LAND AND WATER MANAGEMENT DEPARTMENT

ON – DEMAND PRESSURIZED IRRIGATION SYSTEMS: DESIGN AND ANALYSIS

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In order to facilitate the calculation and the analysis of large networks, a computer software called **COPAM** - **Combined Optimization and Performance Analysis Model**, has been developed by Lamaddalena (1998).

All computer programs developed for the computation and the analysis of irrigation systems require detailed information on the pipes network transporting water from the source to the demand points (hydrants).

This software has several options. Some of them will be explained throughout the course. Please find COPAM enclosed in the directory**********.

In the following, general information on the installation of the program and the preparation of the input data files are referred as well as the use of some options of COPAM.

TU1.2: INSTALLATION AND STARTING

Basic Windows knowledge is required for installing the COPAM Package.

1. Create an appropriate directory in the hard disk (you can call it “Copam”),
2. Insert the install disk in the appropriate drive,
3. Copy all files from the install disk to the directory previously created (Copam). Verify that also the files “*.dll” have been copied,
4. From explorer program, open the directory Copam and create a shortcut on the desktop for the file (icon) “copam.exe”,
5. Change the name occurring below the icon by clicking one time on its label. It is suggested to call it COPAM,
6. Double click on the COPAM icon. Figure 8 will appear for few seconds followed by figure 9.
   Three different sets of programs are available in the COPAM package.
   1) Discharges computation
   2) Pipe size computation
   3) Analysis

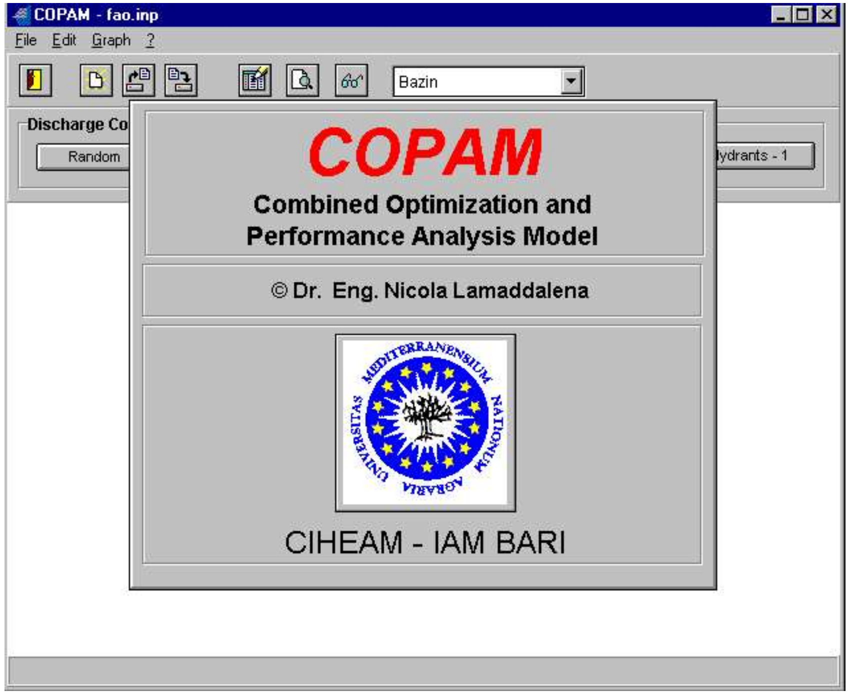


Figure 8: First screen of the COPAM Package

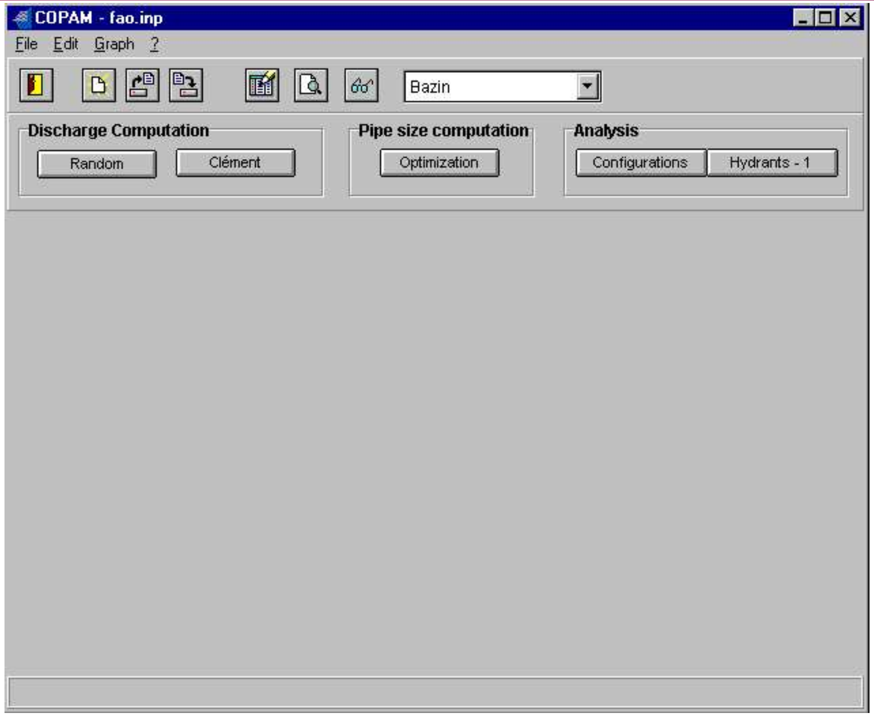


Figure 9: Layout of the COPAM package

Two programs are available under the set " Discharges computation": Clément and Random. One program is available under the set "Pipe size computation": optimization. Two programs are available under the set "Analyses": Configurations and Hydrants.
For all the above softwares, the basic input file is the same and it will be explained below.

When clicking with your mouse on any of the menu bar words, a sub-menu will drop down. Different options are available in the File menu: New, Open, Save, Save as, Print input file, Setup printer, View file, Exit. All these options are familiar for windows users. To create a new file, the option "New" has to be clicked and after, the menu bar "Edit" has to be selected. The sub-menu in Figure 10 will drop down.

By clicking on each of the available options, the input data may be insert in the Edit menu. It is strongly recommended to prepare the input data before entering in the program.

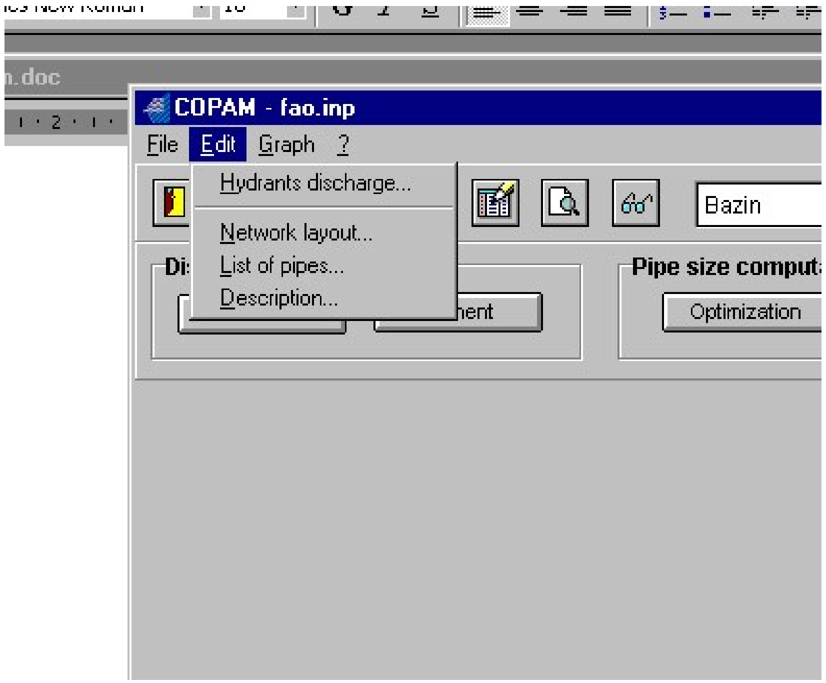


Figure 10: Edit menu bar and its sub menu items

It is suggested to select first the sub-menu “Edit/Hydrants Discharge” by clicking on it. The Figure 11 will appear and the list of the nominal discharges of the hydrants has to be inserted in the appropriate edit box. The list of hydrants discharge has to be introduced in an increasing order.
The command “OK” will close the option and store the information.

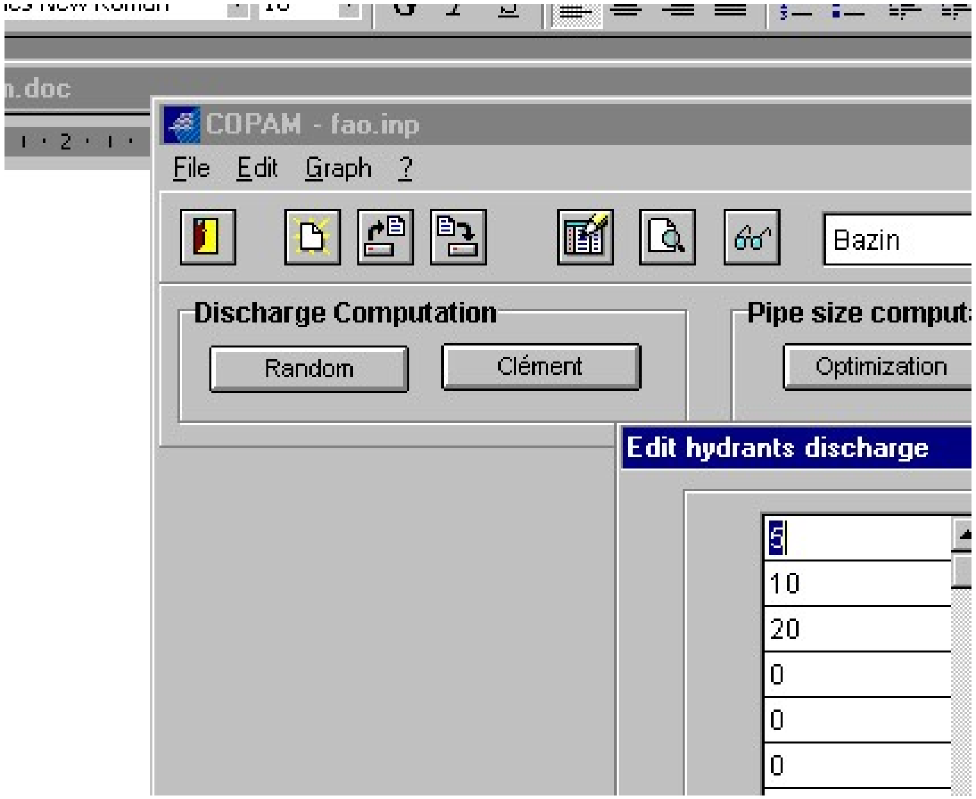


Figure 11 : Sub menu Edit/Hydrants discharge

By clicking on the option **"Network layout"**, the input data may be inserted in the sub-menu **"Edit/network layout"**.
It is assumed that the network is of the branching type. Each node (hydrants and/or linking of sections) is positioned by a number. The node numbering is extremely important for the correct execution of the program. It has to be allocated as follows:

- the upstream node (source) must have number 0,
- the other nodes have to be numbered consecutively, from upstream to downstream. Any node may not be jumped,
- The number of the section is equal to the number of its downstream node,
- All terminal nodes of the branches must have a hydrant
- No more than two sections may be derived by an upstream node. If so, an imaginary section with minimum length (i.e.: l_{min} = 1 m) must be created and an additional node must be considered. This node must have a sequential number.
- No hydrants may be located in a node with three sections join. If so, an additional node with a sequential number must be added.
- If hydrants with two or more outlets exist in the network, one number for each outlet needs to be allocated by creating an imaginary section with minimum length. (Figure. 12).

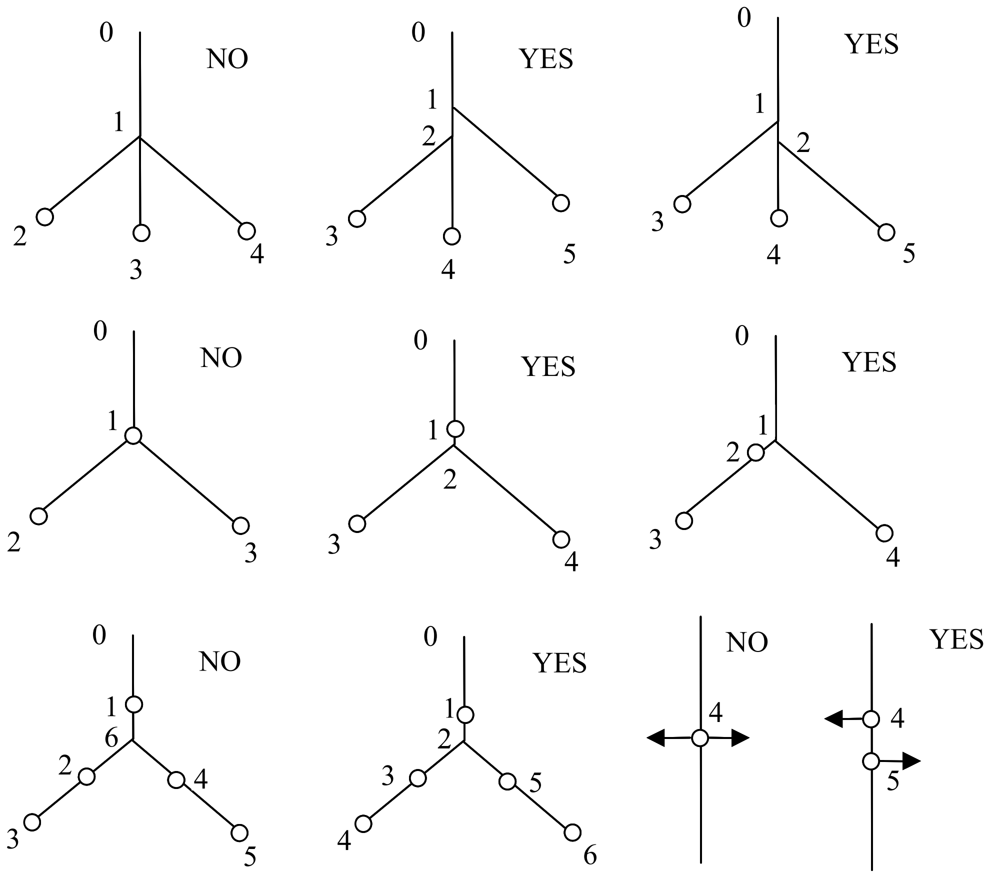


Figure 12: Examples of nodes numbering

When the numbering has been completed, the following information has to be filled in the "Edit/Network layout":

- Area irrigated by each hydrant (in hectares). If no hydrant occurs in the node, Area=0 has to be typed;
- Hydrant discharge (in l s^{-1}). It may be selected by clicking in the combo box;
- Section length (in m),
- Land elevation of the downstream node (in m a.s.l.),
- Nominal diameter of the section pipe (in mm). This information has to be included when the program is used for the analysis. In the design stage, Diameter=0 must be considered.

In Figure 13, an example of the sub-menu "Edit/network layout" is reported.

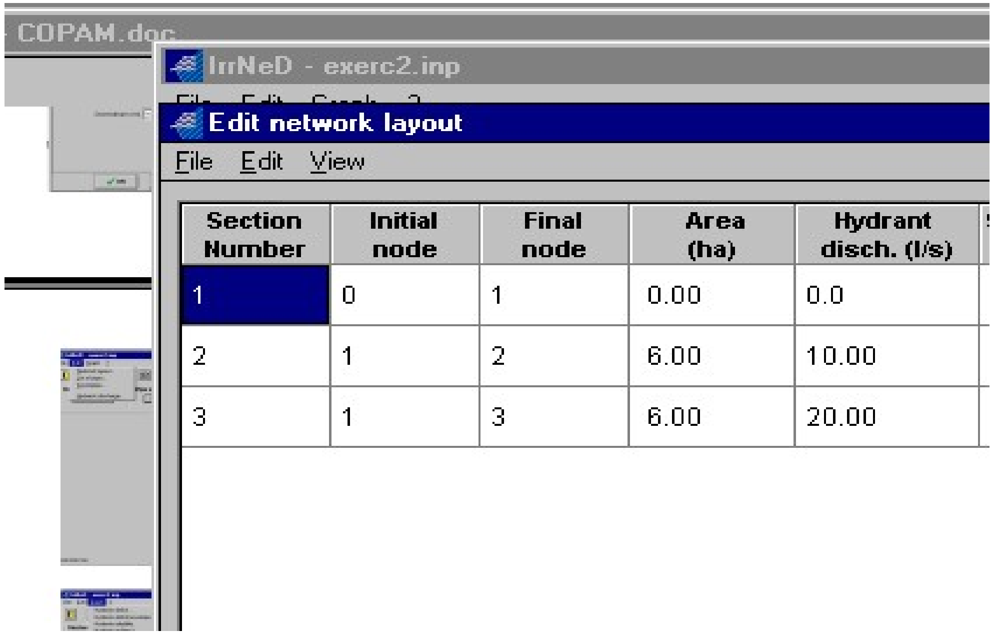


Figure 13: Edit/network layout sub menu

Additional options are available on the bottom of the screen. They may be activated by clicking on the button: **Add Node**, **Canc Node**, **Ins Node** and **Find Section**, respectively for adding a new node, deleting a node, inserting a node and finding a node. The exit button will close the sub menu.

When the network layout is completed, the "Edit/list of pipes" sub menu has to be selected. Figure 14 will appear:

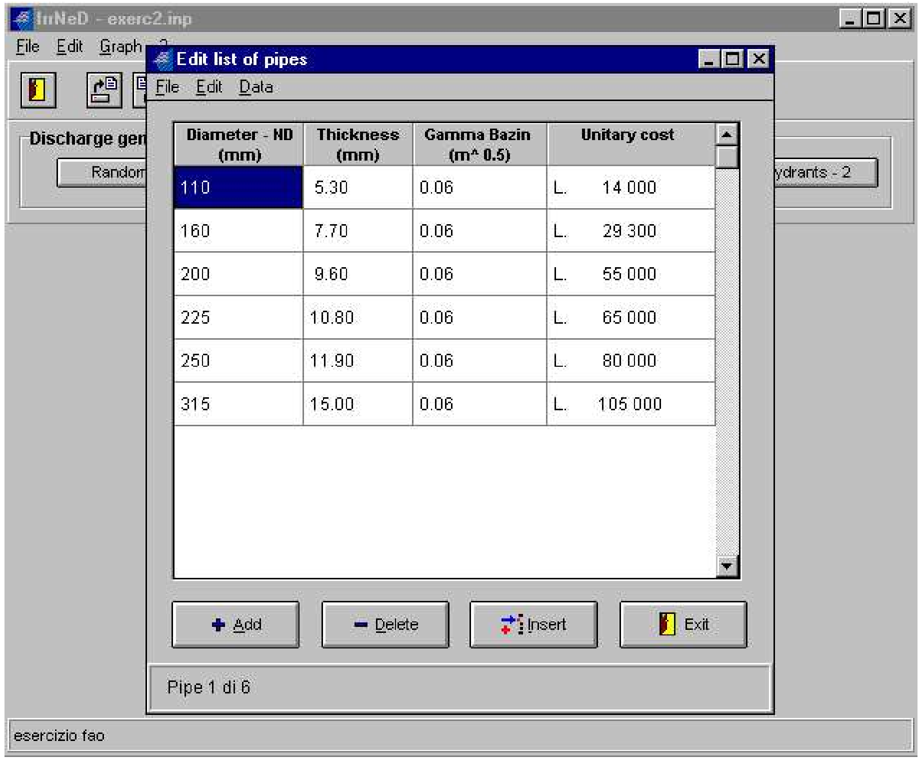


Figure 14: Edit list of pipes sub menu

The list of commercial diameters (in mm) has to be inserted in the "Edit/list of pipes" sub-menu. The list has to be completed by: the thickness (in mm) of the pipes; the roughness (Bazin coefficient) and the unitary cost of the pipe.

An internal procedure of the COPAM package will link, automatically, the currency to the regional setting properties of your computer. The pipes unitary costs must be typed in increasing order.

The nominal diameters have to be typed in the grid. When the nominal diameter corresponds to the internal diameter, the pipe thickness has to be considered equal to zero. The types of pipes are identified by the Bazin roughness coefficient.

In the sub-menu "Edit/Description" (Figure. 15), the description of the file may be typed. This information is important when a large number of data files have to be managed and recognized after time.

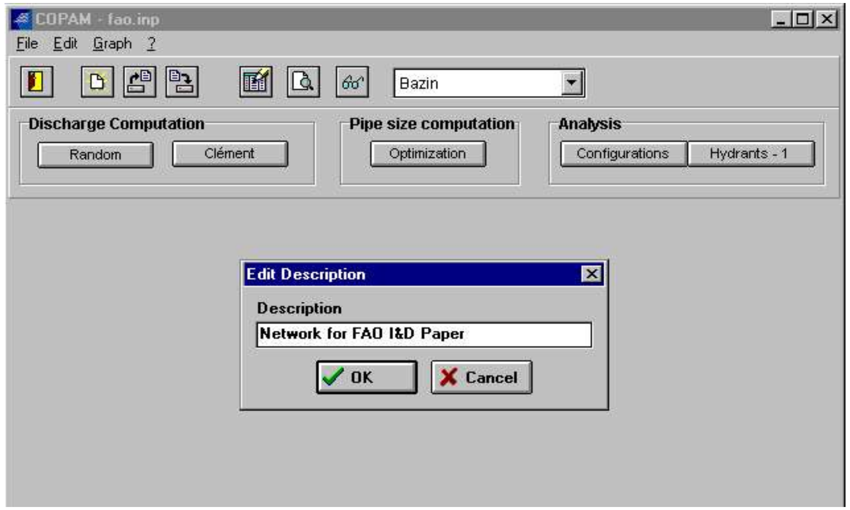


Figure 15: Edit description sub menu

An additional option is available in the COPAM package: the toolbar button "Check input file". It allows to control the most common errors in the input file (Figure. 16).

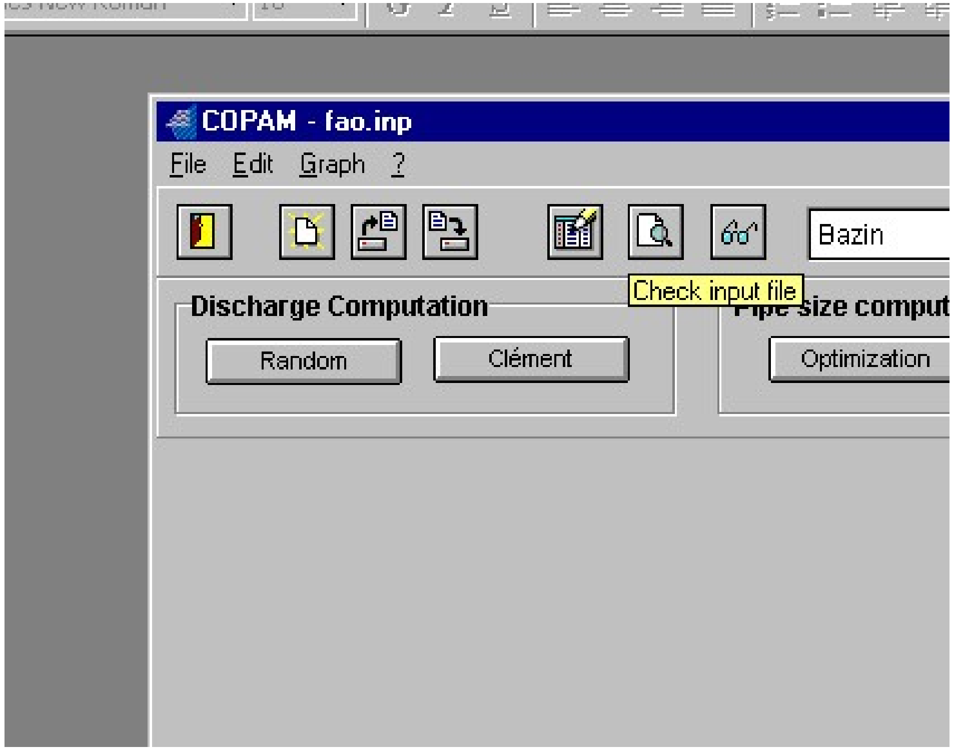


Figure 16: Toolbar button "Check input file"

When the set "Discharge computation" is selected, two different programs are available: **"Clément"** for **OFRM** and **"Random"** for **SFRM**.

TU3.2: OFRM – FIRST FORMULA OF CLEMENT

"Clément" allows for the computation of the discharges flowing into the network through the first and the second Clément models.

When the **first formula** is selected, the following additional parameters have to be typed in the "Clément parameters/sub-menu":

- specific continuous discharge (in l s^{-1} ha^{-1})
- minimum number of terminal open hydrants
- percentage of uncultivated land (in %)
- Clément use coefficient (r)
- Clément operation quality, $U(P_q)$

The name of the output file has to be typed in the appropriate edit box. It will be automatically assigned the extension ".cle" (Figure 17). An example of the output file of the program "Clément" is reported in Table 2.

Table 2 – Discharges flowing into each section of the network under study (output of the COPAM package: computation with the first Clément model)

Section Number	Initial Node	Final Node	Number of Hydrants	Area (ha)	1st Clément discharge (l/s)
1	0	1	19	57.00	60.00
2	1	2	18	54.00	60.00
3	2	3	17	51.00	50.00
4	3	4	16	48.00	50.00
5	4	5	15	45.00	50.00
6	5	6	14	42.00	50.00
7	6	7	11	33.00	40.00
8	7	8	8	24.00	40.00
9	8	9	7	21.00	40.00
10	9	10	6	18.00	40.00
11	10	11	5	15.00	40.00
12	11	12	5	15.00	40.00
13	12	13	4	12.00	40.00
14	13	14	3	9.00	30.00
15	14	15	2	6.00	20.00
16	15	16	1	3.00	10.00
17	7	17	3	9.00	30.00
18	17	18	3	9.00	30.00
19	18	19	2	6.00	20.00
20	19	20	1	3.00	10.00
21	6	21	3	9.00	30.00
22	21	22	2	6.00	20.00
23	22	23	1	3.00	10.00
24	8	24	1	3.00	10.00

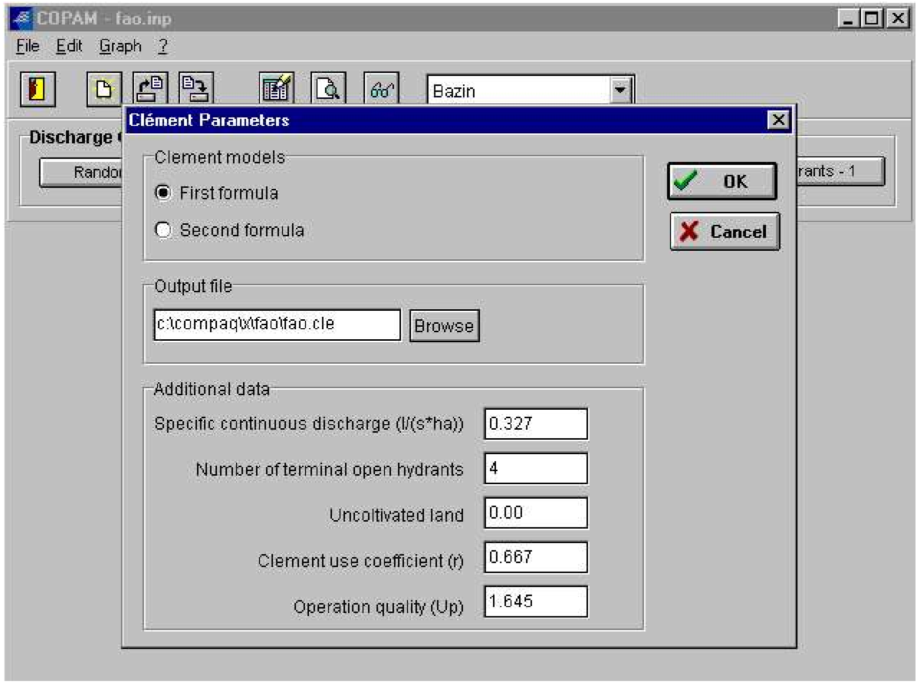


Figure 17: Clément parameters: 1st Clément formula

The program for the random generation of discharge configurations (RGM: Random Generation Model) is integrated in the COPAM package. It may be selected by clicking on the appropriate button (Figure.18):

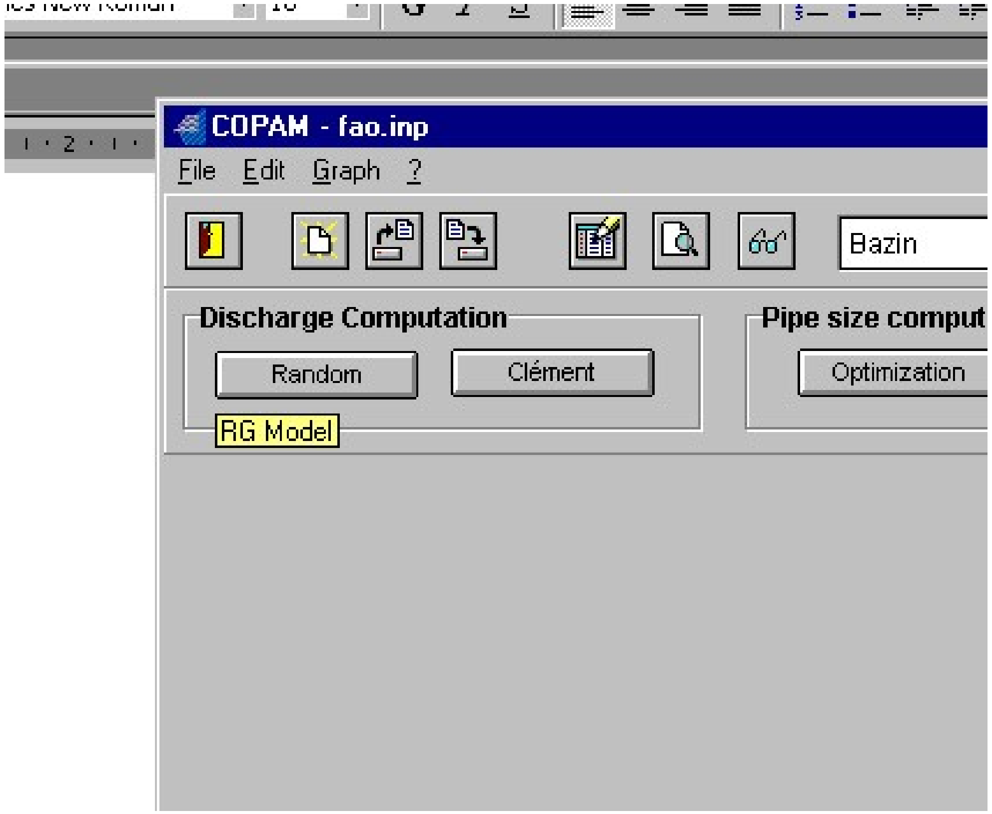


Figure 18: Random Generation Program

Figure 19 will occur on the screen.
The input data concerning the irrigation network, are those illustrated in the previous section.

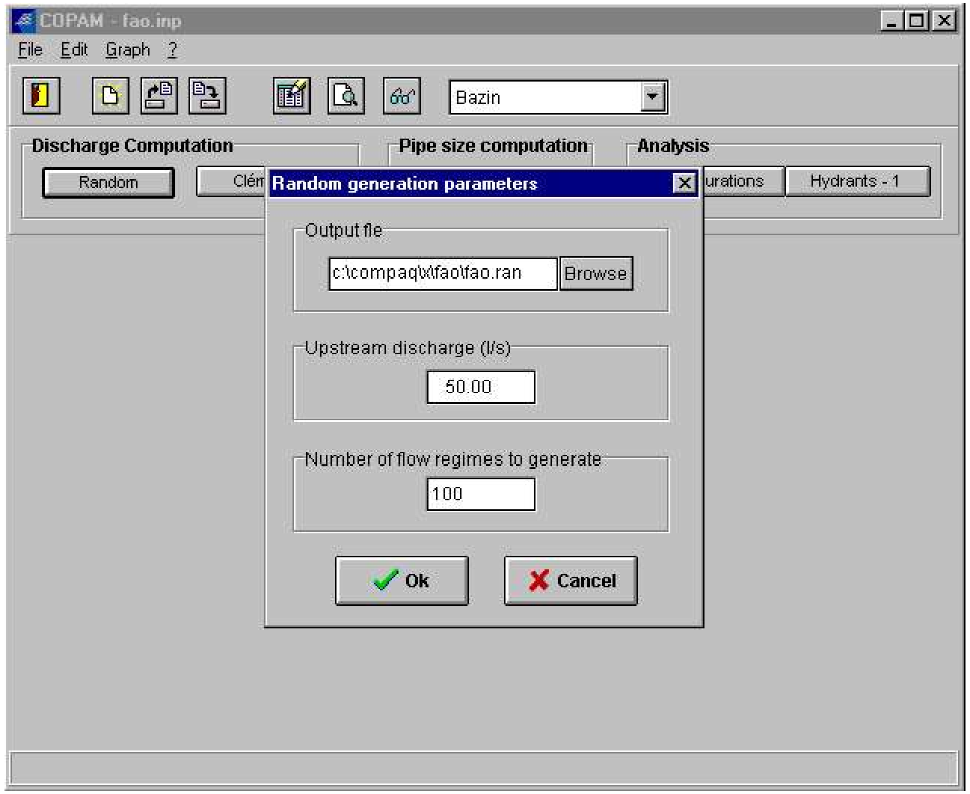


Figure 19: Random Generation Parameters

The RG Model may be used for two different purposes:

- design of new irrigation systems;
- analysis of existing irrigation systems.

In the first case, COPAM package (Clément formula) can be used as explained in the previous section for computing the upstream discharge. In the second, this model is based on the knowledge of the demand hydrograph at the upstream end of the network.

The discharge value will be allocated in the edit box "Upstream discharge" of the "Random generation parameters". After including, in the appropriate edit box, the number of configurations to be generated (it must be multiple of 10), the operation of the network may be simulated by generating the hydrants configurations (fig. 15).

These hydrants configurations, stored in a pre-selected output file, may be taken into account for computing the optimal pipe size of the network.

All the generated flow regimes will be stored in an output file; its name has to be typed in the appropriate edit box. Extension ".ran" will be automatically assigned to this output file.

A software package generating the indexed characteristic curves is available at the CEMAGREF (France, 1990) and it may be coupled with the software XERXES-RENFORS (CEMAGREF, 1990).An alternative software for computing the indexed characteristic curves has been written and integrated in the COPAM package. By clicking on the button program "Configuration" the Figure 20 will appear.

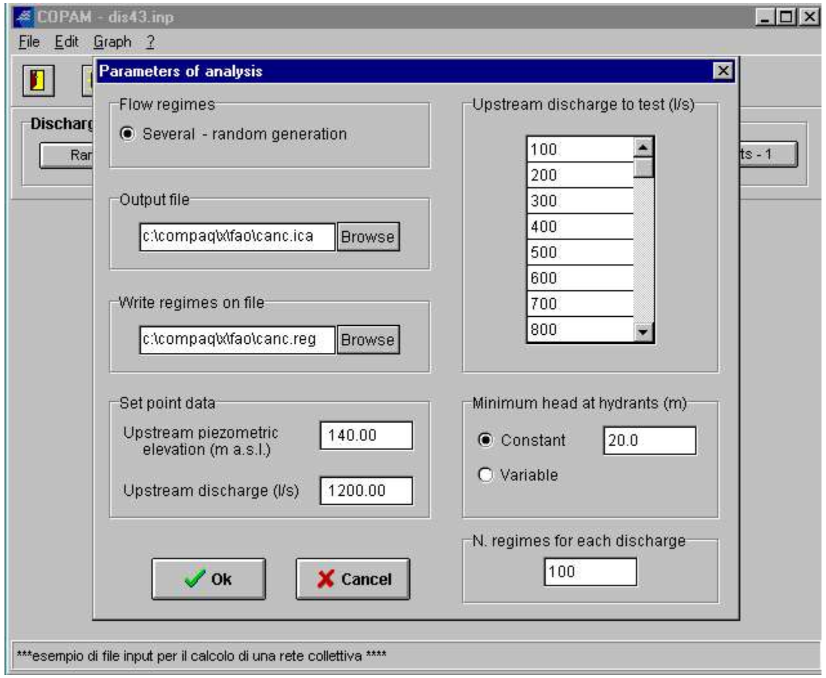


Figure 20: Characteristic curves program: Parameters of the analysis

The name of the output file as well as the one of the file in which the random generated flow regimes will be stored has to be written in the appropriate edit box.

Extensions ".ica" and ".ran" will be respectively automatically assigned.

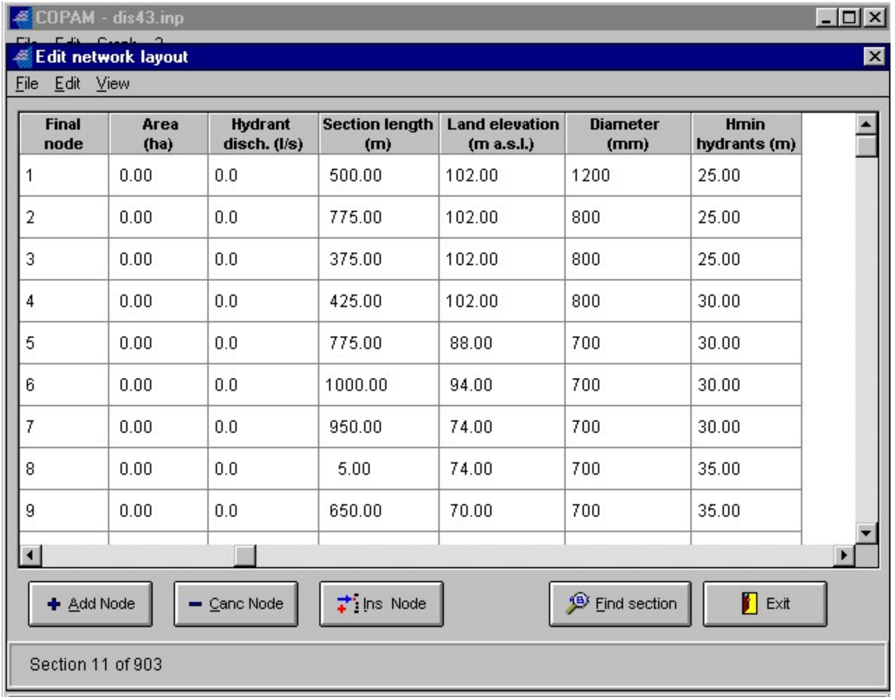
The piezometric elevation (m a.s.l.) available at the upstream end of the network, and the design upstream discharge (l s^{-1}) have to written in the "set point data" option.

The list of discharges to be tested, flowing at the upstream end of the network, has to be inserted in the appropriate box, as well as the number of regimes to generate for each discharge.

The program allows computations for networks where the minimum pressure head H_{min} required for an appropriate on-farm irrigation is constant or variable.

In the first case the radio button "Constant" has to be selected in the frame "Minimum head at the hydrants" and the value H_{min} has to be written in the appropriate box.

In the second case, the radio button "Variable" has to be selected and the values of the minimum head at each hydrant have to be inserted in the last column of the input file (Figure 21).



Final node	Area (ha)	Hydrant disch. (l/s)	Section length (m)	Land elevation (m a.s.l.)	Diameter (mm)	Hmin hydrants (m)
1	0.00	0.0	500.00	102.00	1200	25.00
2	0.00	0.0	775.00	102.00	800	25.00
3	0.00	0.0	375.00	102.00	800	25.00
4	0.00	0.0	425.00	102.00	800	30.00
5	0.00	0.0	775.00	88.00	700	30.00
6	0.00	0.0	1000.00	94.00	700	30.00
7	0.00	0.0	950.00	74.00	700	30.00
8	0.00	0.0	5.00	74.00	700	35.00
9	0.00	0.0	650.00	70.00	700	35.00

Figure 21: Input file: Edit network layout

COPAM has a very easy graphical interface.

It allows to print the characteristic curves of the network by clicking on the "Graph" menu bar and successively on the "Characteristic curves …" Sub-menu item (Figure 22).

The name of the output file (extension ".ica") has to be selected for printing the graphic (Figure 23).

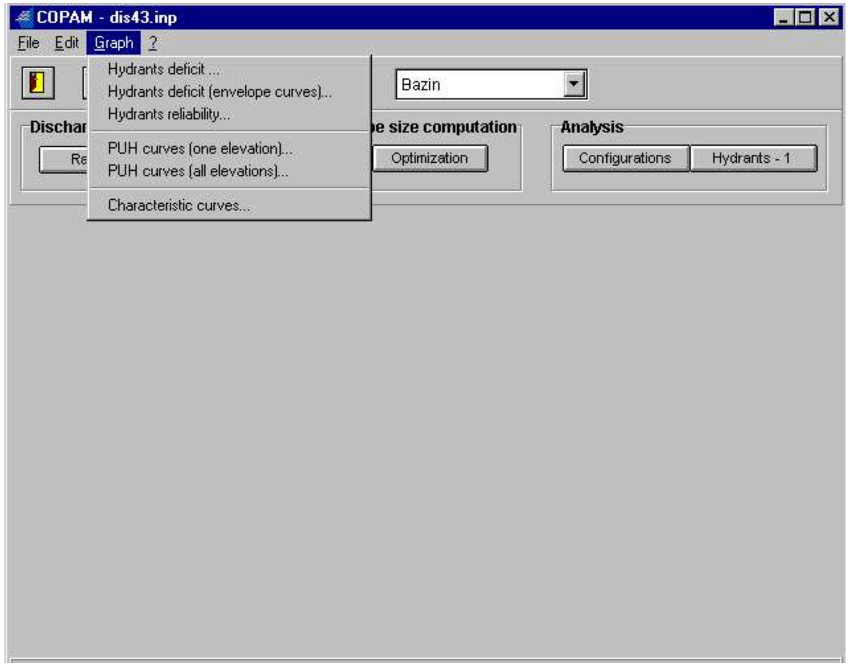


Figure 22: Graph menu bar and sub-menu items

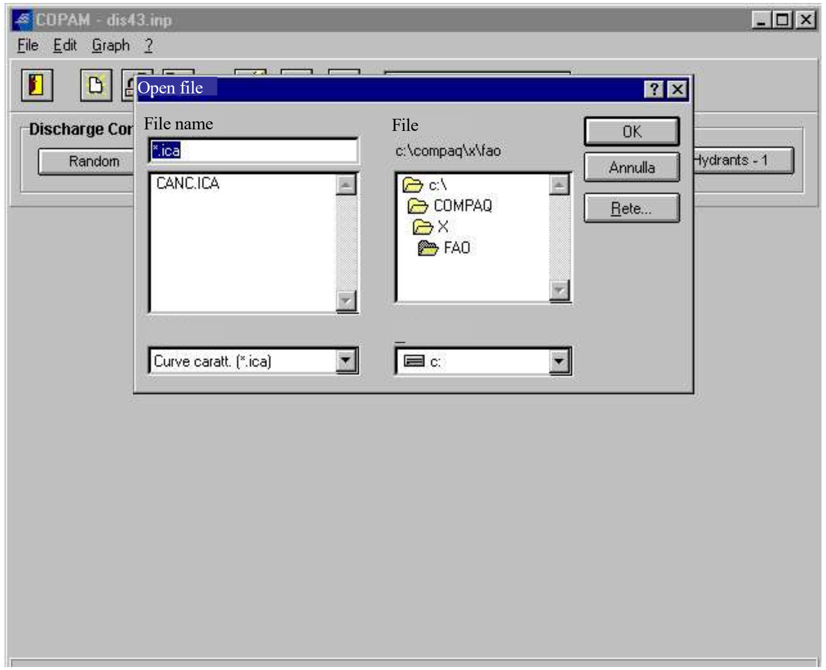


Figure 23: Open file to print the characteristic curves

A computer software for the computation of the percentage of unsatisfied hydrants and the relative pressure deficits, has been integrated in the **COPAM** package (Figure 24). By clicking on the button program **"AKLA"** (Figure 24), the Figure 25 will appear.

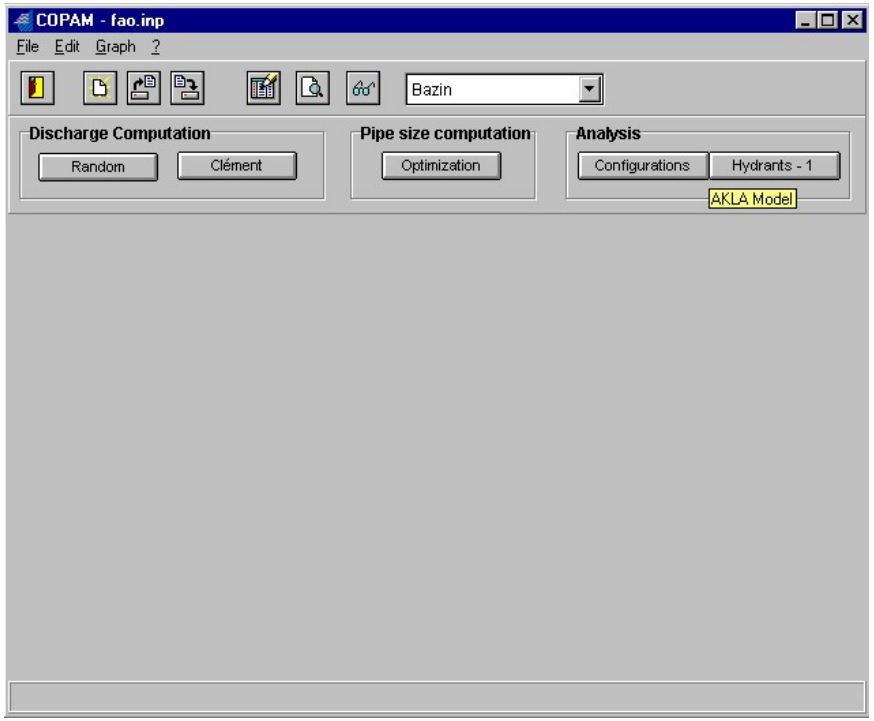


Figure 24: Hydrants analysis program: AKLA model

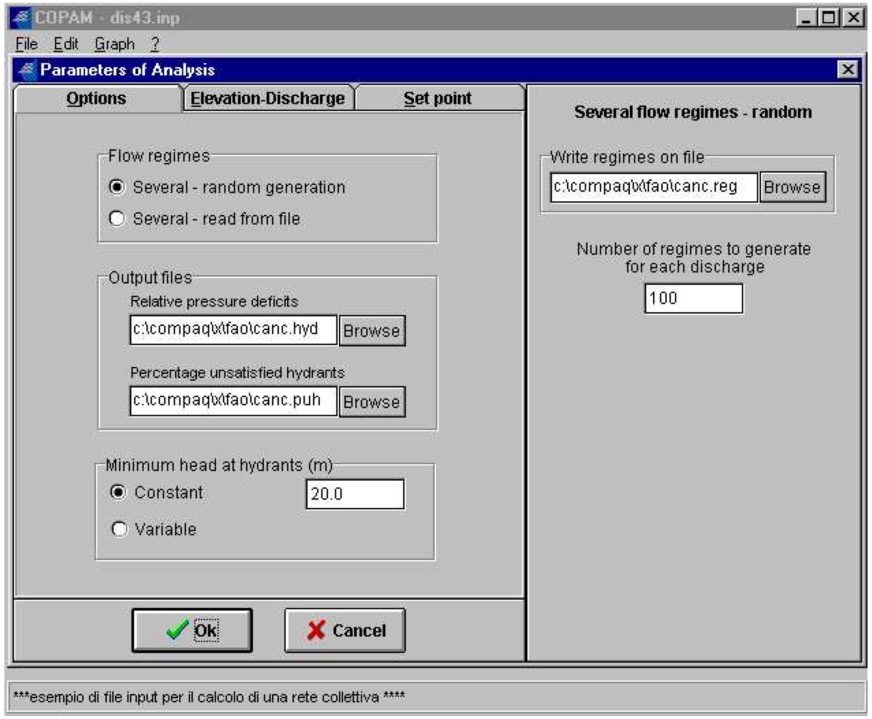


Figure 25: Hydrants analysis program: "Options" Tab control, "Several-random generation" flow regime

Within the “Options” Tab control, two alternative types of flow regimes are available (Figure 25):

- the first allows to generate automatically the random flow regimes
- the second allows to read the flow regimes from an external file. This second option allows the analysis also for irrigation systems operating on rotation and/or on arranged demand. In these cases, in fact, the flow regimes may be previously generated according to the management rules and stored in an appropriate file to be read by the program (Figure 26).

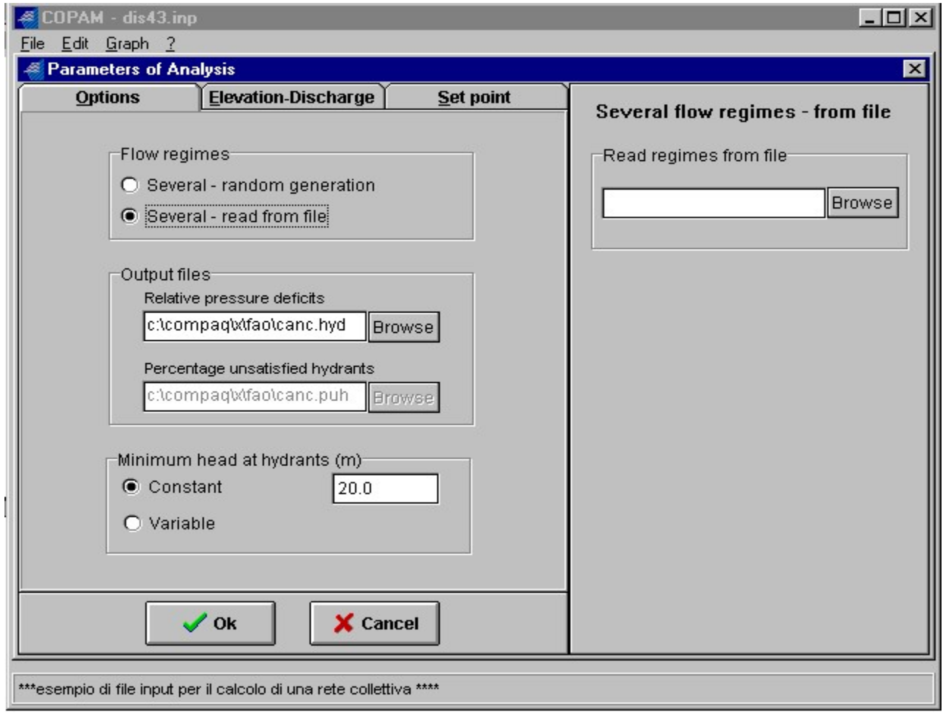


Figure 26: Hydrants analysis program: “Options” Tab control, “Several-read from file” flow regime

The name of the **output files** in which storing information on the hydrants relative pressure deficit, on the percentage of unsatisfied hydrants, as well as the name of the file in which the random generated flow regimes have to be stored, have to be written in the appropriate edit boxes. Extensions ".hyd", ".puh" and ".reg" are respectively, automatically assigned.

In case the option "Several – random generation" is selected, the number of regimes to generate for each discharge has also to be typed in the appropriate edit box (Figure 25).

In case the option "Several - read from file" is selected, the name of the file in which flow regimes have been previously generated and stored has to be written in the box "Read regimes from file …" (Figure 26). In this case the number of flow regimes to be generated is not required because the flow regimes are already stored in the file.

AKLA allows the computations for networks where H_{min} required is constant or variable.

In the first case the radio button “Constant” has to be selected in the frame “Minimum head at the hydrants” and the value of H_{min} has to be written in the appropriate box.
In the second case, the option “Variable” has to be selected and the values of H_{min} at each hydrant have to be typed in the last column of the input file (Figure 21).

The upstream piezometric elevation (m a.s.l) available and the design upstream discharge (l s^{-1}) have to typed in the **“set point”** tab control (Figure 27).

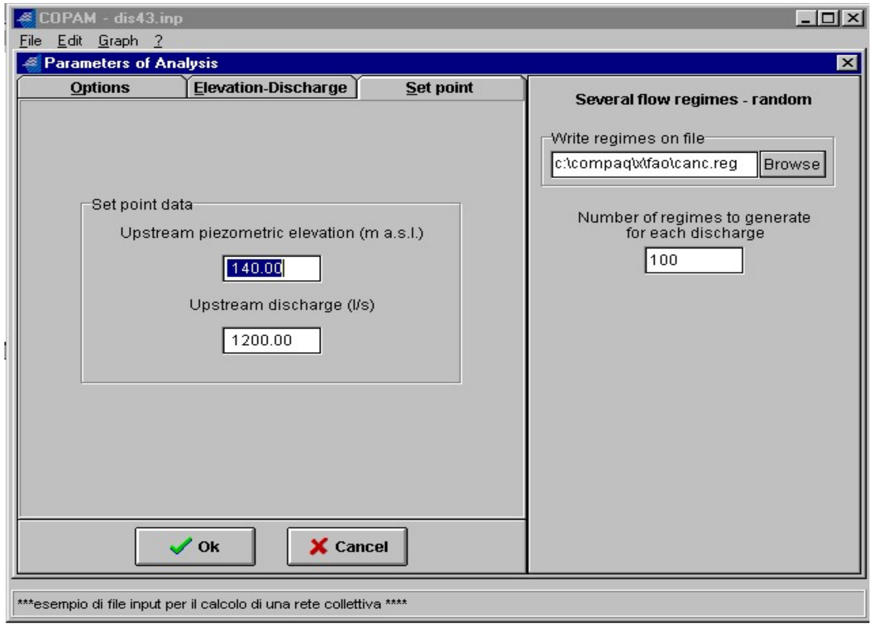


Figure 27: Hydrants analysis program: “Set point” Tab control

The lists of the upstream discharges and piezometric elevations of the network to be tested, have to be inserted in the appropriate boxes under the "Elevation-Discharge" Tab control (Figure 28).
These values allow the computation of the percentage of unsatisfied hydrants when the upstream discharges and piezometric elevations vary.

It is important to include the **set point** data among these values. In fact, the **relative pressure deficits** are computed only for the set point values.

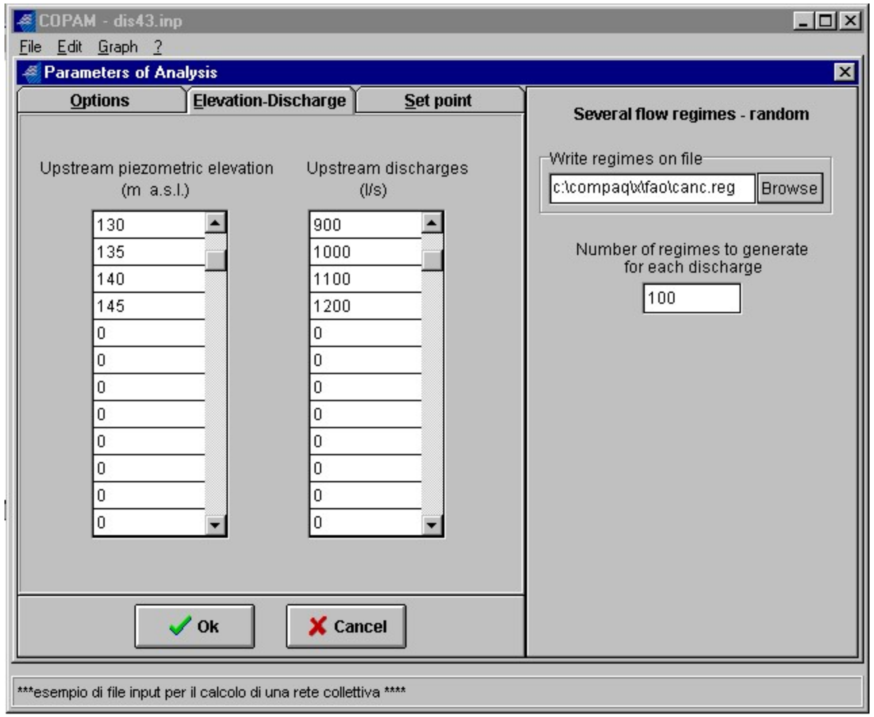


Figure 28: Hydrant analysis program: "Elevation-discharge" Tab control

The graphical interface of the COPAM package allows to print easily all the information obtained by the AKLA model. By clicking on the "Graph" menu bar it is possible to select the available sub-menu items: hydrants deficit, hydrants deficit (envelope curves), PUH curves (one elevation), PUH curves (all elevations) (Figure 29).

The graphical interface allows to print also the hydrants reliability.

For printing the hydrants deficit and the hydrants reliability, the output file ".hyd" has to be selected, while for printing the PUH curves, the output file ".puh" has to be selected.

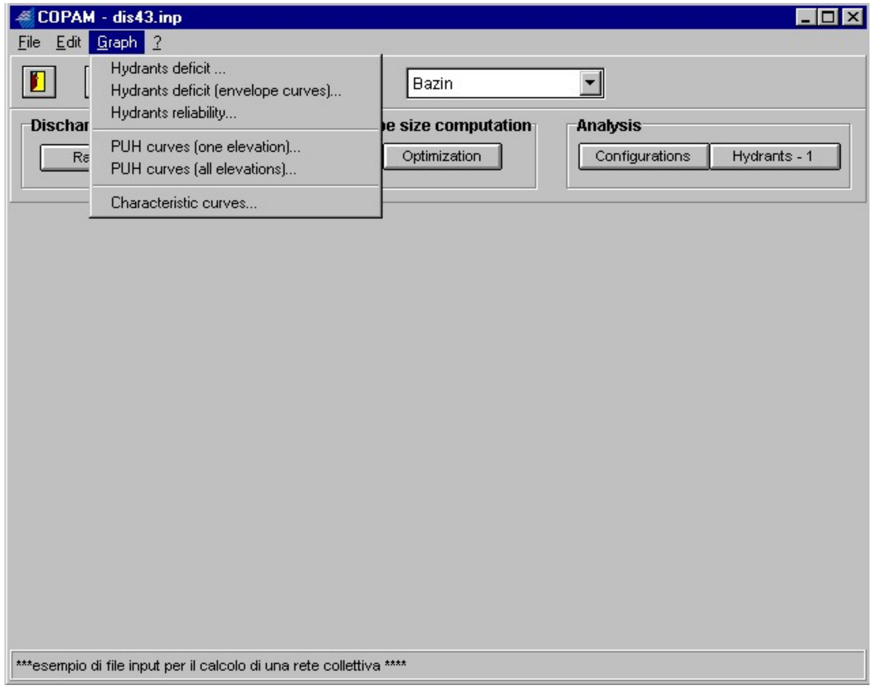


Figure 29: "Graph" menu bar and sub-menu items

SUMMARY

Large pressurised irrigation systems allow for better services and higher distribution efficiency. On demand irrigation systems offer the greatest opportunity to match irrigation demands.

The main objective of this course is the development of the basic skills for the use of a computer tool that permits the design and the analysis of performance of pressurized irrigation systems functioning on demand.

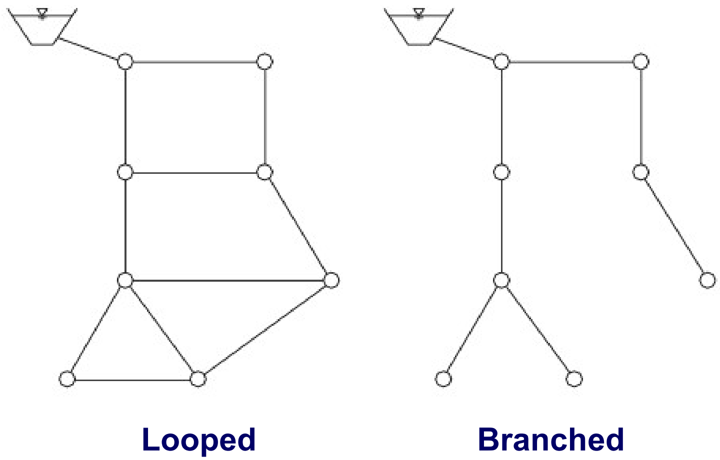
The first formula of Clément and the Random Generation Model are used to compute the design flow, through a user friendly computer package called COPAM.

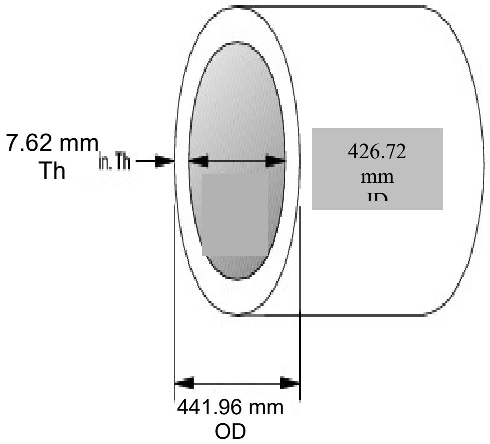
The crucial outputs of this study are the following:

1. “Discharges computation”: Clément and Random
2. “Pipe size computation “: optimisation
3. “Analyses” Configurations and Hydrants

Finally COPAM facilitates the optimal design and the performance analysis of large scale irrigation systems.

GLOSSARY

Title	Abstract	NOTE
Branching type	There are two types of distribution systems: Branched systems have only one path to follow from the source to the customer. Think of the system as *one-way* flow. Looped systems have pipes that are interconnected throughout such that water can move through the entire system back and forth depending on the points of largest demand.	

Nominal diameter of the section pipe (in mm)	A pipe's nominal diameter refers to its common name, such as a (400-mm) pipe. The pipe's internal diameter (ID)refers to the distance from one inner wall of the pipe to the opposite wall. ID may differ from the nominal diameter because of manufacturing standards. The ID may change over time as corrosion, tuberculation, and scaling occur within the pipe. Corrosion and tuberculation are related in iron pipes. As corrosion reactions occur on the inner surface of the pipe, the reaction by-products expand to form an uneven pattern of lumps (or tubercules) in a process called tuberculation. Scaling is a chemical deposition process that forms a material build-up along the pipe walls due to chemical conditions in the water. For example, lime scaling is caused by the precipitation of calcium carbonate. Scaling can actually be used to control corrosion, but when it occurs in an uncontrolled manner it can significantly reduce the ID of the pipe. Of course, no one is going to refer to a pipe as a 426.72-mm pipe, and because of the process just described, it is difficult to measure a pipe's actual internal diameter. As a result, a pipe's nominal diameter is commonly used in modeling, in combination with a roughness value that accounts for the diameter discrepancy.	 Cross section of a pipe: internal diameter, thickness and outside diameter

Standard normal variable

For a population of R homogeneous hydrants, the probability of finding one hydrant open is p, while (1 - p) is the probability to find it closed.
The number of operating hydrants is then considered as a random variable having a binomial distribution law with mean μ = R p and variance σ^2 = R p (1-p).
Therefore, the cumulative probability, P_q, that among the R hydrants there will be a maximum of N hydrants simultaneously operating is

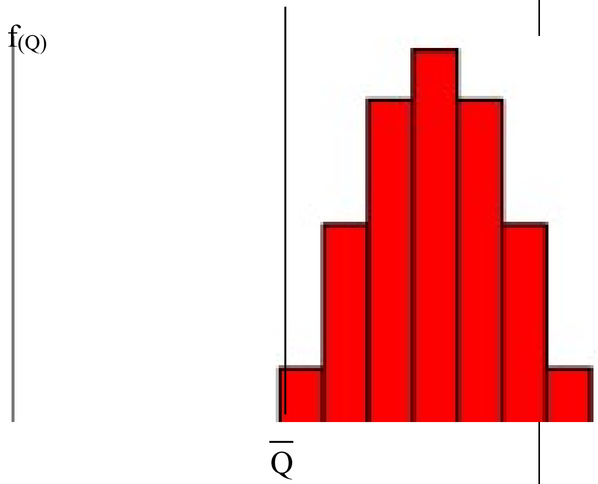
$$P_q = \sum_{K=0}^{N} C_R^K p^K (1-p)^{(R-K)} \quad \text{where} \quad C_R^K = \frac{R!}{K!(R-K)!}$$

is the number of combinations of R hydrants taken K at a time.
When R is sufficiently large (R > 10) and p > 0.2-0.3, the binomial distribution approximates the Laplace-Gauss normal distribution whose cumulative probability (P_q) for having a maximum of x hydrants simultaneously operating (with - ∞ < x < N) is:

$$\mathbf{f_{(x)}} = \frac{1}{\sigma\sqrt{2\Pi}} e^{\frac{-(x-\mu)^2}{2\sigma^2}}$$

$$P_q = \int_{-\infty}^{N} f_{(x)}\,dx = \int_{-\infty}^{N} \frac{1}{\sigma\sqrt{2\Pi}} e^{\frac{-(x-\mu)^2}{2\sigma^2}}\,dx = \frac{1}{\sigma\sqrt{2\Pi}} \int_{-\infty}^{N} e^{\frac{-(x-\mu)^2}{2\sigma^2}}\,dx$$

$$\frac{u}{\sqrt{2}} = \frac{x-\mu}{\sigma\sqrt{2}}$$ *Where u is the standard normal deviate*



$$u = \frac{x-\mu}{\sigma} = \frac{x-Rp}{\sqrt{Rp(1-p)}} = \frac{x-Rp}{\sqrt{Rpq}}$$ deriving both the variables

dx = σ du

$$P_q = \frac{1}{\sigma\sqrt{2\Pi}} \int_{-\infty}^{N} e^{\frac{-u^2}{2}} \sigma\, du$$

The limits of the integral become:

For x = -∞ u = -∞

For x = N   u = (N - μ)/σ = $U_{(Pq)}$

$$P_q = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{U(P_q)} e^{-\frac{u^2}{2}} du$$

where $U(P_q)$ is the standard normal variable corresponding to the probability P_q, and u is the standard normal deviate given by

$$u = \frac{x - R\,p}{\sqrt{R\,p\,(1-p)}}$$

The integral is solved developing in series the exponential function $e^{-\frac{u^2}{2}}$. The solutions of this integral have been tabulated (see Table) and so, according to a prefixed value P_q, it is possible to determine the corresponding value

Standard normal cumulative distribution function

P_q	$U(P_q)$
0.90	1.285
0.91	1.345
0.92	1.405
0.93	1.475
0.94	1.555
0.95	1.645
0.96	1.755
0.97	1.885
0.98	2.055
0.99	2.324

	$U(P_q)$. Knowing $U(P_q)$, it is possible to calculate the number of hydrants simultaneously operating, N $N = Rp + U(P_q)\sqrt{Rp(1-p)}$ (first formula of Clément). Considering hydrants with the same discharge, the total discharge downstream a generic section k is given by: $Q_k = Rpd + U(P_q)\sqrt{Rp(1-p)d^2}$ and, when different classes, i, of hydrants discharges, d_i, are considered $Q_k = \sum_i R_i p_i d_i + U(P_q)\sqrt{\sum_i R_i p_i (1-p_i) d_i^2}$	
Use coefficient	Assuming that T is the duration of the peak period (h) and T' is the operating time of the network (h) during the period T, r is defined as the ratio T'/T. It is defined by Clément as coefficient of utilization of the system in the sense that, during the design phase, the duration of the day for irrigation, within the peak period, is considered shorter than 24 hours. This parameter, defined at the network level in an irrigation system operating on-demand, should have a value equal to one because these systems may have to work 24 hours per day. In practice, the parameter r corresponds to the operating time of each hydrant and, it is not correct to use it for the global design of the system.	