USERS MANUAL
Version 1.0

SprinkNet

By

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Disclaimer

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Although a reasonable effort has been made to assure that the results obtained are correct, the computer program described in this manual is experimental. Therefore the author and the Mediterranean Agronomic Institute are not responsible and assume no liability whatsoever for any results or any use made of the results obtained from this program, nor for any damages or litigation that result from the use of this program for any purpose.

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I-Introduction

SprinkNet is a computer program that analyzes the performance of a sprinkler network under fixed (Pump / Upstream Reservoir) or variable (Hydrant supplied by an on-demand pressurized water distribution system) upstream pressure head. Using the network layout, topographical elevation, hydraulic design and sprinklers characteristics, the software generates the network characteristic curve and relates it to the hydrant or pump characteristic curve. The intersection point between these two characteristic curves represents the effective working pressure and discharge of the sprinkler system *(Fig.1)*. By calculating the pipe friction losses in the network, the working pressure and discharge of each single sprinkler is obtained. Based on their working pressures, sprinklers water distribution profiles are simulated and overlapped under windy (using the ballistic theory on a single drop) or no wind conditions. Statistical analysis on the amount of water applied on the field are than used to evaluate the performance and efficiency of the system.

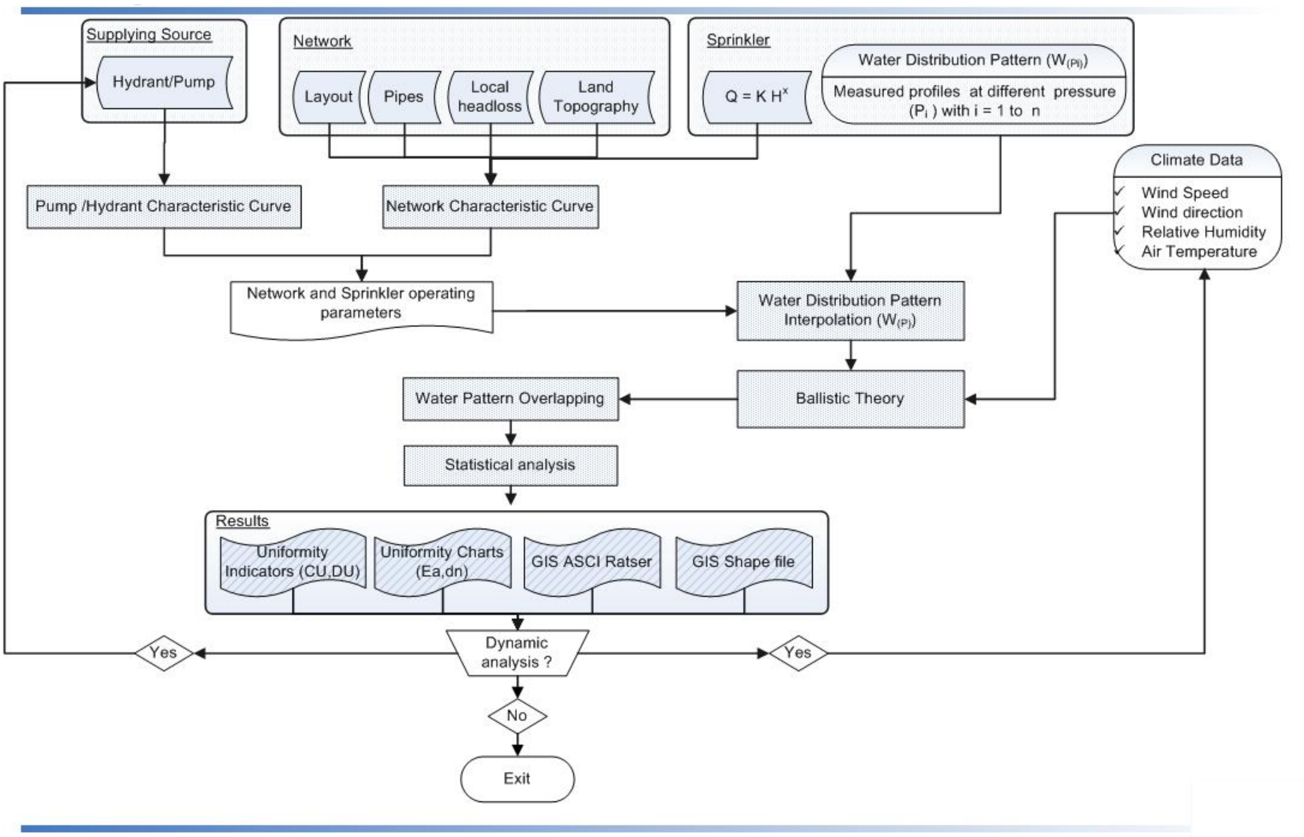


Figure 1: Flow chart of performance analysis of a sprinkler network in "SprinkNet" software

The system could also be evaluated under dynamic upstream pressure change and variable wind parameters.

II- Installing SprinkNet

SprinkNet version 1.0 is designed using VisualBasic.net to run under Windows XP / Vista operating system.

To install Optimum:

1. Select **Run** from the Windows Start menu
2. Enter the full path and name of the "**setup.exe**" file or click the browse button to locate it on your computer
3. Click the **OK** button to begin the setup process.

The setup program will ask you to choose a folder where optimum files will be placed. The default folder is ***C:\Program Files\IAMB\SprinkNet***. After the files are installed your Start Menu will have a new item named SprinkNet. Beside a new shortcut icon  will be placed on your desktop. To launch SprinkNet software, from the Start Menu select SprinkNet or simply click on the SprinkNet shortcut placed on your desktop.

Should you wish to remove SprinkNet from your computer, you can use the following procedure:

1. Select **Settings** from the Windows Start menu.
2. Select **Control Panel** from the Settings menu.
3. Double-click on the **Add/Remove** Programs item.
4. Select **SprinkNet** from the list of programs that appears.
5. Click the **Add/Remove** button.

Troubleshoots

- Since it was developed using visual basic.net, the dotnet framework version 2.0 is required. If this latter was not installed on your computer, the installation wizard will ask you to install the dotnet framework during installation process. You can download the .net framework directly from the website of Microsoft or you can find it with SprinkNet installation CD under the name of "dotnetfx_ver2.exe". Note that installation of .net framework might take few minutes for complete installation. Once done, you can retry installing SprinkNet as previously described.
- Some computers could fail in registering "MapWinGIS.ocx", in that case you might need to install the MapWinGIS ActiveX control on your computer. To do that, click on"MapWinGIS44OCXOnly.exe" that you can find in the installation CD, or you can download it for free using the following link:

  http://www.mapwindow.org/download.php?show_details=2

N.B: Before start using SprinkNet software, be sure that the number format on your computer uses the "." as a decimal separator and not the ",".

III-Quick start tutorial

In the ***File*** main menu, you can find two items. Exit item that could be used together with the close button located on the top right of the main form to get out of the program and the New item used to start a new sprinkler network analysis.

1- Input Data

In this part of the tutorial we will analyze the performance of an existing drip irrigation network. The first step for evaluation is defining the layout and the hydraulic components and characteristics of the network, sprinklers and of the water supplying source (Upstream reservoir, hydrant or pump). For doing that, select from the main menu ***Edit Network*** and automatically the following pages will be added on your main window form:

- Hydraulic values
- Edit Network
- Sprinklers
- Pump/Hydrant
- Weather

1.a- Hydraulic values

In this page you must insert the full list of the pipe diameters that are used in the network under analysis. At the same time in the Local Head losses grid box, insert all the fittings that could create minor losses in the network together with their local loss coefficient (K_L).

- To add a new row or a new pipe or fitting, use the ***Add Row*** button .
- To remove the last row from any data grid, use the ***Remove Row*** button .
- To save the pipe list as ***".pipes"*** file or the fitting list as ***".fit"*** file use the Save button .
- To open a saved pipe list ***".pipes"*** or fitting list "***.fit*** "use the Open button .
- To choose the pipe roughness you can use the default values given by the software by selecting the pipe materials from the drop down list otherwise uncheck the ***Default values*** and assign your roughness value in the ***Pipe Roughness*** textbox.

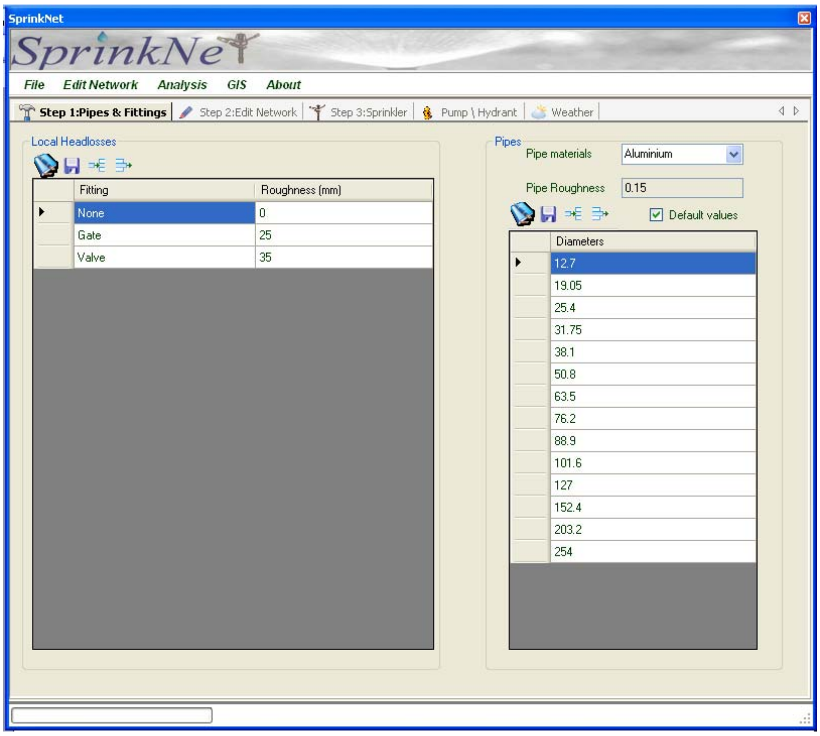


Figure 2: An example of pipe diameters and list of fittings that are used in a sprinkler network

1.b- Edit Network

Edit Network page is reserved to the description of the layout and the hydraulic characteristics of the network under analysis. It is subdivided into 4 different tabs:

1.***Network*** Tab: First step to do is to choose the layout of the network by clicking one of the 4 layouts presented on the top of the page (Fig.3).

a. button corresponds to a network made of a mainline and single lateral.

b.  button corresponds to a network with laterals located on the left side of the manifold.

c.  button corresponds to a network with laterals located exclusively on the right side of the manifold.

d.  button corresponds to a network where the laterals are attached on the both sides of the manifold.

Once you select the proper layout of your system, the necessary tables and text boxes for the required data will be enabled while the others will remain blocked. The input and output of this model is limited to the ***Pipe Reach Unit***, which is defined as a single reach of pipe having a given distance, diameter and slope with the possibility to carry one device from the fittings list.

In the numeric up down box named ***Mainline reach number*** of the mainline group box assign the number of pipe reach units corresponding to the mainline.

In the main line grid box, set the pipe reach unit length and assign a positive value for the slope to indicate a down hill and negative value for an uphill situation. Select your pipes diameter and fittings type from the drop down list that correspond to the lists added previously (Fig.2) in the ***Pipes and Fittings*** page**.**

The three buttons named ***Copy all Rows*** , ***Copy one Row*** and ***Copy selected Cell*** located at the top of any data grid are used to copy a selected row or cell into subsequent rows or cells to reduce the time consuming of data entry.

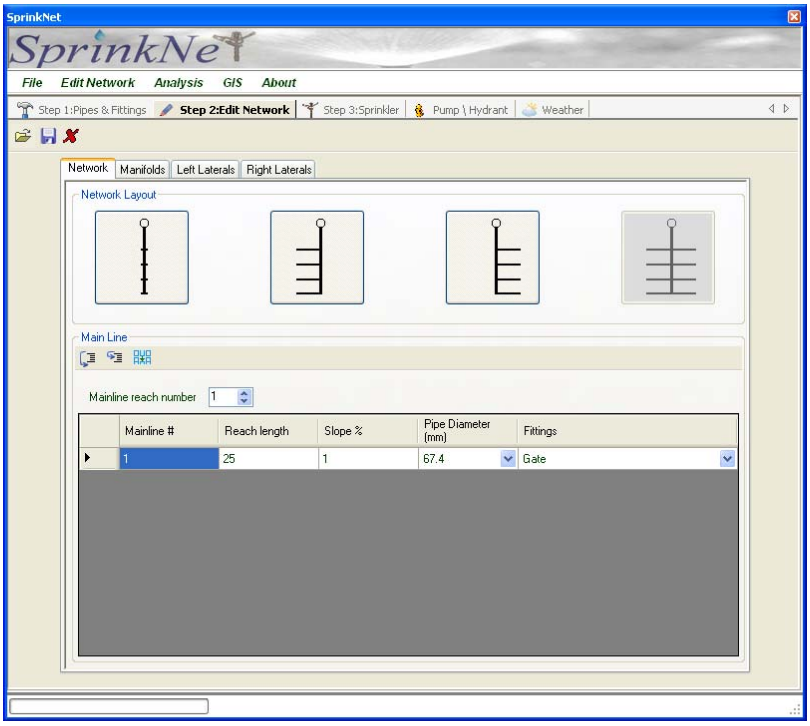


Figure 3: Network description page of the SprinkNet software

2***. Manifold*** Tab: in this page select from the numeric up down box the number of laterals. Thus, based on the layout of the network the number of pipe reaches in the manifold will be added. For example, the number of laterals in layout should be always pair and to have a manifold reach, the number of laterals must be equal or higher than 4 (Fig.4). In case of layout, due to the absence of laterals, ***Number of laterals*** numeric updown box refers to the number of sprinklers.

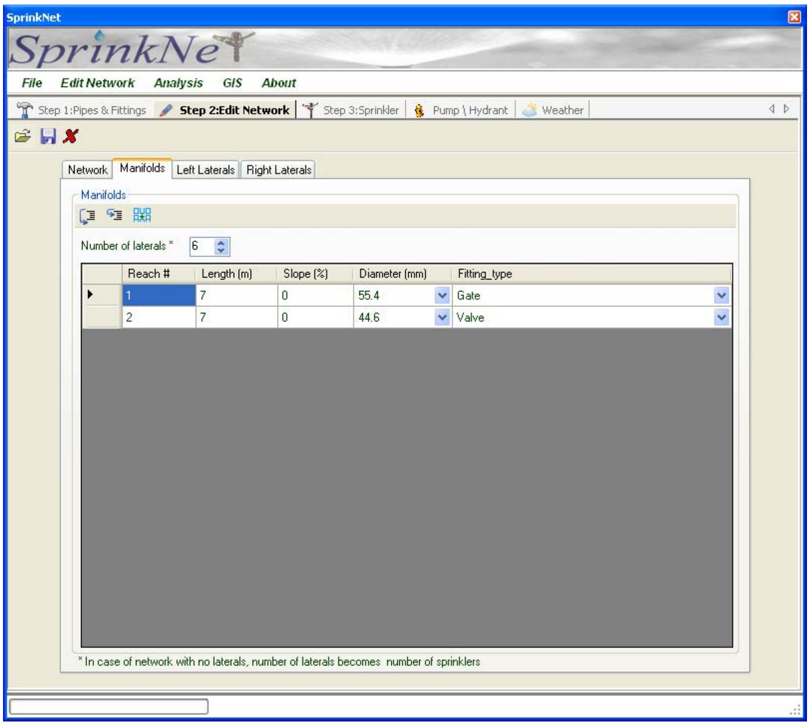


Figure 4: Data entry of manifold reaches characteristics in SprinkNet software

3.Left laterals Tab: This tab is enabled for editing only with  or  layout.

a. In the first upper grid box assign for each lateral the total number of sprinklers in the Number of Sprinklers column.

b. Click the Load button  to load pipe reach unit in the table below. Thus will allow you to assign for each pipe reach of the network the appropriate length, slope, diameter and fitting (Fig. 5).

It should be mentioned that the enumeration of the laterals and those of the sprinklers starts always from the upstream to downstream end of the network.

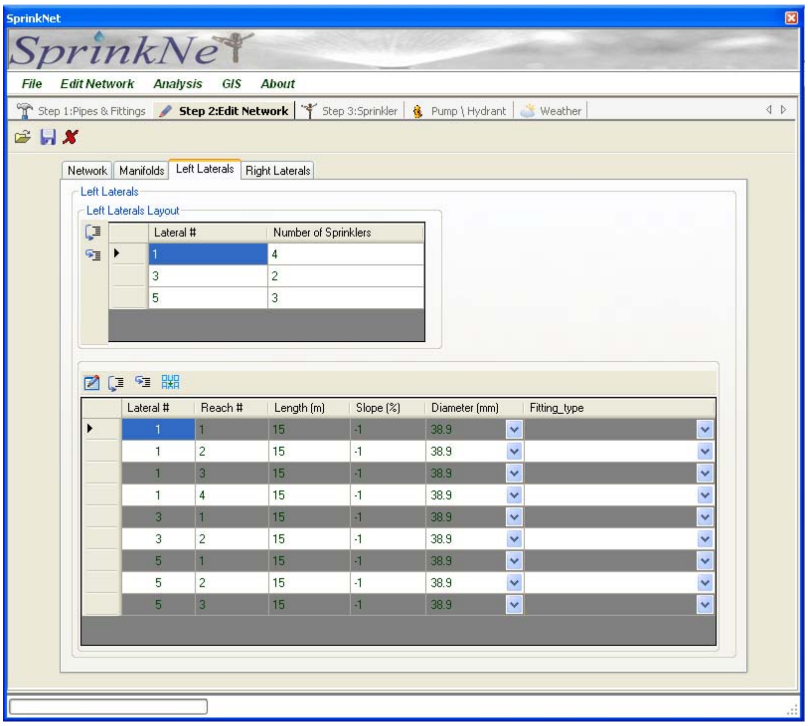


Figure 5: An example of data entry of the pipe reaches units of the left laterals

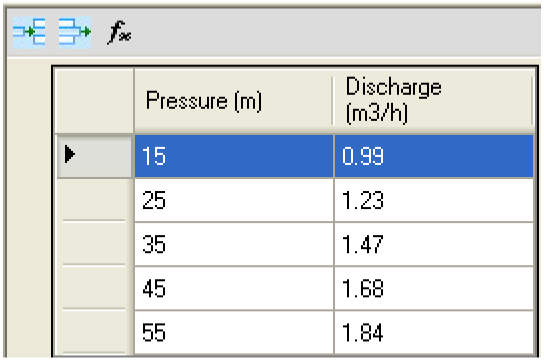
4. ***Right laterals*** Tab: This tab is enabled for editing only when  or  layout button is selected. Data entering is similar to the one previously described for the left laterals tab.

To save the network characteristic file, click on the ***Save network*** button located at the top left of the Edit Network page. The network file have a ".nets" extension. It should be mentioned that not only the network layout and hydraulic characteristic is saved but also the list of pipes and fittings too. Load network  and New  buttons are used to open an existing network file ".nets" and to create a new one respectively.

1.c- Sprinkler

Sprinkler page must be used to insert the indoor radial test results of the sprinkler under study. In the following an example of the double nozzle (4+2.4mm) Agros 40 sprinkler is used to illustrate how the indoor radial test data are inserted in SprinkNet software.
Therefore, in their appropriate text boxes and data grids insert the following:

1. ***Sprinkler Name:*** Agros 40 (4+2.4mm)
2. ***Riser Height:*** 0.6 m
3. ***Nozzle Angle:*** 27°
4. The ***K*** and ***x*** parameters of the characteristic equation that relates ($Q = \boldsymbol{K}.H^x$) the sprinkler working pressure *(H)* with the discharge *(Q)* could be assigned directly in their appropriate text box or could be calculated using a power trend line from at least three pairs of pressure-discharge data as following:
    a. In the ***Pressure-Discharge*** group box, click ***Add Row*** button to add a new row on the table and add a pair of sprinkler pressure-discharge data.
    b. Repeat this operation until you add the data shown in figure 6.



	Pressure (m)	Discharge (m3/h)
▶	15	0.99
	25	1.23
	35	1.47
	45	1.68
	55	1.84

Figure 6: Example of sprinkler Pressure-Discharge pair data

    c. To remove the last row from the list click on the ***Remove Row*** button.
    d. Once all the pressure-discharge data are added, click the ***Trend Line*** button and the values for ***K*** and ***x*** will be assigned automatically and the characteristic equation of the sprinkler under study will have the following form:

$$Q = 0.264.H^{0.48} \tag{1}$$

5. If the uniformity of the network must be evaluated, the user have to check the ***Uniformity Test*** radio button to activate the table in which the indoor test data must be inserted as explained in the following paragraph. If the user wants only to solve the network, in that case the indoor radial data are not required and the user can skip this part by selecting ***No uniformity test*** radio button

6. Now we will add the data of the indoor single radial test obtained at different sprinkler operating pressure. Click on the ***Add Pressure*** button in the ***Sprinkler water profiles*** group box and insert the operating pressures used in the test (*Fig.7*).

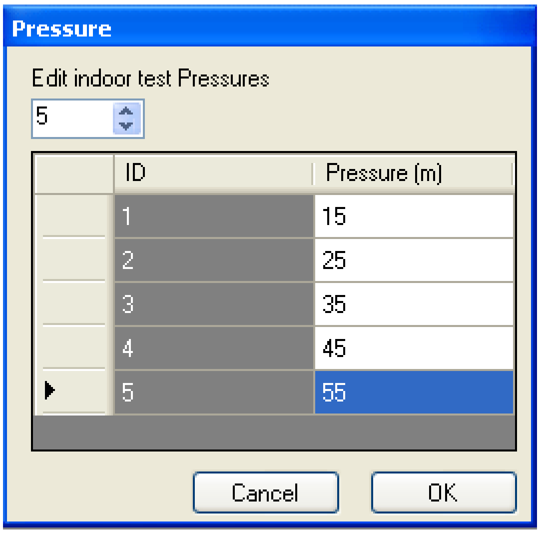


Figure 7: Pressures used to test the sprinkler water distribution pattern

Click ***Ok*** to close the form and automatically, the pressure columns are loaded in the indoor test table. Should you wish to remove some pressure from the test, click the ***Remove Pressure*** button .

7. Assign the catch can distance to 0.6m and Click the Add Row button to add new row or on the Delete Row button to remove the last row of the table. The first column of the table named Spacing (m) represents the catch can distance from the sprinkler while each cell of the table represents the amount of water applied by the sprinkler at a given distance and under a given operating pressure.
Use ***Save*** button to save the sprinkler file as ***.spr*** file. To open an existing saved **"*.spr*"** file use the ***Open*** Button .

The following table represents a real data obtained from an indoor single radial test of Agros 40 *(4+2.4mm)* tested at a pressures of 15, 25, 35, 45 and 55m (*Fig.8*).

Spacing (m)	H = 15 m ; Applied water (mm/h)	H = 25 m ; Applied water (mm/h)	H = 35 m ; Applied water (mm/h)	H = 45 m ; Applied water (mm/h)	H = 55 m ; Applied water (mm/h)
0	9.55	9.05	9.35	10.15	10.41
0.6	7.54	7.71	8.4	9.47	9.95
1.2	5.53	6.38	7.44	8.8	9.5
1.8	3.62	4.37	5.08	6.03	6.13
2.4	3.37	3.72	4.17	4.83	4.62
3	3.37	3.67	3.97	4.42	4.73
3.6	3.22	3.47	3.72	4.37	4.62
4.2	2.61	2.92	3.42	4.17	4.52
4.8	2.36	2.76	3.22	4.12	4.57
5.4	2.01	2.61	3.17	3.82	4.47
6	1.61	2.41	3.12	3.72	4.27
6.6	1.66	2.31	3.17	3.87	4.27
7.2	1.56	2.11	3.02	4.02	4.37
7.8	1.96	2.26	2.92	3.92	4.47
8.4	1.91	2.26	2.66	3.42	4.12
9	1.71	2.21	2.41	3.12	3.32
9.6	2.11	2.01	2.21	2.61	2.82
10.2	2.41	1.96	2.16	2.46	2.51
10.8	2.61	2.11	2.21	2.31	2.41
11.4	1.71	2.11	2.11	2.26	2.21
12	0.35	1.81	1.56	1.96	1.91
12.6	0	1.06	0.96	1.61	1.51
13.2	0	0.3	0.25	1.06	1.01
13.8	0	0	0	0.5	0.5
14.4	0	0	0	0	0

Figure 8: Amount of water applied(mm/h) at different distances from the Agros 40 sprinkler operating at different pressure (15, 25, 35, 45 and 55m)

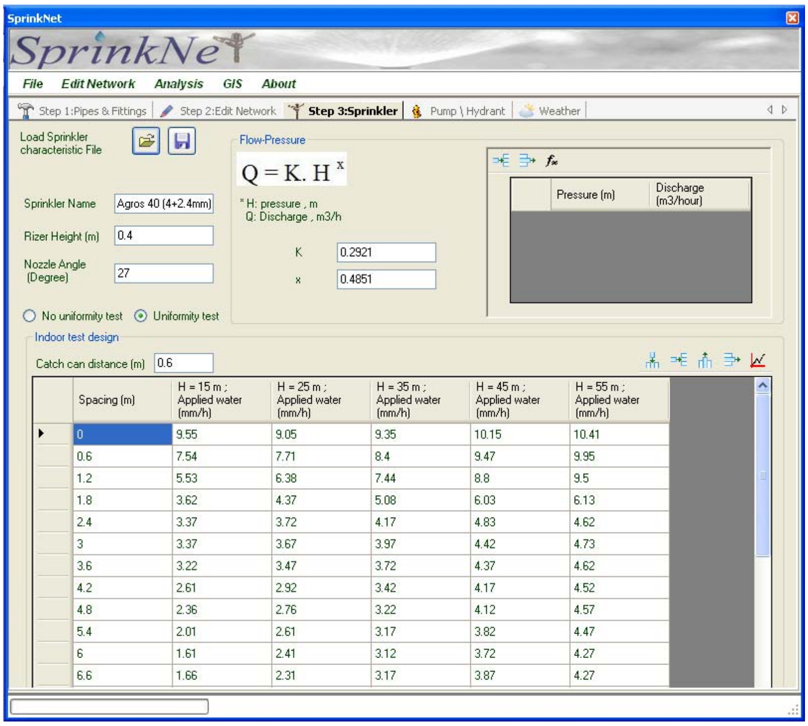


Figure 9: An example of a sprinkler characteristic input data as used by SprinkNet software

You can illustrate graphically the indoor radial test of the sprinkler under study at different operating pressure by selecting the ***Water Profile*** button . Consequently a new page will be added to your main window form named ***Water Distribution Pattern*** showing graphically your indoor radial test table as in figure 10. By hovering the mouse cursor over the curves, a small text box will show you the value of the water applied at the selected pressure. Right Click on the figure and several options for saving, copying and printing options will appear.

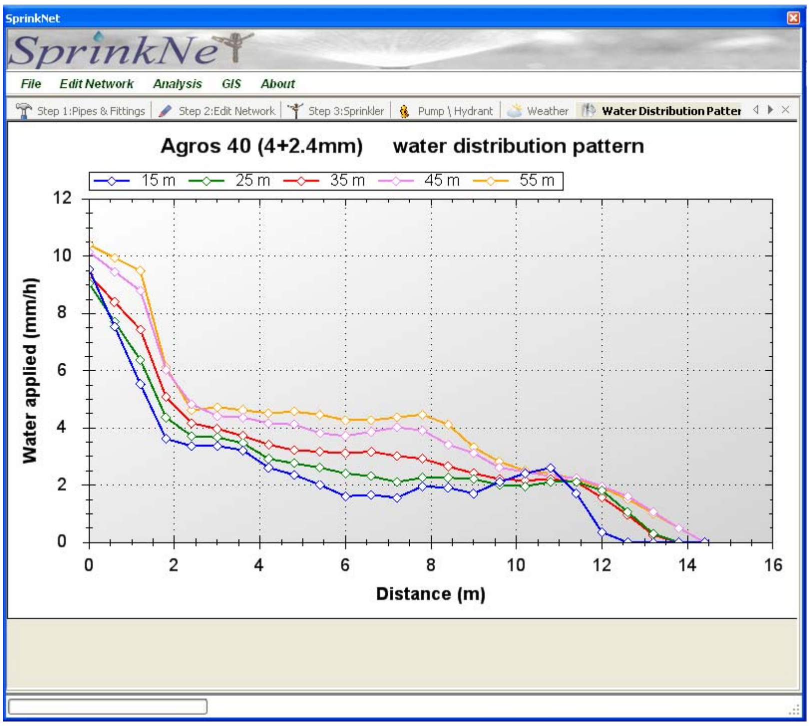


Figure 10: An example of a sprinkler "Agros 40 (4 +2.4mm)" water distribution pattern when operating at different pressure (15, 25, 35, 45 and 55m)

1.d- Pump /Hydrant

Pump or hydrant characteristic curves describe the relation between flow rate and pressure head of that device. These are normally described and illustrated in the manufacturer catalogue as performance curves.

In this page, the water source supplying the sprinkler network could be one of three options (*Fig.11*):

- ***Hydrant with flow limiter***
- ***Pump/hydrant without flow limiter***
- ***Reservoir Elevation (m)***: in that case we have an upstream working pressure fixed to the reservoir elevation (Fed by gravity)

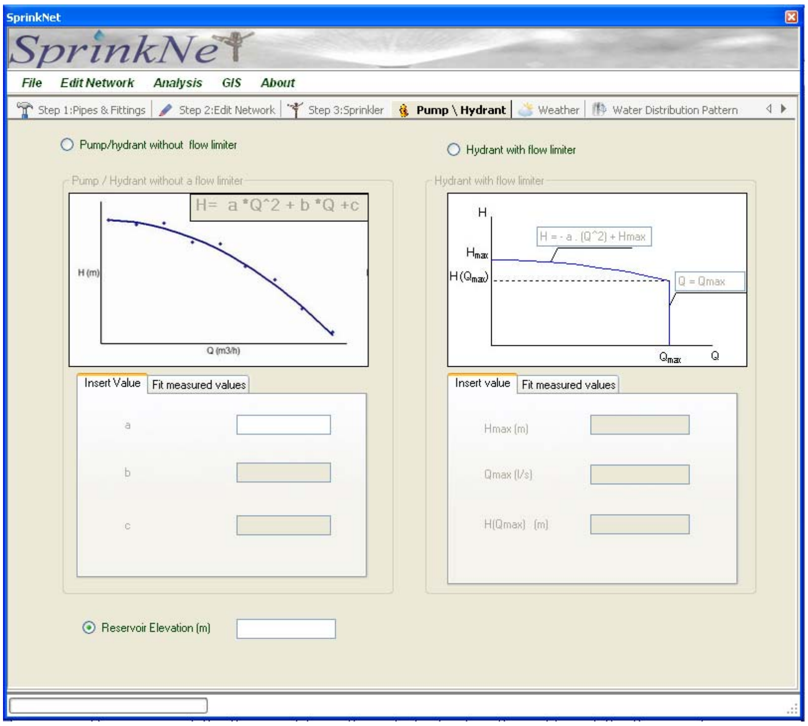


Figure 11: Pump/hydrant characteristics page within SprinkNet Software

The presence of the flow regulator within a hydrant solves the problem of the flow variation resulted from pressure changing by regulating the cross section of the outlet. At high pressure, the restriction of the outlet cross section increases the head losses and consequently maintains the discharge almost equal to the hydrant nominal discharge (Q_n).

These head losses are insignificant at low pressures (*Fig.12*). However, the flow limiter has some flexibility in delivery, such that maximal discharge (Q_{max}) is usually around 15% above the nominal discharge Q_n (Totaro M., 2001).

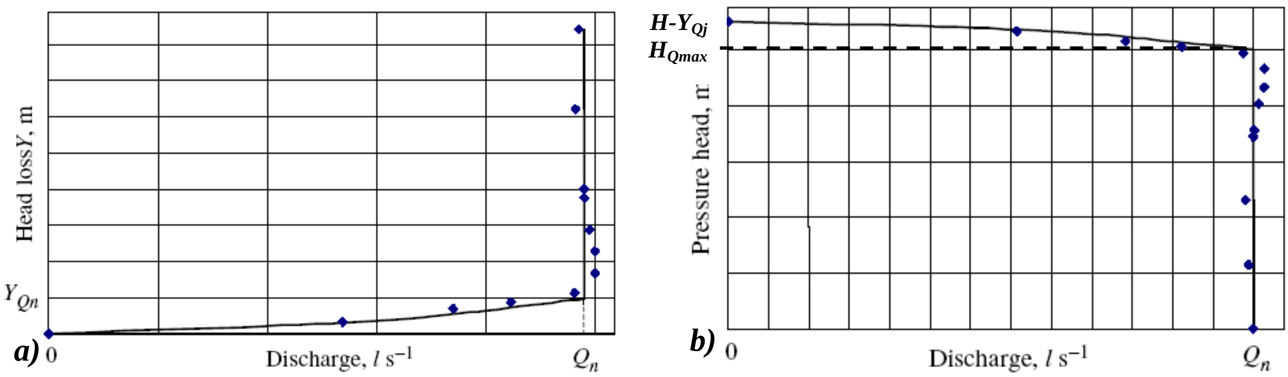


Figure 12:a) Head losses induced by the hydrant flow regulator b) Hydrant characteristic curve

The equation that fit the hydrant characteristic curve (Fig.12.b) is (Lamaddalena N., 1997):

$$Q = \xi_h \sqrt{H} \qquad \text{if} \qquad H_{(Qmax)} < H < H_{max} \tag{2}$$

$$Q = Q_n \qquad \text{if} \qquad H > H_{(Qmax)} \tag{3}$$

Where

Q : Hydrant discharge ($l.s^{-1}$)
H : Hydrant pressure head (m)
H_{max}: Upstream hydrant pressure head *(m)*
$H_{(Qmax)}$: Pressure head corresponding to the maximum or nominal discharge (m)
ξ_h : Shape coefficient depending on the hydrant characteristics.

The values of $\boldsymbol{H_{max}}$, $\boldsymbol{Q_{max}}$ and $\boldsymbol{H_{Qmax}}$ could be assigned directly in the ***Insert value*** tab page of the ***Hydrant with flow limiter*** group box or could be obtained from the pair points of hydrant pressure head-discharge inserted in the grid box of the ***Fit measured values*** tab page using the add row and remove row buttons.

In the absence of flow regulator, the hydrant characteristic curve is expressed as pump characteristic curve and presented as a second order polynomial:

$$h_P = AQ^2 + BQ + C \tag{4}$$

The values of ***A, B*** and ***C*** are constants that can be assigned directly in the ***Insert value*** tab page of the ***Pump / Hydrant without flow limiter*** group box or can be determined by means of at least three data pairs (h_P, Q) inserted in the grid box of the ***Fit measured values*** tab page.

To obtain these coefficients, we write three equations by substituting each data pair into the polynomial to obtain:

$$AQ_1^2 + BQ_1 + C = h_{P1} \tag{5}$$

$$AQ_2^2 + BQ_2 + C = h_{P2} \tag{6}$$

$$AQ_3^2 + BQ_3 + C = h_{P3} \tag{7}$$

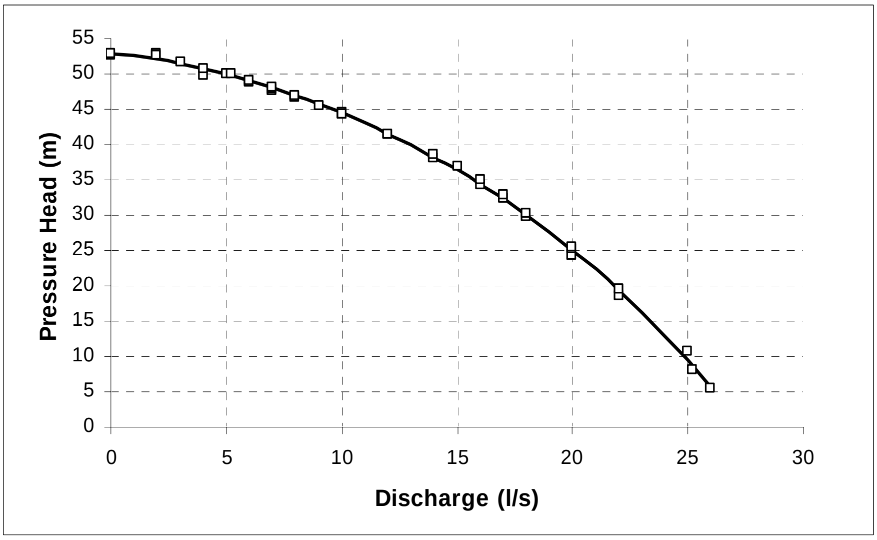


Figure 13: Typical example of a pump characteristic curve

In matrix notation it is represented as:

$$\begin{bmatrix} Q_1^2 & Q_1 & 1 \\ Q_2^2 & Q_2 & 1 \\ Q_3^2 & Q_3 & 1 \end{bmatrix} \begin{Bmatrix} A \\ B \\ C \end{Bmatrix} = \begin{Bmatrix} h_{P1} \\ h_{P2} \\ h_{P3} \end{Bmatrix} \tag{8}$$

To solve this matrix, Lagrangian interpolation was used, where:

$$h_P = \frac{(Q-Q_2)(Q-Q_3)}{(Q_1-Q_2)(Q_1-Q_3)} h_{P1} + \frac{(Q-Q_1)(Q-Q_3)}{(Q_2-Q_1)(Q_2-Q_3)} h_{P2} + \frac{(Q-Q_1)(Q-Q_2)}{(Q_3-Q_1)(Q_3-Q_2)} h_{P3} \tag{9}$$

The head (h_P) is again expressed as a quadratic equation in Q, but the terms are rearranged from the earlier approach. The coefficient A, B and C can be found by expanding the numerators as:

$$c_1 = h_{P1} / (Q_1-Q_2)(Q_1-Q_3) \tag{10}$$

$$c_2 = h_{P2} / (Q_2-Q_1)(Q_2-Q_3) \tag{11}$$

$$c_3 = h_{P3} / (Q_3-Q_1)(Q_3-Q_2) \tag{12}$$

Therefore

$$A = c_1 + c_2 + c_3 \tag{13}$$

$$B = -2[(Q_2+Q_3)c_1+(Q_3+Q_1)c_2(Q_1+Q_2)c_3] \tag{14}$$

$$C = Q_2Q_3c_1 + Q_3Q_1c_2 + Q_1Q_2c_3 \tag{15}$$

1.e- Weather

By default, the test is simulated under no wind condition but the user can perform the analysis in a windy status by checking the ***wind condition*** radio button under the ***Weather*** page. Once done, the Wind condition group box will be enabled to assign all the necessary parameters to simulate wind effect using the ballistic theory on a single drop.
Let suppose that wind have an average speed of 5 m/s registered at 2 m above the ground and is blowing at 45° from the west, in another words from the south west. While air temperature and relative humidity are registering 20°C and 50% respectively.
The uniformity of water distribution will be tested at the crop height level which in this example was set to 2 cm.

Calibration factors are necessary to give the elliptical shape of the sprinkler water profile distorted by wind. By checking the ***Default values*** radio button default values of 1.85 and 0.15 for K_1 and K_2 will be automatically assigned.

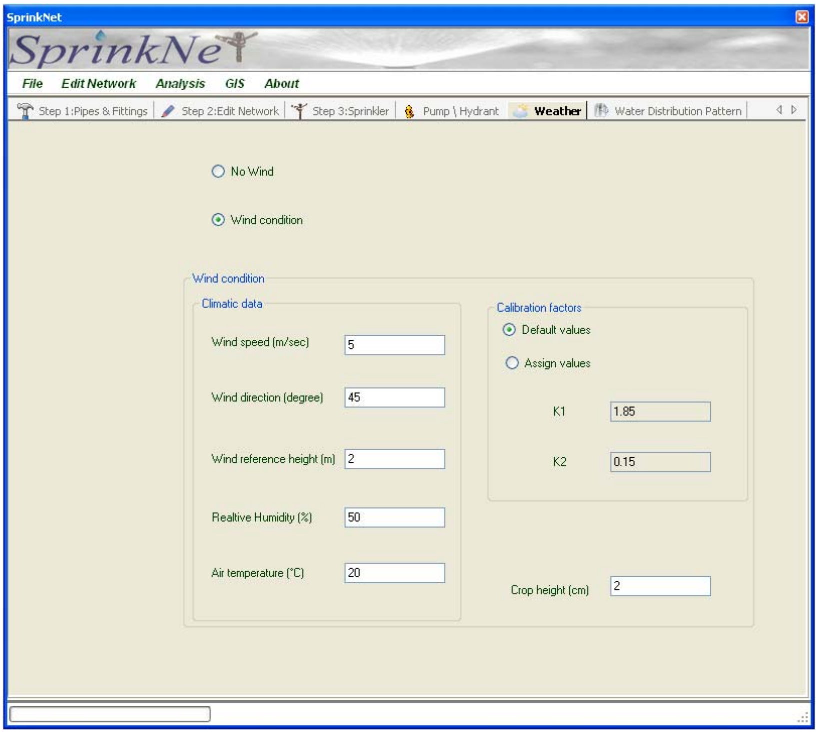


Figure 14: An example of climatic parameters that will be used in the ballistic theory to simulate sprinkler water pattern under windy condition

2- Network Solution

2.a-On-farm network Characteristic curve

Starting from a given low pressure head at the most downstream emitter ($H_{1,1}$)of the lateral, the head losses in the pipes network are calculated upward till reaching the upstream end of the lateral. Thus, the obtained pair of pressure-discharge constitutes the first point of the lateral characteristic curve.

The same procedure will be conducted but this time with a pressure head at the downstream emitter of the lateral slightly increased respect to the one used in the previous iteration ($H_{1,i+1} = H_{1,i} + \Delta H$) and consequently another point on the lateral curve will be obtained (Fig.5). The iterations will continue with a gradual increase of the downstream pressure head (ΔH) until enough points to fit the lateral characteristic curve are obtained. The lateral characteristic equation will have the following form:

$$QL = K_L HL^{X_L} \qquad (12)$$

Where:

QL : Discharge at the upstream end of the lateral ($m^3.h^{-1}$)

HL : Pressure head at the upstream end of the lateral (m)

K_L and X_L: parameters depending on the lateral hydraulic characteristics and on the land topography.

The pressure head of emitter K at iteration i is obtained using the following equation:

$$H_{k,i} = \left(\sum_{ii=1}^{K-1} \left(H_{ii,i} + Y_{ii,i} + hL_{ii,i} \right) \right) + \left(Z_1 - Z_K \right) \qquad \text{With} \quad K \neq 1 \tag{13}$$

Where:

$H_{k,i}$: Pressure head corresponding to emitter k and iteration i (m)

Z_K : Elevation head at the dripper k (m.a.s.l.)

ii: index of the pipe located upstream the emitter K

$Y_{ii,i}$: Head losses (Darcy-Weisbach) within the pipe ii of the iteration i (m)

$hL_{ii,i}$: Local loss within the pipe ii of the iteration i (m)

$$hL_{ii,i} = K_{Loss\ ii,i} \frac{V_{ii,i}^{\ 2}}{2g} \tag{14}$$

Where

$K_{Loss\ ii,i}$: Local loss coefficient depend on the nature of local resistance within the pipe ii

$V_{ii,i}$: downstream mean velocity within the pipe ii of the iteration i $(m.s^{-1})$

g : gravity acceleration $(m.s^{-2})$

$$Y_{ii,i} = f \frac{L_{ii}}{D_{ii}} \frac{\left(\sum_{jj=1}^{K} Q_{jj,i} \right)^2}{2gA_{ii}^{\ 2}} \tag{15}$$

Where:

L_{ii} : Length of pipe ii corresponding to the upstream reach of dripper ii (m)

D_{ii} : Diameter of pipe ii (m)

A_{ii} : Cross sectional area of pipe ii (m^2)

$Q_{jj,i}$: Flow Discharge of emitter jj, at iteration i ($m^3.h^{-1}$)

f: Friction factor depends on Reynolds number *(Re)* and on the relative roughness of the pipe

Once the characteristic curve of each lateral of the network is obtained, the head losses calculation from the downstream end of the manifold, with a low pressure head at the most downstream lateral, upward till reaching the hydrant will reveal the first point of the network curve. A new iteration with a slight pressure increment at the downstream lateral will add another point on the network curve. The iteration will continue until enough points to plot the characteristic curve of the network are obtained. Finally, the equation that fit the network characteristic curve is as following:

$$Qm = K_m Hm^{X_m} \tag{16}$$

Where:

Qm : Discharge at the upstream end of the network ($m^3.h^{-1}$)

Hm : Pressure head at the upstream end of the network (m)

K_m and X_m: parameters depending on the network hydraulic characteristic and on the field topography

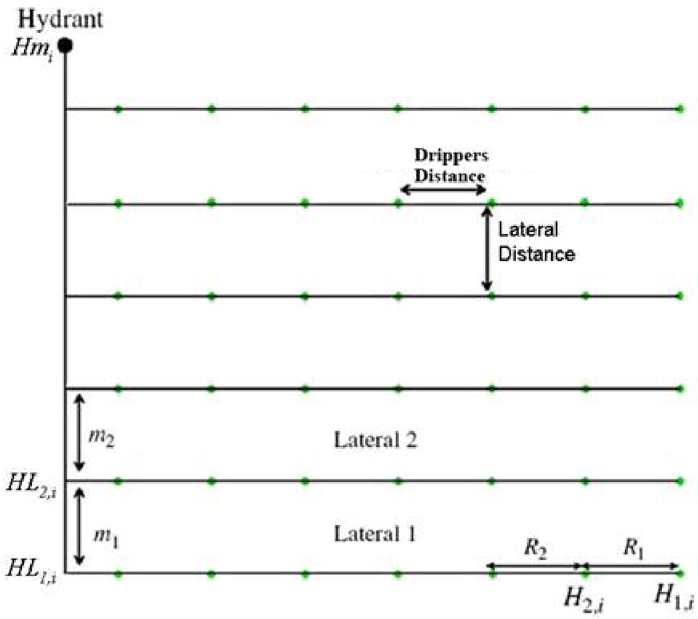


Figure 15 : Network enumeration as used by the model to generate the network characteristic curve

2.b-Solve Network using SprinkNet

Once you enter all the input data required for the analysis of the sprinkler network, you can solve the network by clicking from the main menu on ***Analysis*** >> ***Solve Network*** >> ***Run.*** Three additional pages will be added on your main form illustrating the obtained results.

- ***Network/Pump curve*** page will reveal the effective operating pressure and discharge of the network by generating and relating the network characteristic curve with the pump/hydrant curve (*Fig.15*). The k and x text boxes at the bottom of the page represent the parameters of the network characteristic curve equation that link the discharge with the pressure head as following:

$$Q = KH^{x} \tag{16}$$

Where:
Q: Network upstream discharge ($l.s^{-1}$)
H: Network upstream pressure head (m)
K and x : parameters depend on the topographic elevations, hydraulic characteristics and sprinkler network components.

Use the copy and save buttons to copy or save the graph of the interface between the network and hydrant/pump characteristic curve

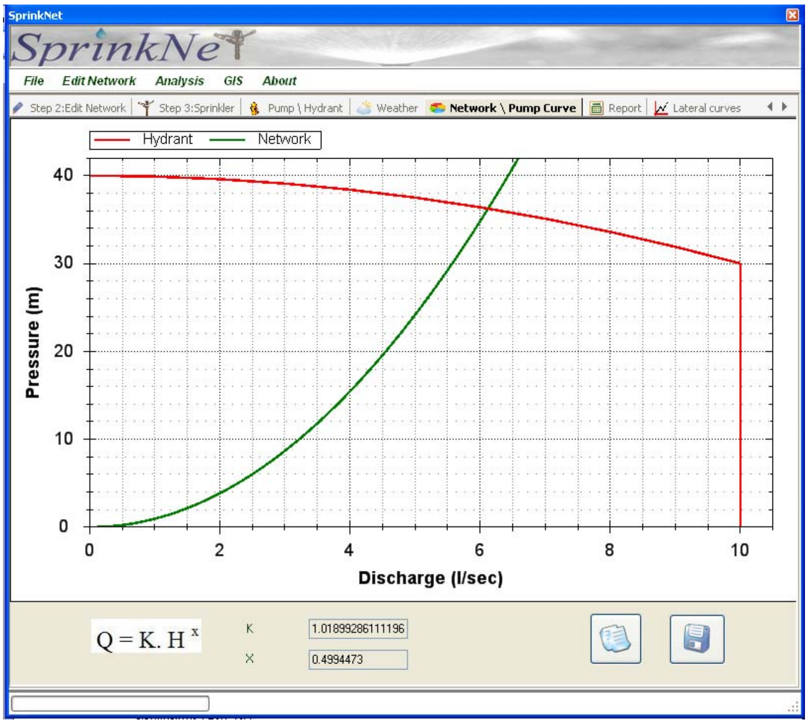
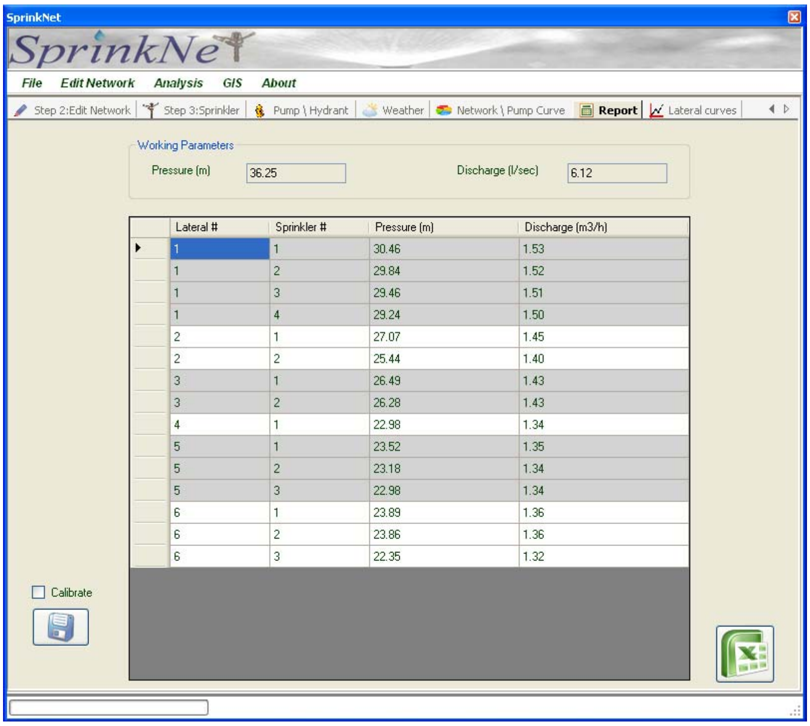


Figure 16: Network and hydrant characteristic curve as generated by SprinkNet software

- In the ***Report*** Page the simulated working pressure (m) and discharge ($m^3.h^{-1}$) for each single sprinkler of the network are presented in a table and could be exported into an excel table by just clicking on the export table button. In the working parameters group box, the values of the upstream working pressure head and discharge of the sprinkler network, obtained by interfacing the network with the hydrant or pump characteristic curve, are presented (Fig.16).



Lateral #	Sprinkler #	Pressure (m)	Discharge (m3/h)
1	1	30.46	1.53
1	2	29.84	1.52
1	3	29.46	1.51
1	4	29.24	1.50
2	1	27.07	1.45
2	2	25.44	1.40
3	1	26.49	1.43
3	2	26.28	1.43
4	1	22.98	1.34
5	1	23.52	1.35
5	2	23.18	1.34
5	3	22.98	1.34
6	1	23.89	1.36
6	2	23.86	1.36
6	3	22.35	1.32

Figure 17: Working Pressure and discharge of each single sprinkler of the network obtained by SprinkNet software

If the user would like to calibrate the sprinkler pressures before performing the uniformity analysis of the network, he can check the ***Calibrate*** checkbox, disabling by this the read only property of the results table. Once the sprinklers pressures are calibrated and modified, the user must click on save button to save the modifications and consequently be used in uniformity performance analysis.

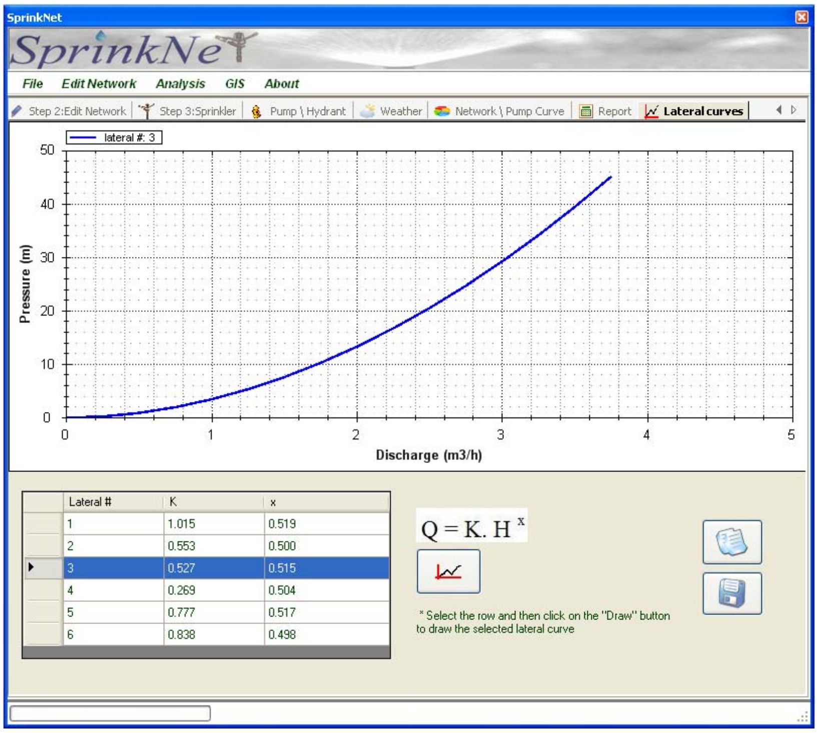


Figure 18: Lateral characteristic curves of the sprinkler network as generated by SprinkNet software

k and *x* parameters of the laterals characteristic curves equations ($Q=K.H^x$) are presented in the data grid of the ***lateral curves*** page (Fig.12). Select the row that corresponds to the lateral that you would like to draw its characteristic curve and by clicking on the draw button, the appropriate lateral curve will be obtained. Use save as and copy buttons in order to save the figure or copy it to be pasted later on.

- Once the network has been solved, the layout and pipe size diameters of the network and the sprinklers position and working parameters could be saved as shape file by selecting ***Analysis >> Solve Network>> Save Shapefiles>> Pipes*** and ***Analysis >> Solve Network>> Save Shapefiles>> Emitters*** respectively. These shapefiles could be saved and used later under the GIS section.

3- Performance Analysis

Once the network is solved as explained in the previous paragraph, the performance of the sprinkler network could be evaluated by clicking from the main menu on ***Analysis*** >> ***Analyse Performance***>> ***Run.*** This operation will simulate for each sprinkler based on its operating pressure (under ***Report*** page) and on the climatic parameters (under **Weather** page) the appropriate water distribution pattern. According to the layout of the network, the water distribution profiles of the adjacent sprinklers will be overlapped. Finally the performance of the system will be evaluated using several uniformity and efficiency indicators.

3.a- Simulation of pressure change

For a given working pressure *(P)*, SprinkNet model simulates from the measured water applied data (*Fig.8*) using the linear interpolating technique, the appropriate sprinkler water profile. Each catch can *(i)* presents a measured water amount $(Y_{i,H})$ obtained at a testing pressure *(H)*.

The linear interpolation technique applied on a set of catch can data *(i)* measured at different testing pressure $(H_1, H_2, \ldots H_n)$ is used to simulate the water applied value *(Y)* of that catch can at the given pressure *P* as following:

$$Y_{i,P} = Y_{i,H1} + (P - H_1)\left(\frac{Y_{i,H2} - Y_{i,H1}}{H_2 - H_1}\right) \qquad for \qquad Y_{i,H1} \leq Y_{i,H1} \qquad (17)$$

$$Y_{i,P} = Y_{i,H2} + (H_2 - P)\left(\frac{Y_{i,H1} - Y_{i,H2}}{H_2 - H_1}\right) \qquad for \qquad Y_{i,H1} > Y_{i,H2} \qquad (18)$$

With $H_1 \leq P \leq H_2$

The sprinkler water profile for the given working pressure *(P)* is obtained when the amounts of applied water on the entire catch cans are calculated.

3.b - Wind effect simulation

Following the work and the contribution of many researches (Fukui et al. (1980), Von Bernuth and Gilley 1984; Vories et al.,1987; von Bernuth 1988, Seginer et al.,1991; Han et al. 1994; Tarjuelo et al.1994 ;Carriòn et al.(2001) ;Montero et al.(2001)), ballistic theory on an isolated drops was used to simulate the wind effect on the sprinkler water distribution profile.

The process of jet break-up into drops is quite complex. At least two phases can be distinguished. In the first (no more than 1 or 2 m) the jet is quite compact, and in the second the jet has nearly completely disintegrated, with a corresponding transitional phase (Von Bernuth and Gilley 1984; Seginer et al., 1991). To simplifies this process, the following main hypotheses have been considered:

- The jet is disintegrated at the nozzle exit into individual droplets with different sizes, which move independently in the air and present drag coefficients that are a function of Reynolds number of a spherical drop (Seginer et al. 1991).
- The drag coefficient is independent of the sprinkler height over the soil surface, the discharge angle of the jet, the wind velocity, the nozzle diameter and other factors. Consequently different sized drops fall at different distances.

By applying ballistics theory on an isolated drop, the distance (r_i) at which each drop size (D_i) falls is calculated:

$$D_i = f(r_i) \qquad (19)$$

From the water distribution radial curve, each drop size (D_i) represents a corresponding water volume and is function of the impact point of the drop on the ground after the flight in no-wind conditions (*Fig. 19*). This procedure is first carried out in no-wind conditions, and afterwards taking into account the wind action.

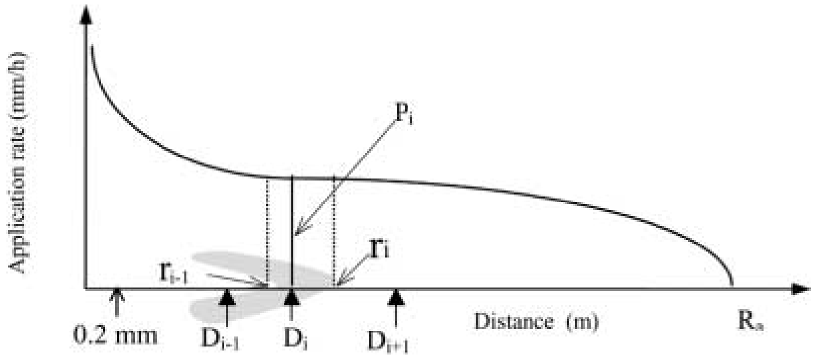


Figure 19: Scheme of the assignation of application rate to each drop diameter (Carriòn et al.(2001))

The water velocity at the nozzle end can be calculated using Torricelli equation:

$$U_0 = c\sqrt{2gH} \tag{20}$$

Where:
U_0 : initial velocity of the drop with respect to the ground at the exit of the nozzle (m.s^{-1})
c : discharge coefficient
g : Gravity acceleration (m.s^{-2});
H : pressure in the nozzle (m)

The drop in the air is subjected to gravity force, in the vertical direction and to a resistance force, which opposes the relative movement of the drop in the air (Vories et al. 1987; Seginer et al. 1991). In absence of wind, the trajectory of a drop moves in the vertical direction, but in general, the trajectories have three dimensions. In no-wind conditions, the drop velocity with respect to the ground *(U)* is equal to the drop velocity with respect to the air *(V)*. When wind acts (Fig. 20) the drop velocity is described by the following equation (Seginer et al. 1991):

$$\vec{U} = \vec{V} + \vec{W} \tag{21}$$

Where
W is wind velocity (relative to the ground), supposing that it acts in a horizontal plane. So, the velocity *(V)* and the resistance force *(F_R)* are not tangential to the segment of the water jet.

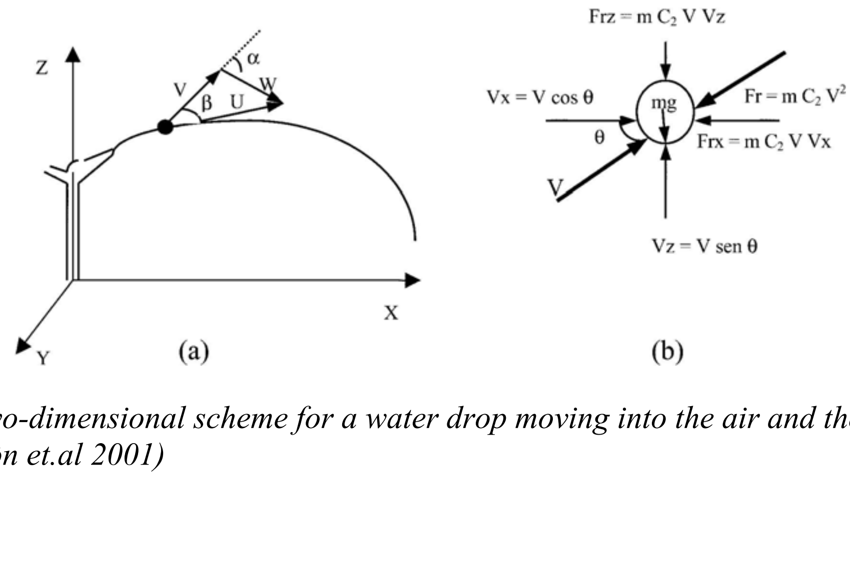


Figure 20: A two-dimensional scheme for a water drop moving into the air and the forces that act upon it. (Carriòn et.al 2001)

The drag force (F_R) for an isolated drop is calculated as (Seginer et al. 1991):

$$F_R = \frac{1}{8}\rho_a C\pi D^2 V^2 = mC_2V^2 \tag{22}$$

Where:
m : mass of the drop,
V : velocity of the drop in the air,
ρ_a : density of the air,
D : nominal diameter of the drop
C : drag coefficient, defined for an isolated drop as a function of the Reynolds' number *(Re)* (Fukui et al. 1980; Seginer et al. 1991) as:

$$Re \leq 128 \quad \rightarrow \quad \mathrm{C} = \frac{33.3}{\mathrm{Re}} - 0.0033\mathrm{Re} + 1.2 \tag{23}$$

$$128 \leq Re \leq 1440 \quad \rightarrow \quad \mathrm{C} = \frac{72.2}{\mathrm{Re}} - 0.0000556\mathrm{Re} + 0.48 \tag{24}$$

$$1440 \leq Re \quad \rightarrow \quad C = 0.45 \tag{25}$$

Where

$$Re = V\frac{D}{\gamma} \tag{26}$$

γ : Kinematic viscosity of the air

The relationship existing between *C* and *C2* is (Carriòn e.al 2001):

$$C_2 = \frac{3\rho_a C}{4\rho_b D} \tag{27}$$

Finally, the equations that define drop movement are obtained from their dynamic balance:

$$\Sigma F = m\frac{dU}{dt} \tag{28}$$

$$A_x = \frac{d^2x}{dt^2} = -\frac{3\rho_a C}{4\rho_w D}V\left(\frac{dx}{dt} - W_x\right) = -C_2V\left(U_x - W_x\right) \tag{29}$$

$$A_y = \frac{d^2y}{dt^2} = -\frac{3\rho_a C}{4\rho_w D}V\left(\frac{dy}{dt} - W_y\right) = -C_2V\left(U_y - W_y\right) \tag{30}$$

$$A_z = \frac{d^2z}{dt^2} = -\frac{3\rho_a C}{4\rho_w D}V\left(\frac{dz}{dt} - g\right) = -C_2VU_z - g \tag{31}$$

where:

x, y, z are coordinates referring to the ground (with origin in the nozzle of the sprinkler), *dx/dt, dy/dt, dz/dt* are components of drop velocity *(U)*,
t: time
A: acceleration of the drop in the air.

The water distribution pattern for a single sprinkler obtained with this procedure is nearly circular, not reproducing well the real distortion caused by wind. Since droplets interfere with each other in

the air, it is necessary to introduce the correction coefficient (*C'*) to better adjust the simulation to reality (Seginer et al. 1991; Tarjuelo et al. 1994; Li and Kawano 1995). This distortion consists basically of a narrowing in the direction perpendicular to the wind as well as a windward shortening and an even greater leeward lengthening (von Bernuth and Seginer 1990). To achieve this deformation, Tarjuelo et al. (1994), following Seginer et al. (1991),
suggested a correction for the *C* air drag coefficient, as a function of correction coefficient K_1 and K_2, in the following way:

$$C' = C(1 + k_1.\sin\beta - K_2.\cos\alpha) \tag{32}$$

Where:

α : Angle formed by vectors *V* and *W*
β : Angle formed by vectors *V* and *U*

$(k_1.\sin\beta)$ shortens the pattern in the direction perpendicular to the wind, but less so in the same direction as the wind. With $(K_2.\cos\alpha)$ a windward shortening and a greater leeward lengthening are produced, without effect on the perpendicular direction of the wind. These correction coefficients are fundamental to achieve a good fit between the simulated models and the field measurements.

Simulation of the evaporation and drift losses implemented in this model is the one used by Carriòn (Carriòn et al. 2001) and described hereafter:

- Based on statistical analysis of field tests and weather conditions, evaporation and wind drift losses were quantified and the following results have been obtained (Montero 1999; Ortega et al. 2000):

  $$P_{er} = 7.63(e_s - e_a)^{0.5} + 1.62W \text{ (Tests in block irrigation)} \tag{33}$$

  where:
  P_{er} : evaporation and drift losses *(%)*
  W : wind speed $(m.s^{-1})$
  $(e_s - e_a)$: Vapor pressure deficit of the air (k_{Pa})

  $$e_s = 0.6108e^{\left(\frac{17.27T}{T+237.3}\right)} \tag{34}$$

  $$RH = 100\left(\frac{e}{e_s}\right) \tag{35}$$

  e_s : Saturation Vapor Pressure
  RH : Relative Humidity *(%)*
  T : Air Temperature *(°C)*

- Correct the water distribution radial curve, by subtracting the estimated evaporation and drift losses. Edling (1985), Kohl et al. (1987), and Kincaid and Longley (1989) deduce that the evaporation of the drops in sprinkler irrigation is negligible for drop diameter greater than *1.5 - 2 mm*.
  To determine the relationship between the evaporation losses and drop diameter, data from Edling (1985) and Kincaid and Longley (1989) have been used. In this way, the following equation that links the drop diameter with the evaporation percentage loss is used:

  $$E_i = 1.8271D_i^{-1.5379} \tag{36}$$

Where E_i is the percentage loss assigned to the drop diameter D_i *(mm)*, valid for drops larger than 0.2 mm, due to the fact that in the simulation smaller drop diameters are not considered.

- Once the evaporation and drift losses are quantified, the equation that relates the total losses with the distributed ones must be fulfilled (Carriòn e.al 2001):

$$\frac{(E + D_r)}{100} Q'_s = K \sum_{i=0.2}^{2} E_i Q_i = K \sum_{i=0.2}^{2} \left(1.8271 D_i^{-1.5379}\right) Q_i \qquad (37)$$

Where:

Q'_s : Discharge of the sprinkler *(l.h^{-1})*
Qi : Discharge of the sprinkler with the drop diameter Di *(l.h^{-1})*
Pi : Application rate *(mm.h^{-1})*
E : Percentage of the discharge flow lost by evaporation *(%)*
Ri : Higher radius assigned to drop diameter Di *(m)*
Dr : Percentage of the discharged flow lost by drift *(%)*
K : Constant to multiply the losses distribution law for the equation to be fulfilled

- Once K is known, the new corrected distributed flows (Q_{ci}) is calculated as:

$$Q_{ci} = Q_i \left(K (1.8271) D_i^{-1.5379}\right) \qquad (38)$$

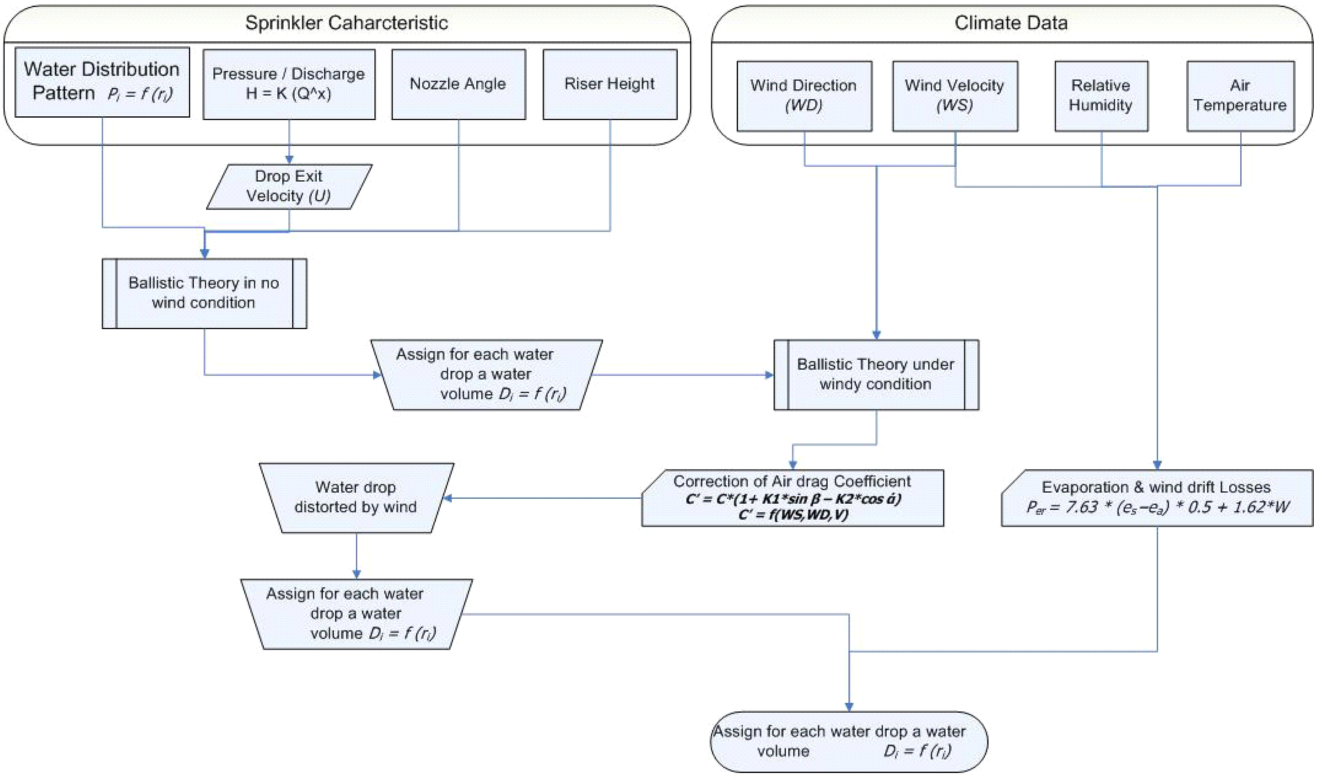


Figure 21: Flow chart of the ballistic theory for wind simulation

3.c- Uniformity Indicators

The sprinklers water profiles calculated using sprinklers pressure head, wind speed and direction, are overlapped according to the network layout. This operation is necessary to perform the statistical analysis on the wetted area in order to evaluate the irrigation performance.
Uniformity of water application in sprinkler irrigation systems is usually reported as either Distribution Uniformity (DU) or Christiansen's Coefficient of Uniformity (CU):

- The distribution uniformity (DU) indicates the uniformity of application throughout the field and is computed by (Heermann et al.,1990):

$$DU = 100 * \frac{Z_{lq}}{Z_{av}} \tag{39}$$

Where:
Z_{lq} average of the lowest one-quarter of the measured values, *mm*
Z_{av} average infiltrated depth in the entire field, *mm*

- The Coefficient of Uniformity (CU), developed by Christiansen (1942):

$$CU = 100 * \left(1 - \frac{\sum |Z - m|}{\sum Z} \right) \tag{40}$$

Where:
Z : individual depth of catch observations from uniformity test, *mm*
$|Z-m|$: absolute deviation of the individual observations from the mean, *mm*
m : mean depth of observations, *mm*

Distribution Uniformity *(DU)* is based on the low quarter of irrigated area and it does not tell you how uniform is the water distribution but how big or severe the dry spot is. While Coefficient of Uniformity *(CU)* is an indicator of how equal (or unequal) the application rates are throughout the field. A low coefficient of uniformity indicates that the application rates are very different, while a high value indicates that the water is distributed evenly to all plants.

The water distribution efficiency *(DE)* described by Keller and Bleisner (Keller and Bleisner, 2000) is used to give more useful meaning to the concept of *CU*. It is expressed as:

$$DE_{pa} = \frac{Minimum \quad net \quad depth \quad received \; by \quad wettest \quad pa\% \quad of \; area}{Average \quad net \quad depth \quad received \quad over \quad entire \quad area} \tag{41}$$

Where:
pa percentage of adequately irrigated area, *%*
DE_{pa} distribution efficiency for the desired percentage adequacy, *%*

At the end of the uniformity analysis process, a *Uniformity* page will be added presenting all the uniformity indicators previously described (*Fig.22*). By hovering the mouse cursor over the relative application ratio and minimum net depth of applied water graph, the appropriate values will appear in a small text box. Beside the user can use the save as and copy buttons to save the graph or to copy it in order to be pasted in another place.

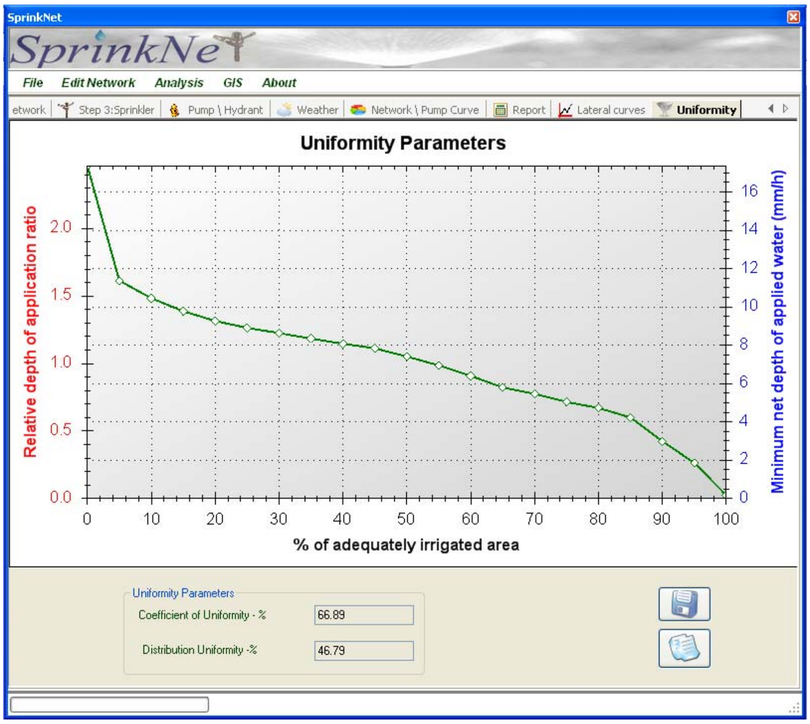


Figure 22: Uniformity indicators obtained by analyzing the performance of a sprinkler network using SprinkNet software

The spatial water distribution patterns of the analyzed network could be saved as raster ".asc" or as shapefile ".shp" by selecting ***Analysis >> Analyse Performance>> Save as >> .asc*** or by selecting ***Analysis >> Analyse Performance>> Save as >> shape file*** respectively**.**

4- Dynamic analysis

Wind is the major factor affecting the uniformity of a sprinkler irrigation system. Together with the upstream pressure head (case of hydrant supplied by on-demand water distribution system) are subjected to high temporal fluctuations. For that reason, SprinkNet model was programmed to perform the analysis of the network under these continuous variable conditions.

Select from the main menu ***Edit network*** >>***Dynamic Analysis*** and six pages will be loaded: ***Pipes and fittings, Edit Network, Sprinkler, Pump/Hydrant, Weather*** and ***Dynamic analysis.*** The first five pages are edited as previously described and correspond to factors or parameters that do not change with time. While the constantly changing parameters must be assigned in the ***Dynamic Analysis*** page as following:

1. Click on the Add Row button to add a time step in the dynamic analysis. Fill for each time step (T1, T2 ….) its duration in minutes and the corresponding variable parameters (Pressure, wind speed, direction, relative humidity and air temperature). Each time one of these variables change, a new time step must be added as well as its duration in minutes.

2. To add a new time step use the Add Row button . To remove a time step click on the Remove Row button . The other two buttons, named ***Copy all Rows*** and ***Copy one Row*** are used to copy the entire selected row into the successive rows to facilitate the data entry.

To select the row to be copied, click on the right margin of the table ▶ at the desired row level (*Fig. 23*).

	ID	Time (minutes)	Sprinkler Pressure (m)	Wind Speed (m/s)	Wind Direction (Degree)	Relative Humidity (%)	Air Temperature (°C)
	T1	60	20	5	45	50	20
▶	T2	80	40	4	35	45	19
	T3	50	50	0.5	0	48	20
	T4	20	30	2	350	52	22

Figure 23: Example of the data entry for the temporal variation of the sprinkler analysis

3. Once you edit the dynamic analysis select ***Analysis*** >> ***Solve Network*** >> ***Run*** in order to solve the network at different time steps. A folder dialog box will ask you to create or to choose a folder in which the report file "Report.txt" will be saved. This file will also appear on your main form as a mobile ***Report*** page docked on the top right of the main form showing the working parameters of each sprinkler at different operating condition (Fig.24).

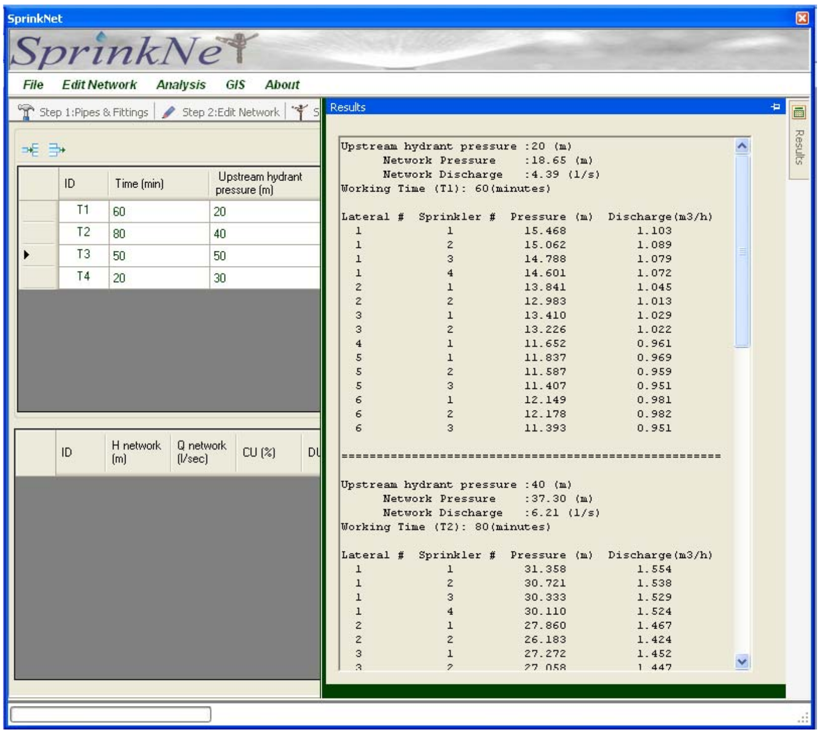


Figure 24:Results of the dynamic network analysis at different time step

4. After that, you can perform the analysis of the sprinkler network uniformity by selecting ***Analysis*** >> ***Performance Analysis***>> ***Run.*** In the folder selected or created to save the results in, you will find a report file named Report.txt presenting the operating pressure and discharge of each sprinkler at different time step and GIS files (.asc and .shp) corresponding to each time step. The GIS files represent the spatial and temporal water distribution pattern of the network throughout the field and could be opened using the internal GIS of the SprinkNet software.

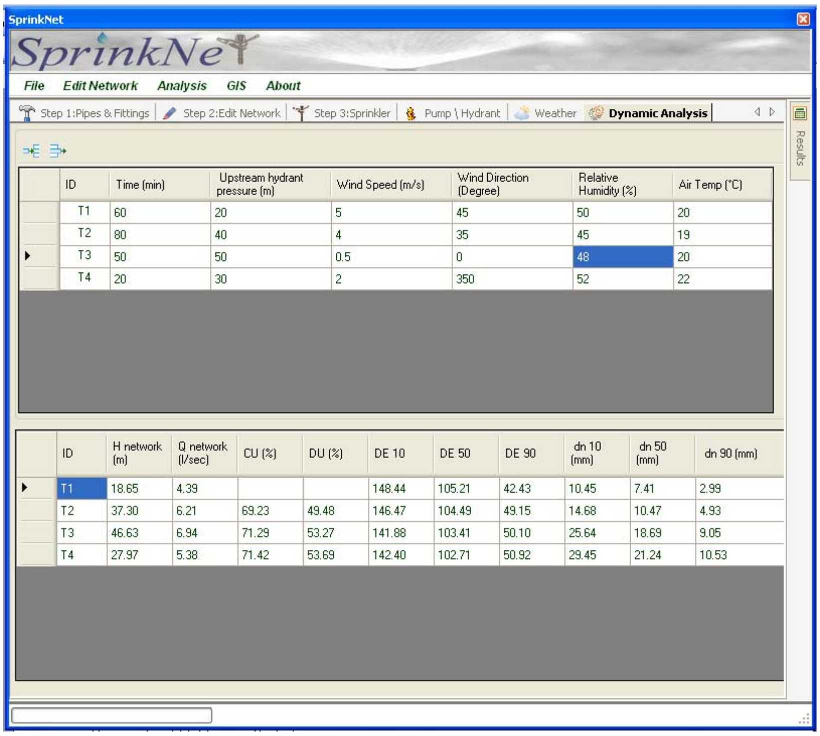


Figure 25: Uniformity analysis of a sprinkler network under dynamic wind and pressure conditions as simulated by SprinkNet software

The uniformity parameters in terms of Coefficient Uniformity ***(CU)***, Distribution Uniformity ***(DU)***, minimum net depth of applied water ***(dn)*** and relative application efficiency ***(DE)*** at different percentage of adequately irrigated areas (10, 50 and 90%) are presented in the uniformity table located at the bottom of the ***Dynamic Analysis*** page.

5- Using GIS

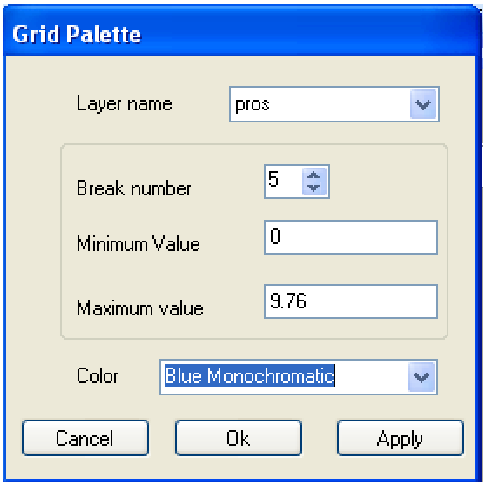
SprinkNet software has the ability to save the results as ASCI raster files ".asc" as well as shape files ".shp" to be used by any GIS software or even by the internal GIS. To access on this latter select the ***GIS*** from the main menu and a new GIS page will appear with a tool box showing the following items (*Fig 26*):

- Add layer button : allows you to add a shape file ".shp" or a raster file ".asc".
- Remove layer button : allows you to remove a selected layer from the GIS page.
- Identifier button : allows you to identify the value of the selected layer by clicking on the map. The values will be shown in the text box located at the bottom left of the window form.
- Zoom in , Zoom out , Zoom to extent and Pan buttons could be used to change the visualization of the maps.

To change the symbology of the loaded layers, select first the appropriate layer by clicking on it. Then right click on the map legend and choose the ***Shape Palette*** or the ***Grid Palette*** depend on the type of the your layer .

- For a raster file ".asc", choose the grid palette and in the ***layer name*** drop down list select the name of your layer. Change your break number and the minimum and maximum values of the legend as well as the color and click ***Ok*** to apply changes, *Cancel* to close the palette without any modifications or ***Apply*** for a modification preview.

- For a shape file .shp, choose the shapefile palette and in the ***layer name*** drop down select the name of your shape layer. Select the field to be classified and the type of legend to be used and the color from the appropriate drop down lists. Click ***Ok*** to apply changes.



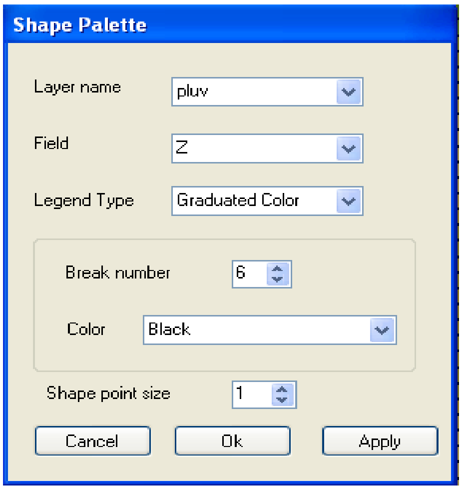


Figure 26: Symbology palettes of a Grid and shape file as presented by SprinkNet Software

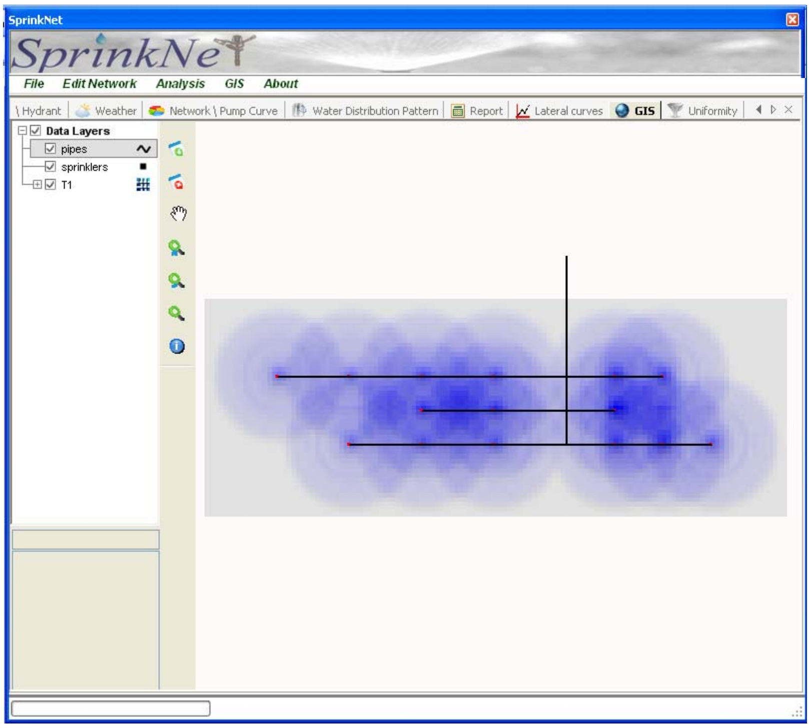


Figure 27: An example of the results showed by the internal GIS of the SprinkNet software

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