should be taken into account in deciding of a particular value. Use of information coming from remotely sensed data is planned for further versions of the model. The smallest value should be given to CFR and the greatest to CFD. Actual values will usually range between 2 and 5 mm d^{-1} $°C^{-1}$;

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

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

- TS (°C): threshold temperature for melt. This temperature is assumed to be 0°C by Riley et al. (1972). Standard degree-day equations use values of TS different for forested and open areas in order to take into account the radiation effect. In the current model, the value of TS is assumed to be identical for all three land-use classes, the radiation effect being taken into account by both the melt factors and the radiation indices.

3.4 EVAPOTRANSPIRATION

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

3.4.1 Thornthwaite potential evapotranspiration

3.4.1.1 The equation

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

The equation is:

$$E_{th} = \frac{16.2}{30.4} \left(\frac{10\,\bar{T}_a}{X_1} \right)^{X_2} C_1 \qquad (3.3)$$

where:

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

$\bar{T}_a$ = mean daily air temperature (°C);

X_1 = Thornthwaite's thermal index;

X_2 = exponent derived from X_1;

C_1 = adjustment factor for latitude and day length.

3.4.1.2 Input data

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

- X_1: an initial value for X_1 can be obtained from the following formula: $X_1 = \sum_{i=1}^{12} \left(\frac{\bar{T}_{M_i}}{5}\right)^{1.5}$. The variable $\bar{T}_{M_i}$ is the mean interannual monthly temperature for a particular month i;

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

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

3.5 VERTICAL WATER BUDGET

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

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

3.5.1 CEQUEAU (modified)

3.5.1.1 Description of the function

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

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

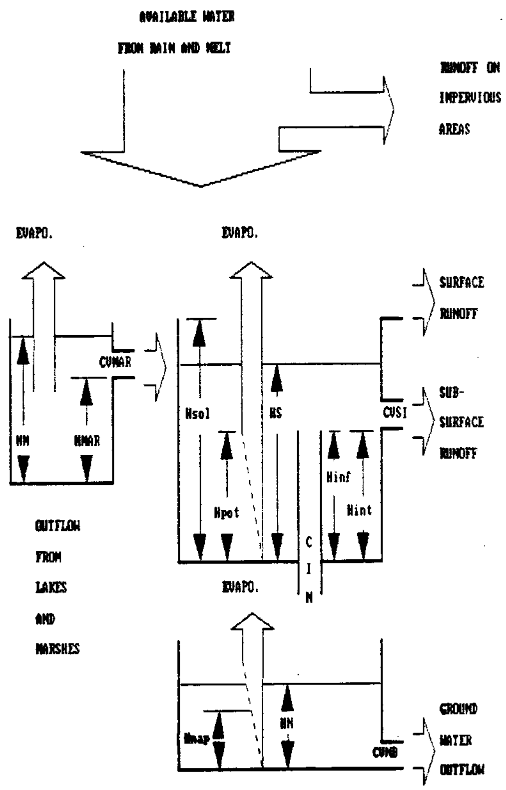

Figure 3.1 Vertical water budget adapted from the CEQUEAU model.

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

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

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

3.5.1.2 Input data

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

. Runoff on impervious areas:

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

. Unsaturated zone reservoir:

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

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

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

- H_{inf} (mm): threshold level for percolation from the unsaturated zone to the saturated zone;

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

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

- H_{pot} (mm): threshold level for evapotranspiration to occur at potential rate.

. Saturated zone reservoir:

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

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

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

. Lakes and marshes:

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

- CVMAR: outflow coefficient.

. Initial levels in the reservoirs:

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

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

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

3.6 SURFACE AND SUB-SURFACE RUNOFF

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

In the model, water available for runoff is first transferred from square to square as surface and sub-surface runoff until a square containing a river reach is found out (figure 3.2). The upstream flow is then transferred to the channel reach crossing that square as channel inflow. The path from square to square to that first river reach is defined by the main drainage network obtained from topography (relative height, slope and aspect of contiguous squares).

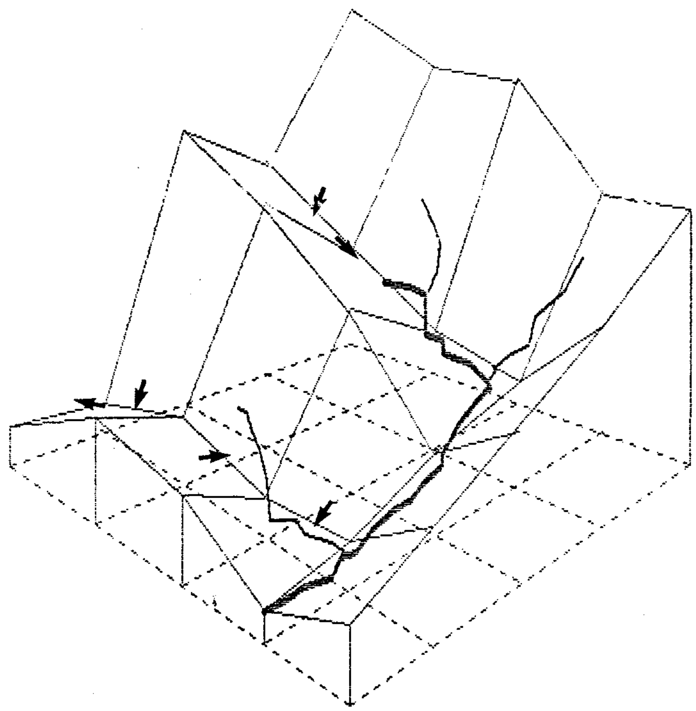

Figure 3.2 Surface and sub-surface runoff and channel flow.

Only one method of transfer is currently available.

3.6.1 Kinematic wave equations

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

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

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

where:

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

h = flow depth (m);

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

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

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 Input data

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

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

- basin mask: binary matrix identifying squares within ("one") or outsite ("zero") the basin;

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

- aspect: determined to eight directions from the difference in altitude between contiguous squares, by a steepest descent algorithm. Slope and aspect for each square are interrelated;

- land-use: information on land-use is used to determine values of the Manning's roughness coefficient n.

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

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

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

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

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

3.7 CHANNEL ROUTING

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

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

3.7.1 Modified kinematic wave equations

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

- continuity equation

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

- dynamic equation

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

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

- cross-section-discharge relationship

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

- depth-discharge relationship

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

where:

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

A = flow cross section (m^2);

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

x = reach length (m);

t = time (s);

h = flow depth (m);

S_o = channel bottom slope (m/m);

S_f = friction slope (m/m);

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

β = coefficient . β* = 0.6;

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

s = coefficient . s* = β;

B = channel width (m).

* For a rectangular cross-section.

3.7.2 Input data

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

For each reach end:

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

For each reach:

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

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

3.8 LAND-USE CLASSIFICATION

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

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

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

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

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

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

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

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