The image shows the cover of a manual. The background is a photograph of a dam with water flowing through its spillways. The water is turbulent and white with foam. The dam structure is made of concrete and has a blue-painted metal railing in the foreground. The title is written in white, bold, uppercase letters. A cluster of white water droplets is positioned below the title. The logo 'FOR SAT' is located in the bottom right corner, with the 'O' containing a satellite symbol and the 'A' having a stylized signal wave to its right.

INSTRUCTIVO DE MODELACIÓN Y PREDICCIÓN HIDROLÓGICA

FOR SAT

Content

1. Introduction	4
2. Tools and software and hardware requirements	5
3. Information organization and workflow	6
4. Preparation of the hydrological model	7
4.1 Preparation of the basin model	7
4.1.1 Creating a new project	7
4.1.2 Defining the basin model.....	8
4.1.3 Saving the project.....	10
4.1.4 Include cartographic base (maps of the basin, fluvial network, etc.).....	10
4.1.5 Adding hydrological elements	13
4.2 Creation of the meteorologic model.....	27
4.3 Introduction of time series, precipitation data grids and data pairs.....	32
4.3.1. Time series.....	32
4.3.2 Precipitation data grids	35
4.3.3 Data pairs	36
4.4 Control specifications.....	37
4.5 Creation of simulation runs.....	38
4.6 Calibration of the model	40
5. Rain data assimilation	43
5.1. Rainfall data generated by quantitative estimation and by quantitative forecast.....	43
5.1.1 Operation of precipitation matrix assimilation applications	46
5.1.1.a. Data entry	46
5.1.1.b. Predesigned queries.....	48
5.1.1.c. Exporting ArcInfo ASCII grids	53
5.1.1.d. Predesigned reports.....	55
5.1.2. Importing rain grids in HEC-DSS	55
5.2. Rain data measured in conventional rainfall stations	61
5.3. Rain data measured in automatic rainfall stations.....	67
5.4. Estimation of regional Precipitation-Duration-Frequency curves from 24-hour-accumulated precipitation sheets.....	67
5.4.1. Obtaining PDF curves	69
6. System operation for flood hazard assessment (contribution to outputs from the flood hazard study due to heavy rains from HVR studies).....	72
7. Real-time system operation (hydrological prediction process)	76
8. References and bibliography	82
Annex I. Regional analysis of the annual maximum daily rainfall series. Study case: Zaza river basin	84

1. Introduction

Hydrologists have the mission to provide information for a variety of activities and studies on water resources that include: the planning and design of new hydraulic conduction and control works or water storage; the operation and/or evaluation of existing water control and conduction works; the preparation for and control of floods and the regulation of activities in flood plains.

On rare occasions historical records of flows, levels and rainfall are sufficient. More commonly, runoff in the basin must be predicted to provide information. For example, a study on flood damage reduction may require an estimate of the increase in runoff volume for proposed land use changes in a basin. However, no record will be available to provide this information because the change has not yet occurred. Similarly, a forecast in a reservoir inflow may be needed to determine the discharge of water in case a tropical storm changes its course and moves over a basin. In both cases, waiting to observe the flow is not acceptable. The alternative is to use a model to provide the information.

A model is a tool that links something unknown (the output) with something known (the input). In the case of the models included in the HEC-HMS hydrological modeling system, the known input is precipitation and the unknown output is runoff, or the known input is the upstream flow and the unknown output is the downstream flow.

Models take a variety of forms. Physical models are small-scale representations of real-world systems. The physical model of a basin can be a large surface with water sprinklers to represent the entry of precipitation. The surface can be altered to simulate different land uses, soil types, slopes, etc; and the intensity of rain can be controlled. Runoff can be measured directly in the model.

Researchers have developed the so-called analog models that represent the water flow with the electricity flow in a circuit. With these models the input is controlled by adjusting the amperage and the output is measured with a voltmeter.

In the HEC-HMS, a third category of models is included; the mathematical models. This term defines an equation or a set of equations that represent the response of a component of a hydrological system to a change in hydro-meteorological conditions.

Mathematical models, including those present in HEC-HMS, can be classified based on the following criteria: the way they consider time (continuous models and eventual models); the spatial variation of the characteristics and processes (added and distributed); the knowledge base on which the model is developed (empirical and conceptual); the way in which they address randomness (deterministic and stochastic); and the availability of observations of input and output parameters (observed parameters and adjusted parameters). These classifications are not necessary to use the system but are useful when deciding which of the models to use for several applications.

2. Tools and software and hardware requirements

For the execution of the different activities and processes included in the present hydrological modeling/prediction system, the following computer applications of storage, processing, simulation, visualization and edition of data and information are required both alphanumerically and geographically:

- MS-Office 2007 or higher with Access installed
- ArcGIS Geographic Information System version 10.2
- ArcHydro hydrological processing extension for ArcGIS version 10.2.
- Hydrological Modeling System HEC-HMS version 4.0
- HEC-RAS River Analysis System version 4.1
- Geospatial extension of hydrological modeling HEC-GeoHMS version 10.2
- Support tools for HEC-RAS using ArcGIS, HEC-GeoRAS version 4.3
- Visual utility engine of data storage system HEC-DSSVue version 2.01
- HEC-GridUtil grid utility program version 2.0
- Database Application of Numeric Rainfall Forecast
- Database Application of Numerical Rain Estimation
- Database Application of Special Information Network Rain in Extraordinary Events

The minimum hardware and software requirements are similar to those of ArcGIS. However, when working with geographic information systems, it is important to take into account the size of the data packages as well as the complexity of the analysis when determining the appropriate computing resources. Even when applications can work on slower machines, the user will often experience long computing times. To guarantee that performance is not compromised, the following hardware recommendations should be considered with the idea that more computing resources, in terms of the speed of the central processing unit (CPU), memory and hard disk space, can improve performance of the applications.

For example, in the case of HEC-HMS, the minimum equipment will be suitable for the simulation of events with basin models containing only between 20 and 30 hydrological elements. However, better equipment will be needed if you are trying to make basin models with more than one hundred elements, perform continuous simulations for large time windows, or use the distributed Mod Clark transformation method.

- RAM memory: minimum 1 GB, recommended 2 GB or higher
- Central processor speed: recommended 1.6 GHz or higher
- Hard disk capacity: must be at least 20 times the size of the digital elevation model data used in the GeoHMS. In many cases, having big capacity available in the hard drive will improve performance because spatial operations sometimes generate several intermediate temporary files and repeatedly perform file accumulation.
- Screen resolution: minimum 1024x768

3. Information organization and workflow

In order to facilitate management and exchange of data between the different computer applications involved in the modeling/prediction system, a folder structure organized in correspondence with the applications, the nature of the data, data origin or destination, process activities or stages, etc. was created. As a general directory for the entire process of capturing, storing, processing, simulating, analyzing and delivering data and information, the "ModelacionFORSAT" directory located at the root of the PC working partition was defined. This would be, for example, "D:\ModelacionFORSAT".

It is recommended to use the root of the work partition and folder names without spaces so that the file paths are as short as possible and thus avoid files reading/writing errors either definitive and temporary files and processes interruptions.

In the directory "D: \ ModelacionFORSAT" the following folders are included:

- DSS Files
- DSSUTL Files
- Documents: for the storage of manuals, instructions for all the system tools.
- EstimacionNumlluvia: for the management of data and information of quantitative rainfall estimates.
- PronosticoNumlluvia: for the management of data and information on quantitative rain predictions.
- ProjectsGeoHMS
- ProjectsRAS

4. Preparation of the hydrological model

To simulate the hydrological response in a basin using the HEC-HMS Hydrological Modeling System, a hydrological model is developed and run, whose primary components are the basin models, the meteorological models and the control specifications.

The basin model represents the physical basin. The user develops a basin model by adding and connecting hydrological elements which use mathematical models to describe physical processes in the basin. The hydrological elements available in HEC-HMS are: sub-basin, reach, junction, source, sink, reservoir and diversion.

The meteorological model calculates the input of precipitation required by a sub-basin-type element in the basin model. The meteorological model can use both specific data and data grids and has the capacity to model liquid and frost precipitation along with evapotranspiration.

The control specifications define the period and the temporal resolution of the simulation run. The information in the control specifications includes the start date and time, the closing date and time and the increasing time for the calculation.

There are also data entry components such as time series, paired data, and data grids which are often required as parameters or as border conditions in watershed and meteorological models.

In general, a simulation calculates the rain - runoff transformation in the basin model from a certain input of the meteorological model.

4.1 Preparation of the basin model

To develop a basin model in HEC-HMS, cartographic bases, basin model files, meteorological model files and grid cell parameters files, generated by using the ArcGIS software and its HEC-GeoHMS extension, can be used. By having a detailed Digital Elevation Model, the analyst can use these tools to delineate sub-basins, establish drainage lines and calculate physical parameters of the watershed such as length, location of centroid and average slope. A step-by-step description of this process can be found in Chapter 13 of the HECGeoHMS user manual.

The construction of the basin model in the HEC-HMS, means to graphically represent in the "Desktop" the information obtained in the previous processing of the basin, through the hydrological elements available in the software. The following is a summary of this process.

To execute the software HEC-HMS v. 4.0 double click on the shortcut icon found on the "Desktop" of the computer.

4.1.1 Creating a new project.

- In the "File" menu choose "New" or press the key combination (Ctrl + N). With this the "Create a new Project" window opens. In this window:

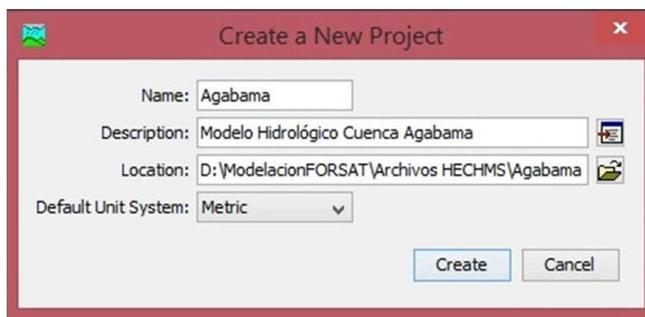


Figure 4.1. "Create a New Project" dialog box

- Write in the "Name" text box the name with which the model will be identified, this will be the name of the project that is created and also the name of the directory where all the project files will be saved.
- In the "Description" text box you can optionally record interest information of the basin, for example: the area, the location, or the condition that you want to simulate.
- In "Location", select the directory where the project will be saved, it is always recommended to save the project in directions near the root of the hard disk, to avoid simulation errors.
- In "Default Unit System": Keep the Metric system ("Metric"), in addition you can choose the "U. S. Customary ", if this is the case of your data origin.
- Then click on the "Create" button.

4.1.2 Defining the basin model.

Basin models are one of the main components of a project. Its main purpose is to convert atmospheric conditions into river runoff in specific places within the basin. Hydrological elements are used to divide the basin into manageable pieces. These elements are connected to each other in a dendritic network to form a representation of the fluvial system. Digital cartographic bases can be used to help during the location of the hydrological elements in a spatial context.

To define the model of the basin in the HEC-HMS, execute the command "Basin Model Manager" of the "Components" menu. The "Basin Model Manager" window will appear where you will click on "New" to open the "Create A New Basin Model" window. See figure 4.2.

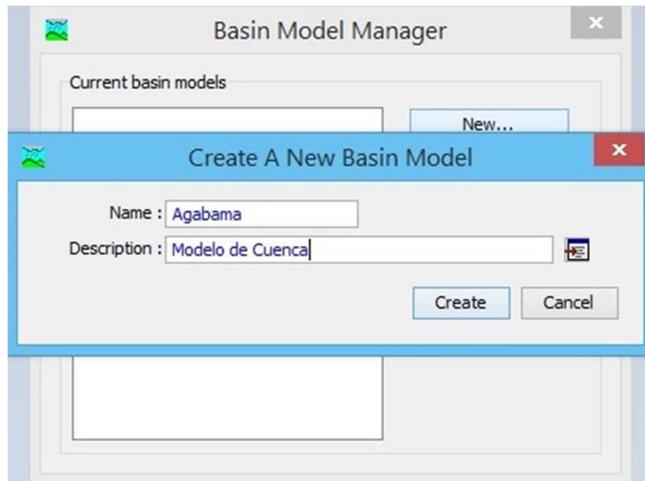


Fig. 4.2 Manager of the basin model (Basin Model Manager) and window "Create A New Basin Model".

- In the "Name" box, the name of the basin of the project will be written, which will also be the name of the file where all the data corresponding to the basin created for the project will be saved.
- In Description: This description is optional.
- Click on the "Create" button to return to the "Basin Model Manager" window, and then close this window by clicking the button in the upper right corner.
- Automatically, in the Explorer panel of the basin, the basin model previously created will be displayed. ("Basin Models"). See figure 4.3.

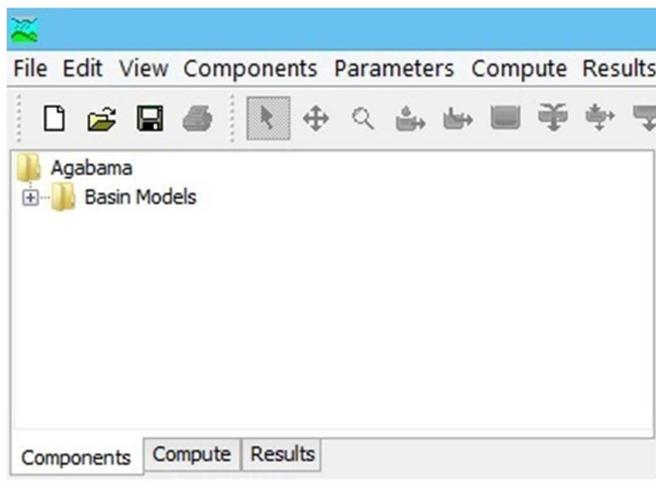


Figure 4.3 Basin explorer showing the created model

Double clicking on "Basin Models" shows the name of the created basin and clicking on it shows its components, both in the Component Editor Panel and in the Desktop area, where it is going to graphically represent the basin model. Next, the icons of the toolbar that show the seven types of hydrological elements (enclosed within a red ellipse in figure 4.4) that are used to represent the model of the basin are activated automatically.

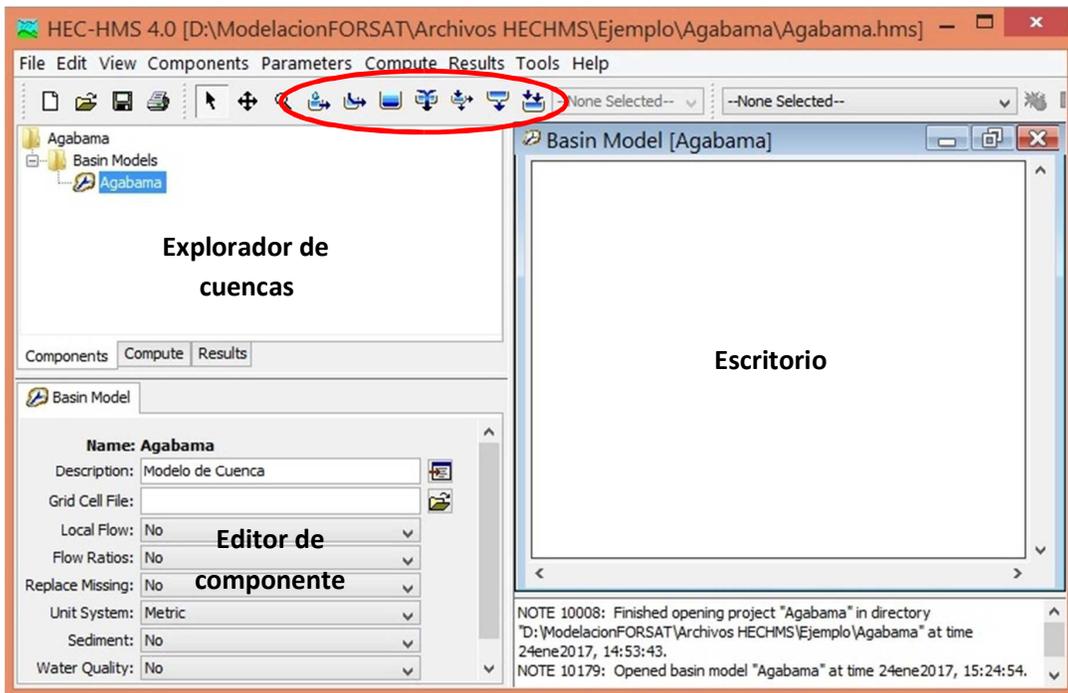


Figure 4.4. General environment of HEC-HMS (tools of hydrological elements enclosed within the red ellipse).

4.1.3 Saving the project

Click on the "Save" command in the "File" menu. The project will be automatically saved in the address set at the beginning of these instructions in the directory already defined.

4.1.4 Include cartographic base (maps of the basin, fluvial network, etc.)

The map of the basin, is a base of orientation in the process of introducing the hydrological elements, which allows the user to achieve a distribution of the components as close to reality, therefore it has no real effect on simulations and calculations carried out in the HEC-HMS project. HEC-HMS does not generate the maps, but it does allow the use of digitized maps, for example from ArcView, Auto CAD Map, among others.

In the case of maps digitized with ArcView, the map file with extension .shp is created, and in turn two other extension files, .dbf and .shx. Care should be taken to copy the three files to the Maps subdirectory, in this case within the project directory, since they are necessary to display the .shp extension. The general process is the following:

- Copy the .map extension file (or extension files .shp, .dbf, .shx) from the map of the digitized basin, to the "Maps" folder, which is in the directory where the project is being saved.
- Select, in the Basin Explorer, the basin of the model. This will activate the Work Desktop.
- From the main menu, execute the command: View/Background Maps. In the "Background Maps" window that will open (Figure 4.5), select "Add...". The standard "Select" file dialog box will open.

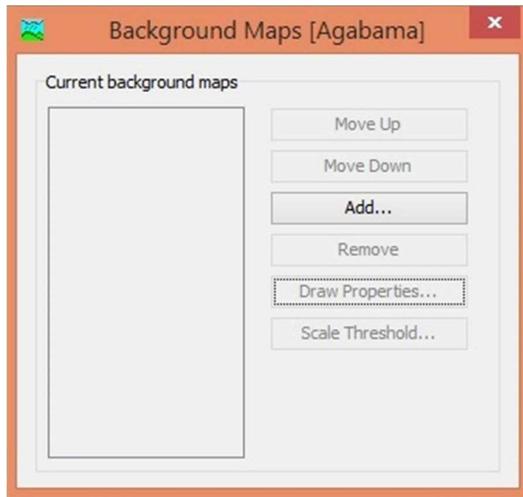


Figure 4.5. "Background maps" window

- Search the directory where the file you want to display was copied. If the map file was generated in ArcView, (with extension .shp) it will be displayed automatically. In case of being a .map extension map, you must change the extension type by selecting from the drop-down list "Files type:" (Figure 4.6). Once the map has been selected, the "Select" button will be clicked to return to the "Background maps" window where the name of the selected map will be displayed. In case it is required to show information contained in more than one map (eg, the contour of the basin and the sub-basins in one map and the river network in another one), the process "Add ..." must be repeated for each map in question.

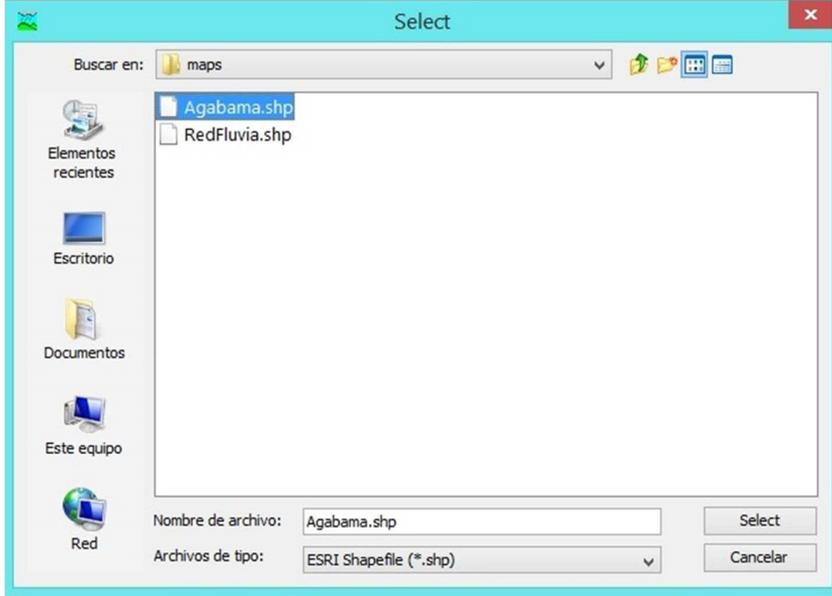


Figure 4.6. "Select" dialog box

- Close the "Background maps" window by clicking on the button in the upper right corner. In the Desktop area, the map will be displayed as in the example of Figure 4.7. This process can be repeated to import other maps such as the fluvial network, measurement stations, etc.

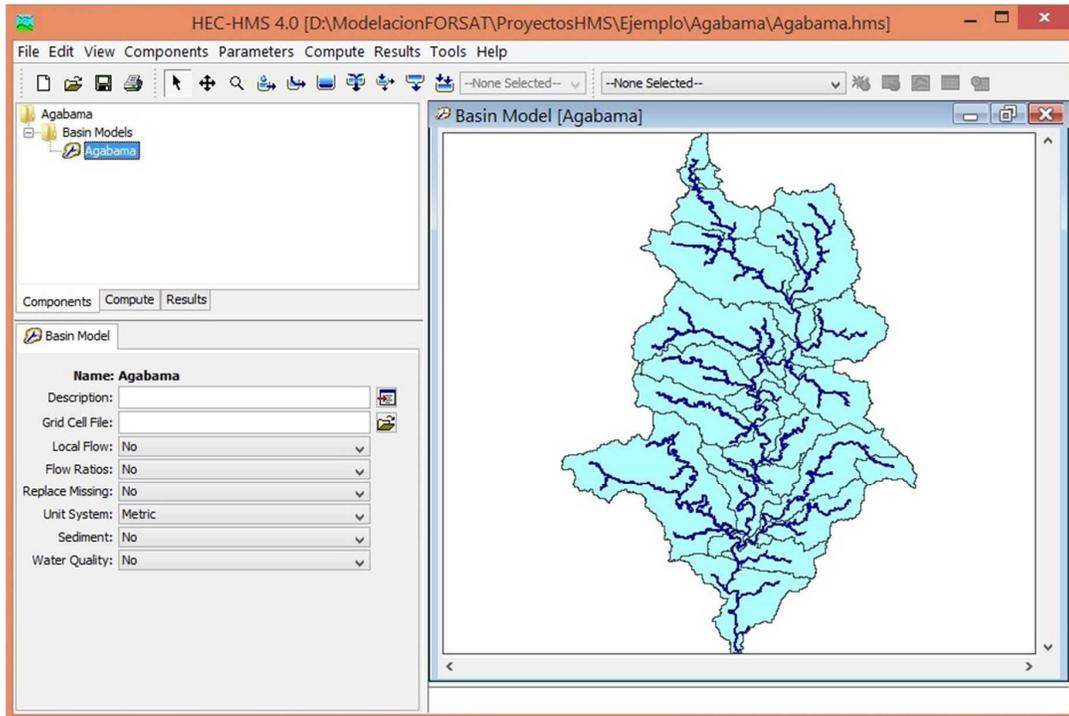


Figure 4.7. Basin map opened in the desktop area.

4.1.5 Adding hydrological elements

HEC-HMS has 7 types of elements for the conformation of hydrological models. They are:

- **Subbasin ("Subbasin"):** It is used to represent the physical basin. Having the precipitation, the effluent of the Sub-basin element can be calculated by subtracting the precipitation losses, calculating the surface runoff and adding the base flow.
- **Section ("Reach"):** Used to conduct runoff in the basin model. The affluent flow may come from one or more elements located upstream. The effluent flow is calculated by inferring conversion and attenuation processes.
- **Confluence ("Junction"):** It is used to combine runoff from hydrological elements located upstream. The input flow can come from several elements and the output flow is calculated by totalizing the incoming flows.
- **Source ("Source"):** Used to introduce flow in the model of the basin. It has no input flow and the output is defined by the user.
- **Sink ("Sink"):** It is used to represent the exit of the physical basin. The inlet flow can come from one or several elements upstream and there is no outflow.
- **Reservoir ("Reservoir"):** Used to model the detention or attenuation of the hydrographer in a natural or artificial reservoir. The inflow of water can come from one or several elements upstream while the effluent can be calculated by one of the three methods of flood transit that the system has.
- **Derivation ("Diversion"):** It is used to model the flow that leaves the main channel. It can receive flows of any element upstream. The effluent is divided into derived flow and non-derived flow. Both can be connected to any downstream element.

For the modeling of Agabama basin, this has been divided into 21 sub-basins associated to the closures of the three reservoirs and the three existing gauging stations; and closures in vulnerable settlements. In addition, nine other sub-basins called Anexa01, Anexa02, ..., Anexa09 were incorporated to represent the areas between a certain closure and the next closure downstream. To the elements to be represented in the model of the 30 sub-basins and the three reservoirs were added 21 confluences, 20 connections and one sink, for a total of 75 elements. Figure 4.8 shows the connection diagram of these elements.

Once the elements to be represented in the model have been defined, the next step is its conformation, for which, in an orderly manner, each of the elements with the corresponding parameters will be placed on the Desktop according to the calculation methods to be used, at the same time that these elements are linked. The place where the elements are located has no relevance because the relationships between the elements is what really matters.

For hydrological modeling HEC-HMS (in version 4.0) offers different methods to simulate infiltration losses that include: initial losses and constant infiltration rate, Curve Number (CN) of the Soil Conservation Service (SCS), SCS CN for grids and Green & Amp, among others. Seven methods are available for the transformation of precipitation excess into surface runoff (direct runoff) including Unitary Hydrograph methods such as Clark's, Snyder's and SCS's. An implementation of the kinematic

wave method is also included. Five methods are available for the representation of base flow such as the recession method (exponential decay function), the monthly constant base flow method and the non-linear Bossiness method. Six avenue transit methods can be used to simulate flow in open conduits, including a delay method for non-attenuation modeling and Muskingum and “Straddle stagger” methods for simple approximations of attenuation. For the case of the hydrological model of Agabama basin, the methods listed in Table 4.1 have been selected, and based on this parameterized the elements.

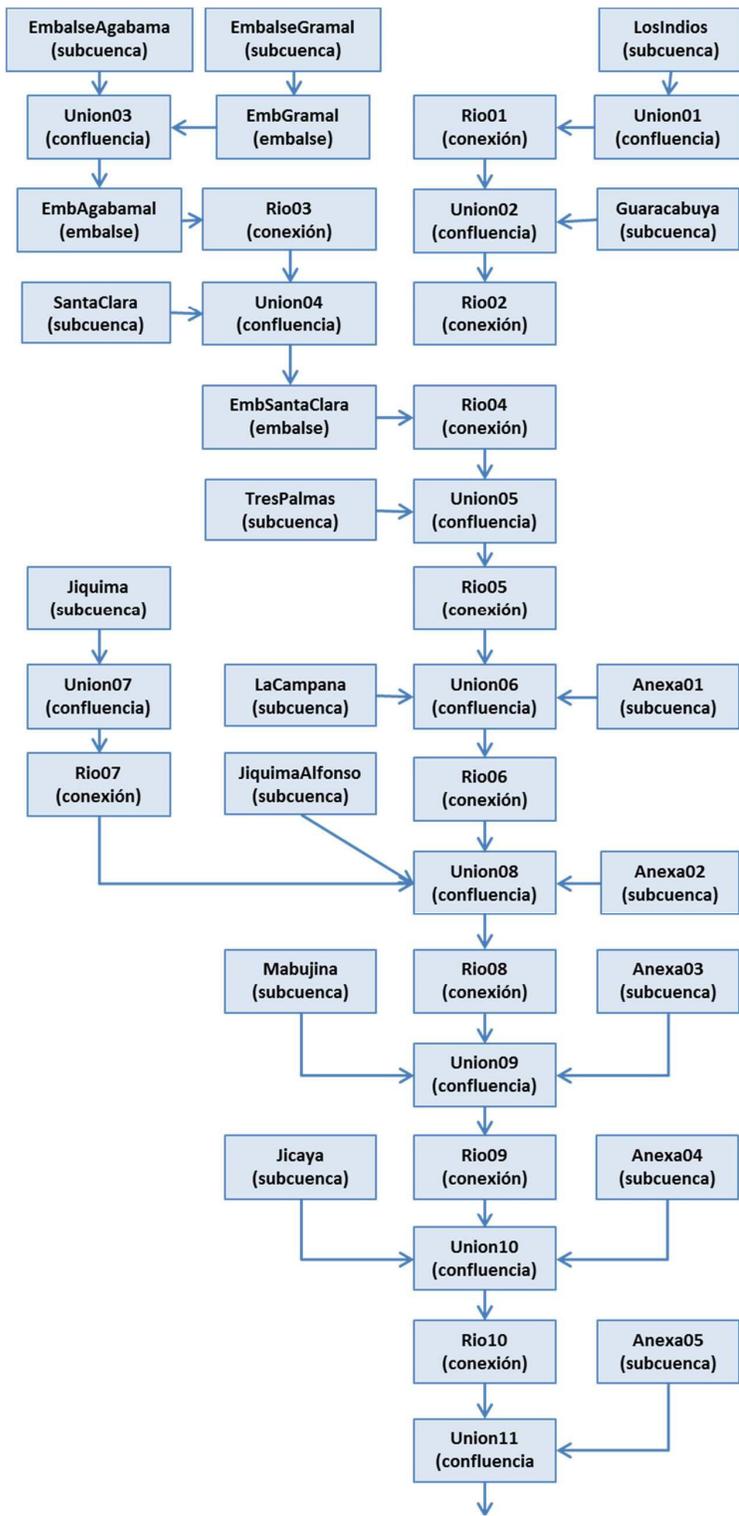


Figure 4.8a. Connection diagram of Agabama basin hydrological elements.

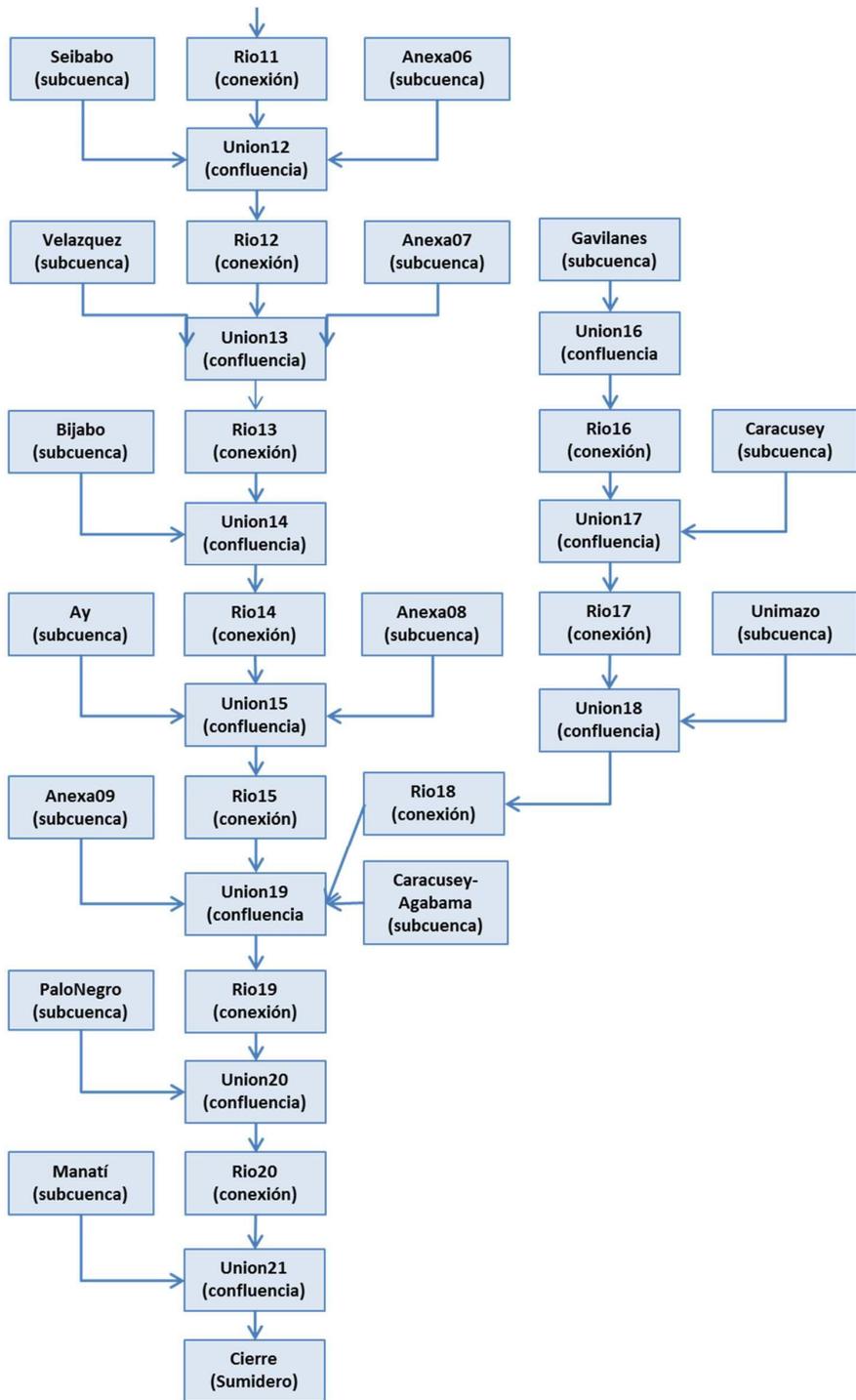


Figure 4.8b. Connection diagram of Agabama basin hydrological elements (continued).

Table 4.1. Calculation methods used in the hydrological model of Agabama basin.

Process	Method	Parameters
Infiltration losses	SCS curve number	<ul style="list-style-type: none"> Initial abstraction (mm) Curve number Percentage of waterproof surface
Net rain transformation - runoff	Unit Hydrograph of SCS	<ul style="list-style-type: none"> Type of hydrograph Time of (min)
Base flow		
Avenue Transit	Muskingum	<ul style="list-style-type: none"> Muskingum K (Hr) Muskingum X Number of sub-sections

To represent the sub-basins in the model, the steps are:

- Select the "Subbasin Creation Tool" command in the "Edit" menu or select the corresponding tool in the toolbar. When passing over the Desktop the mouse pointer will change its usual shape (arrow) to that of a cross.
- Click on the place on the Desktop where the sub-basin will be placed.
- In the "Create A New Subbasin Element" window that will be shown below, write in the "Name" box the name that will be assigned to the new sub-basin element that is being created (eg "LosIndios") and in the box "Description" add (optional) a description for that element. Click on the "Create" button.

After this process, the basin explorer panel will have the following:

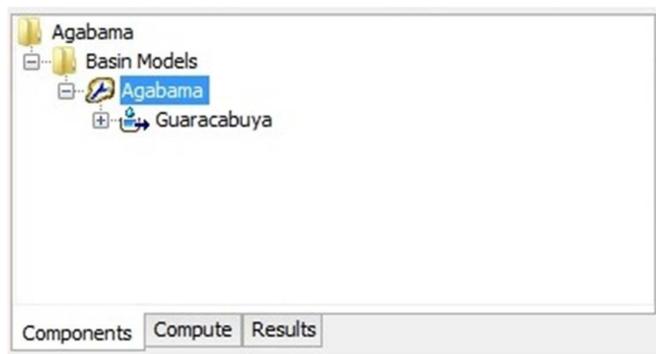


Figure 4.9. Expanded basin explorer showing the hydrological element "Sub-basin" for the Guaracabuya sub-basin in the Agabama basin model.

Meanwhile, the Desktop will have:

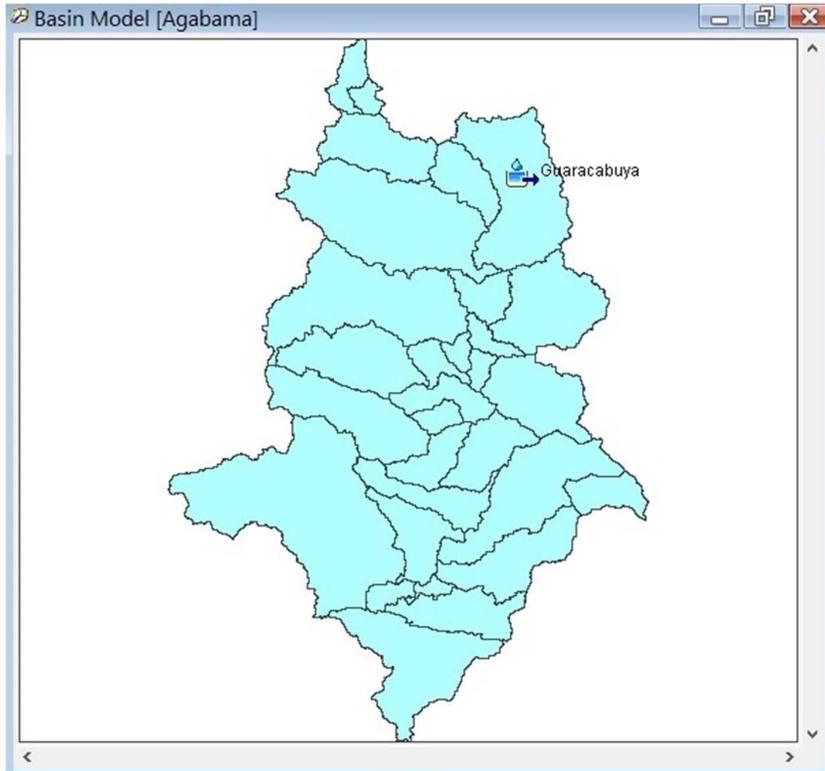


Figure 4.10. Map of Agabama basin and hydrological element "Sub-basin" for the Guaracabuya sub-basin.

- This process will be repeated to create the remaining sub-basins of the model. Since the "Subbasin" tool is active, you just have to click on conveniently selected places on the Desktop to create the other elements. When all the necessary elements have been created, press the "Esc" key to return the pointer to the classic form. Once all the sub-basins were created, the Explorer and the Desktop would look like Figure 4.11.

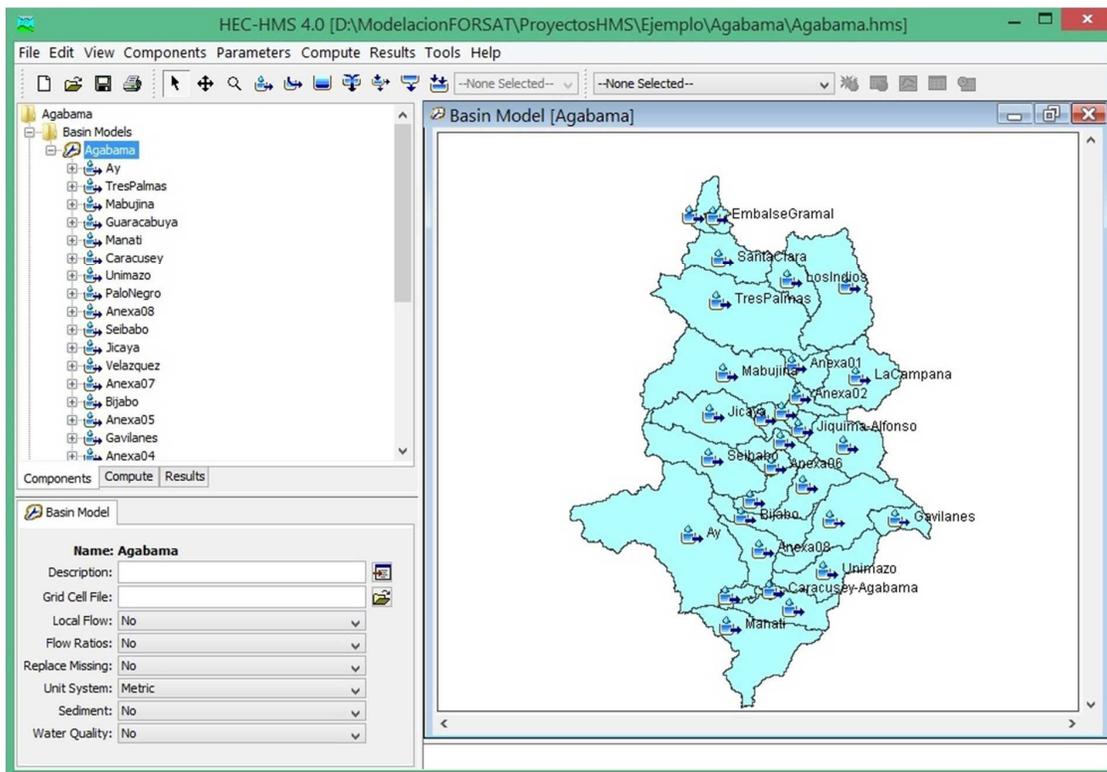


Figure 4.11. View of the Explorer and the Desktop after all the "Sub-basin" elements have been created.

To represent the junctions in the model, do the following:

- Select the "Junction Creation Tool" command in the "Edit" menu or select the corresponding tool in the toolbar. When passing over the Desktop the mouse pointer will change its usual shape (arrow) to that of a cross.
- Click on the place of the Desktop where the confluence will be placed
- In the "Create A New Junction Element" window that will be shown below, write in the "Name" box the name that will be assigned to the new junction element that is being created (eg "Union01") and in the box "Description" add (optional) a description for that element. Click on the "Create" button.
- After this process, the following will be displayed in the basin Explorer panel and on the Desktop:

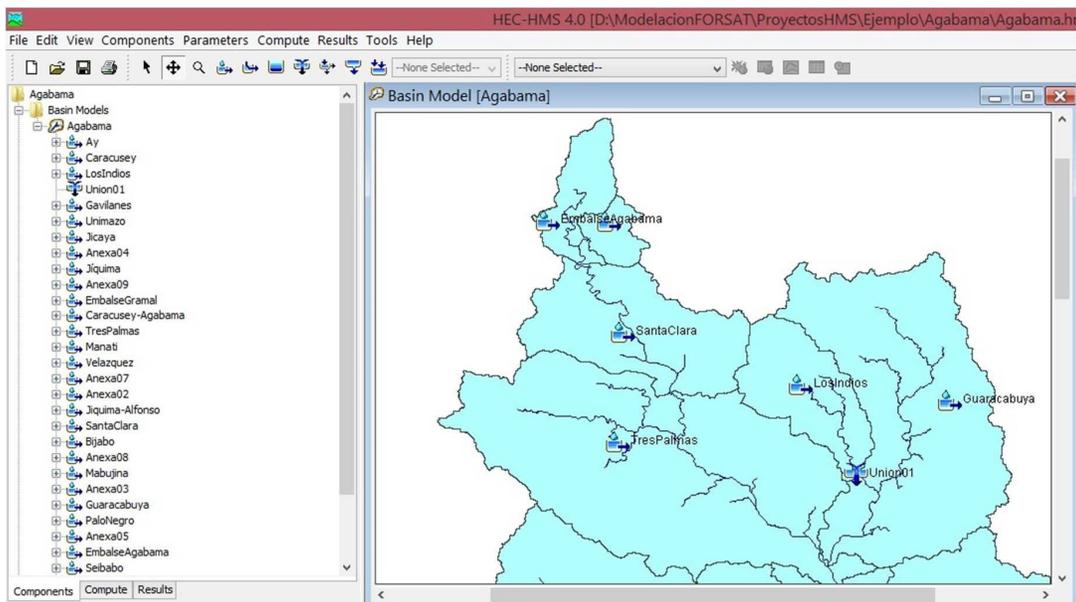


Figure 4.12. View of the Explorer and the Desktop after the insertion of the element "Junction" named "Union01".

- This process will be repeated to create the remaining confluences of the model. As the "Junction" tool is active, you just have to click on conveniently selected places on the Desktop to create the other elements. When all the necessary elements have been created, press the "Esc" key to return the pointer to the classic form. Once all the junctions were created, the Explorer and the Desktop would look like Figure 4.13.

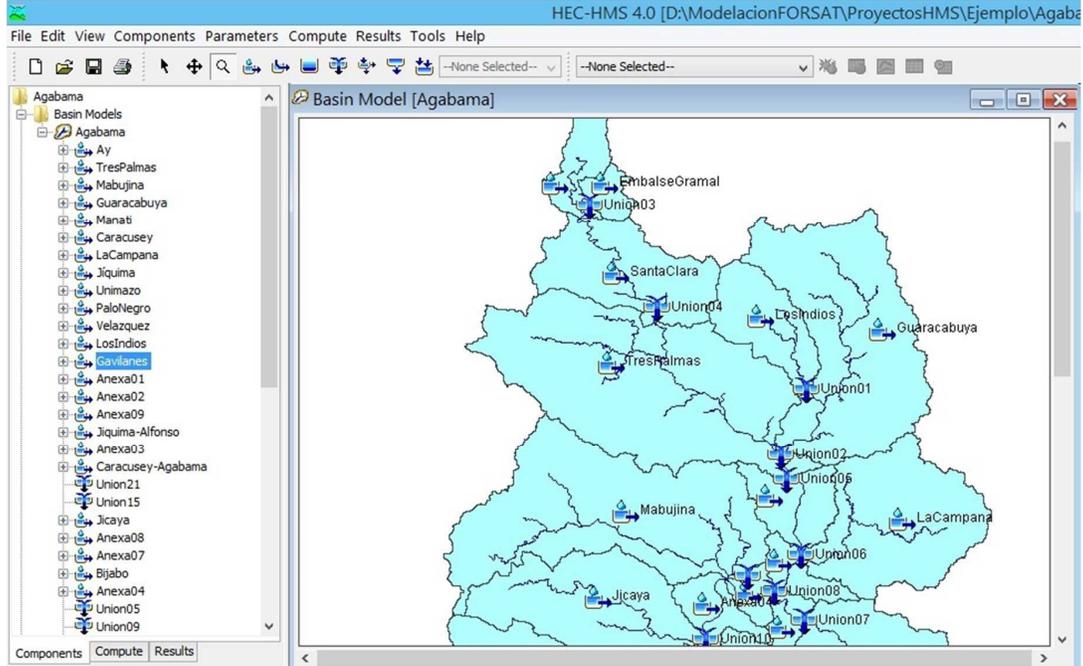


Figure 4.13. View of the Explorer and the Desktop after the insertion of all "Junction" type elements.

To represent the reservoirs:

- Select the "Reservoir Creation Tool" command in the "Edit" menu or select the corresponding tool in the toolbar. When passing over the Desktop the mouse pointer will change its usual shape (arrow) to that of a cross.
- Click on the place on the chosen Desktop where the reservoir will be placed.
- In the "Create A New Reservoir Element" window that will be shown below, write in the "Name" box the name that will be assigned to the new reservoir element that is being created (eg "EmbGramal") and in the box "Description" add (optional) a description for that element. Click on the "Create" button.
- This process will be repeated to create the remaining reservoirs of the model by clicking on conveniently selected places on the Desktop. When all the necessary elements have been created, press the "Esc" key to return the pointer to the classic form. Once all the junctions were created, the Explorer and the Desktop would look like Figure 4.14.

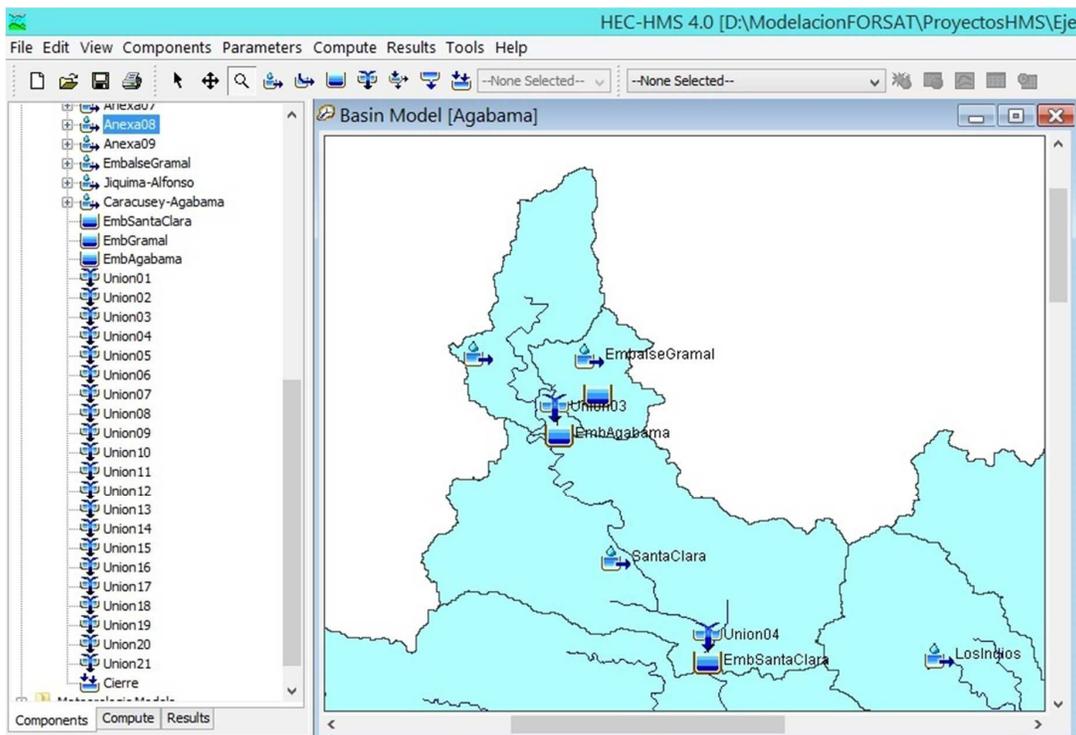


Figure 4.14. View of the Explorer and the Desktop after the insertion of all "Reservoir" type elements.

To represent the closure of the basin:

- Select the "Sink Creation Tool" command in the "Edit" menu or select the corresponding tool in the toolbar. When passing over the Desktop the mouse pointer will change its usual shape (arrow) to that of a cross.
- Click on the place of the chosen Desktop to represent the closure of the basin.
- In the "Create A New Sink Element" window that will be shown below, write in the "Name" box the name that will identify the basin closure that is being created (eg "Close") and in the "Description" box add (optional) a description for that element. Click on the "Create" button.

To represent the sections or river reaches, it is recommended to review the connection scheme of the basin elements (Figure 4.8) because for them it is very important to respect the direction of circulation, which will rule the definition of the initial and final points of each river section. It is also recommended to activate the "Draw Flow Directions" option in the "View" menu. With this, when the end points of the river section are fixed, the direction of its flow will be automatically shown. Then, we proceed as follows:

- Select the "Reach Creation Tool" command in the "Edit" menu or select the corresponding tool in the toolbar. When passing over the Desktop the mouse pointer will change its usual shape (arrow) to that of a cross.
- Click on the hydrological element in which the river reach begins (eg: EmbAgabama reservoir) and then on the hydrological element where the river reach ends (eg: with "Union4").

- In the "Create A New Reach" window that will be shown below, write in the "Name" box the name that will be assigned to the new river or current element that is being created (eg "Rio03") and in the box "Description" add (optional) a description for that element. Click on the "Create" button.
- Repeat this process to create the remaining river reaches of the model by clicking on the Desktop on the initial and final elements previously defined for each section. When all the necessary elements have been created, press the "Esc" key to return the pointer to the classic form. Once all the junctions were created, the Explorer and the Desktop would look like Figure 4.15.

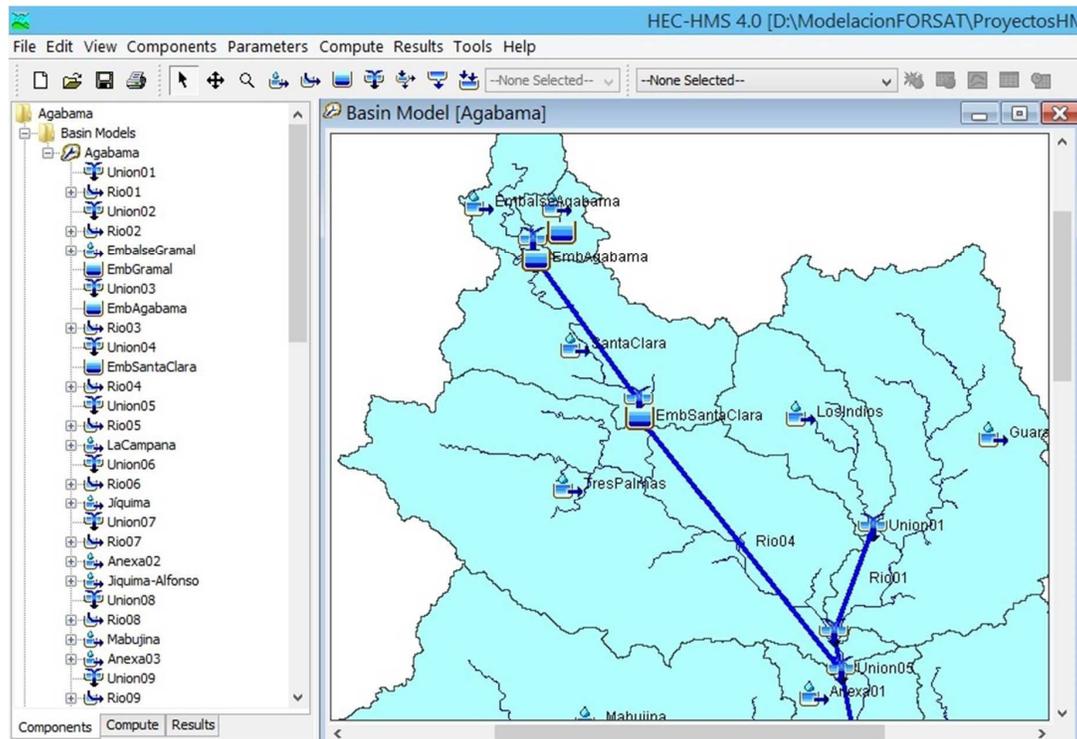


Figure 4.15. View of the Explorer and the Desktop after the insertion of all "Reach" type elements.

Even though all the elements that make up the hydraulic hydrological system that we want to model have been represented and these have been located in a hydrologically organized way, from the perspective of the simulation system there is no connectivity between them. Therefore, one should proceed to connect with each other starting from upstream to downstream, following the scheme outlined in Figure 4.8.

Before starting to create the connections, activate the object selection tool ("Arrow Tool" in the "Components" toolbar). The mouse pointer will adopt a black arrow shape. Then:

- Click with the right mouse button on the element to be connected (eg sub-basin "EmbalseAgabama"). A context menu will appear in which, with the left click, "Connect Downstream"

will be selected (see Figure 4.16) and then click on the element downstream to which you want to connect (eg junction "Union03").

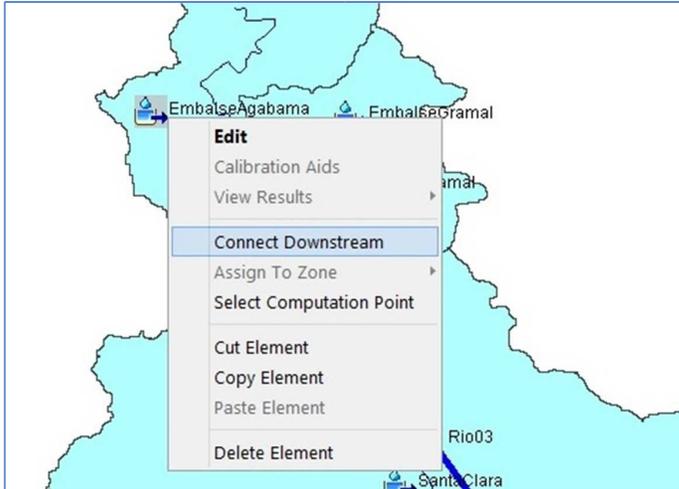


Figure 4.16. "Connect Downstream" tool in context menu.

- After this operation, both elements are connected and a black line appears indicating that there is a direct connection between both elements (see Figure 4.17).

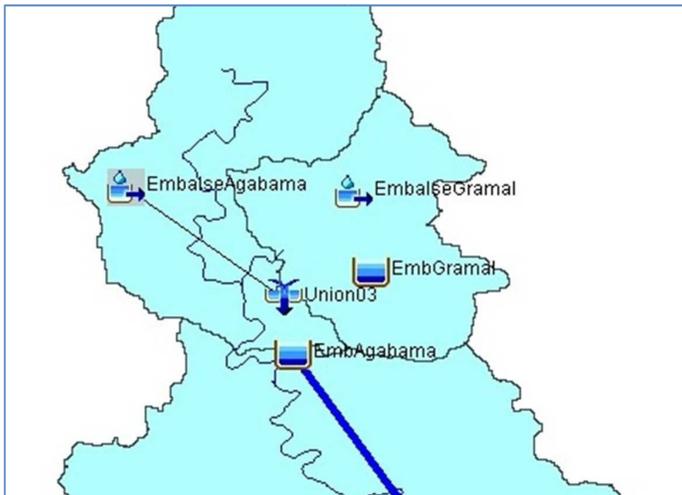


Figure 4.17. Connection between a sub-basin element and a junction element

- Repeat this process for the connections indicated between the sub-basins and the confluences, as well as for those that may take place with other elements such as "Reservoir", "Sink", "Diversion".
- The connection process when "Reach" elements are involved is the same. The water element is connected first with the river reach and then with the element downstream. In these cases, the system does not incorporate the black line because the river section becomes the connection itself.
- To remove a mistaken connection, right click on the element upstream and "Delete Connection" will be selected in the contextual menu shown.

It is important that all the elements are properly connected to avoid, in this way, errors in the simulation of the model. Checking connections from the Desktop in cases where very dense basins are modeled, is quite cumbersome. For these cases it is recommended to verify the connection between elements from the "Component Editor" where it is shown, from the selected element, where it is connected downstream. In Figure 4.18, it can be verified, for example, that the element "EmbalseAgabama" (sub-basin) is connected to the junction "Union03".

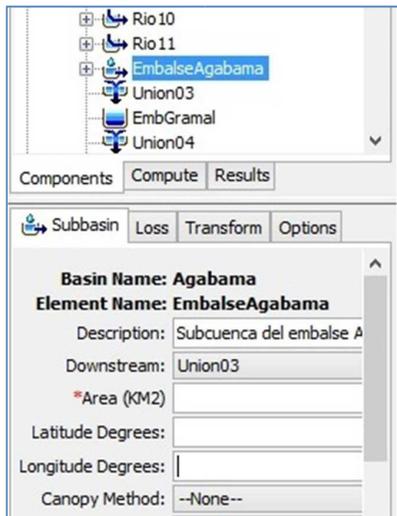


Figure 4.18. Sub-basin element shown in the Components Editor.

Finally, the hydrological elements must be connected as shown in the Figure 4.19.

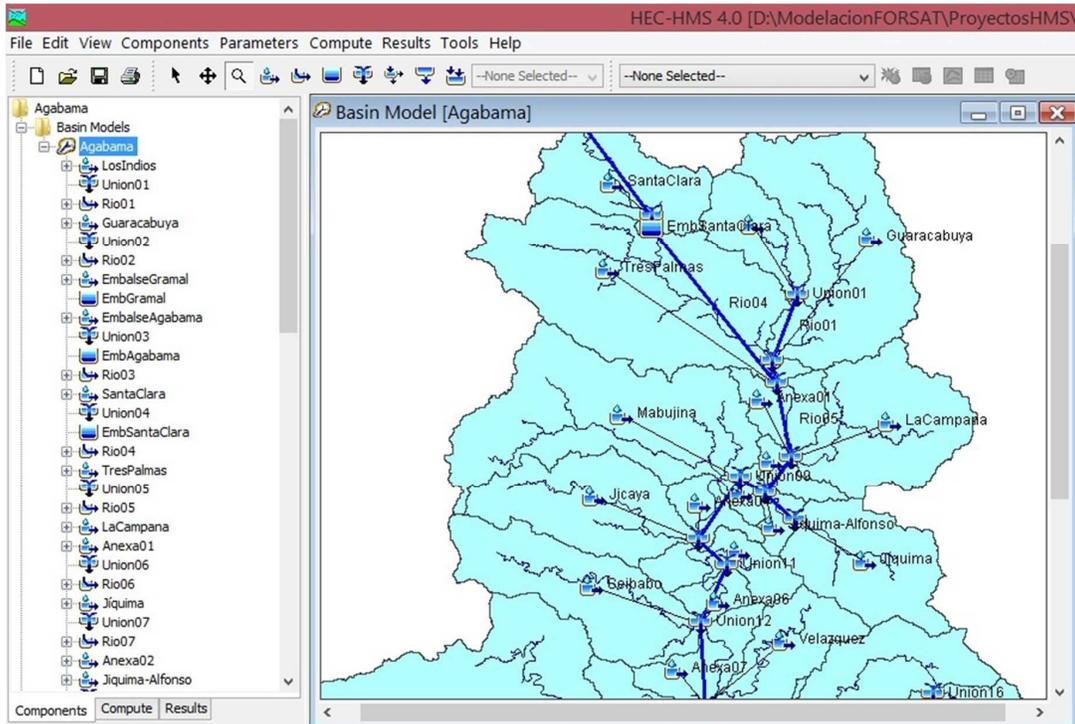


Figure 4.19. View of the Explorer and the Desktop after the connections have been made.

With the process carried out so far, it is possible to introduce the necessary data for the simulation in river basins and river reaches:

Data of the sub-basins	Data of the river reaches
<ul style="list-style-type: none"> • Name • Area (km²) • SCS curve number <ul style="list-style-type: none"> ○ Initial extraction (mm) ○ Curve number ○ Waterproof surface (%) • Conversion of the SCS <ul style="list-style-type: none"> ○ Delay Time (min) 	<ul style="list-style-type: none"> • Connections <ul style="list-style-type: none"> ○ Name ○ K of Muskingum (hr) ○ X of Muskingum ○ Subconnections • Junctions <ul style="list-style-type: none"> ○ Name ○ Type

It is recommended to establish the calculation methods that HEC-HMS will use in its simulations by default. For it:

- Execute the command "Program Settings" in the "Tools" menu. The "Program Settings" form will open.
- Click on the "Defaults" tab.
- Select each method until you get the configuration presented in Figure 4.20.

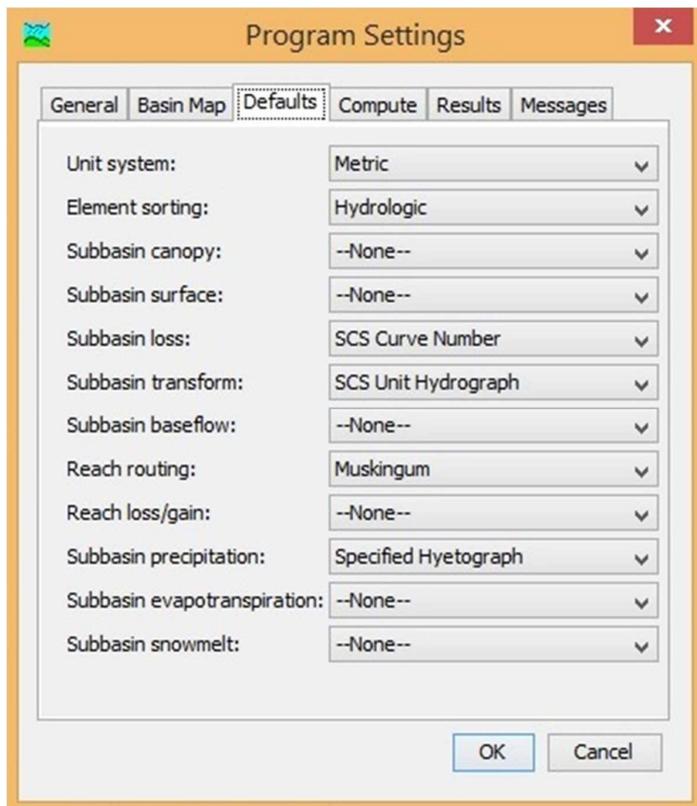


Figure 4.20. Default calculation methods in the "Program Settings" form.

4.2 Creation of the meteorologic model

Creating the meteorological model means associating each rain data source (rain gauges or rain grids) with the corresponding sub-basin, that is, giving the application the information of the measurement element (precipitation, flow, level, etc.) that is going to be located in each sub-basin. You can create as many meteorological models as you want to study (eg one for each return period), such as types of data sources (conventional rain gauges, automatic rain gauges, estimated rain grids, predicted rainfall grids, etc.). For its creation, we proceed as follows:

- Execute the "Meteorologic Model Manager" command in the "Componets" menu. The "Meteorologic Model Manager" window will appear.
- For each weather model you wish to create, click on "New" to open the "Create A New Meteorologic Model" window. See figure 4.21.

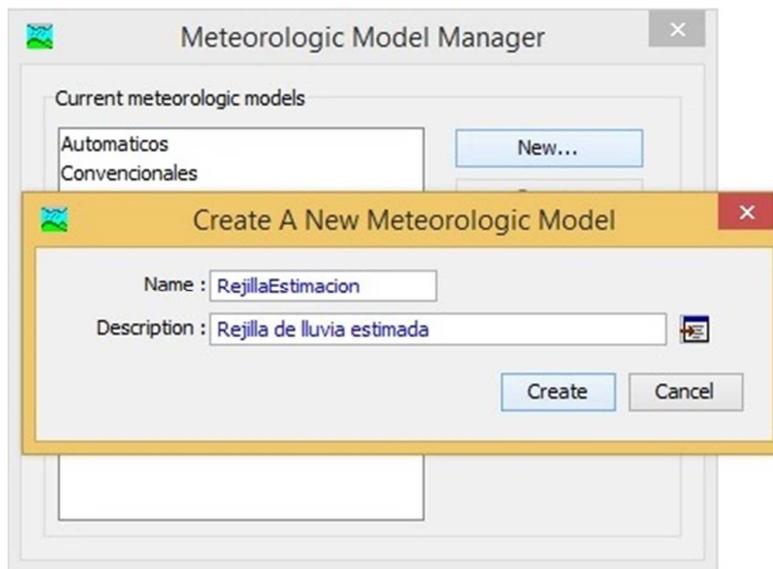


Fig. 4.21 Meteorologic Model Manager and window "Create A New Meteorologic Model".

- In the "Name" box, the name of the model that is created will be written. Eg "Grid 1".
- In the "Description" box, a text will be written describing the meteorological model that is created. This description is optional.
- Click on the "Create" button to return to the "Meteorologic Model Manager" window.
- Repeat the process from the second step for each meteorological model to be created. In the example, four models are created: two ("Automatic" and "Conventional") for spot surface measurements according to automatic rain gauges or conventional rain gauges; and two ("Estimation Grid" and "Grid Prediction") for the preceding distributed data of the quantitative estimation and quantitative rainfall prediction.
- Once all the weather models have been created, close this window by clicking on the button in the upper right corner.
- Automatically, in the Explorer panel of the basin, the folder "Meteorologic Models" will appear and within it, as many icons with the names of the meteorological models as they have been created. See figure 4.22.

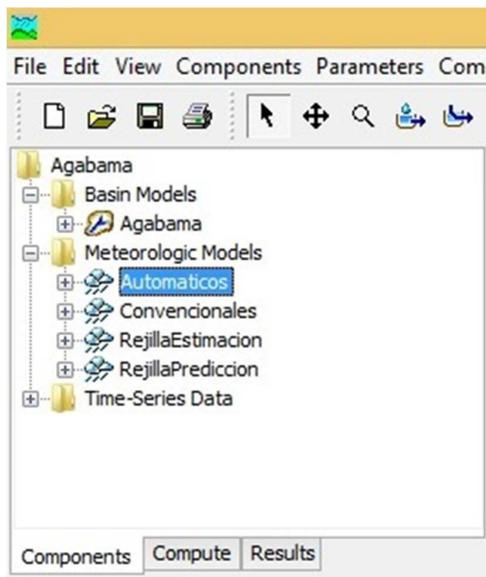


Figure 4.22 Basin explorer showing the meteorological models created

- Click on one of the weather models to configure it. Several tabs will appear in the component editor window. In the case of models for point measurements ("Automatic" and "Conventional"), specify in the "Meteorology Model" tab as shown below:

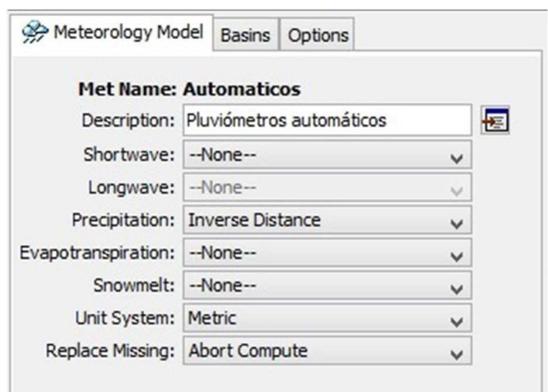


Figure 4.23 Editor of the meteorological model components.

In the "Precipitation" field, "Inverse Distance" can be read, meaning that the system will generalize the rain data observed in the rain gauges by the weighting method based on the inverse of the distance square (from each rain gauge to the centroid of the basin). When this method is selected, the system will allow the user to define whether the calculation is made for the entire basin or for each sub-basin, and the rain gauges that participate in the calculation. This method was originally designed for real-time prediction because it assimilates dynamic problems in data since it can use an unlimited number of rain gauges to proceed automatically when missing data is found, which is usual in this type of process (especially if of intense rains and hurricanes).

No evapotranspiration ("Evapotranspiration") or de-icing ("Snowmelt") data is available, so "None" is selected for both cases. The system of units with which you work is the metric, then, select "Metric" as well.

- In the "Basins" tab, it will be defined whether the averages are calculated for the entire basin or for each sub-basin. To do this, the "Yes" option will be selected in the "Include Subbasins" field as shown in Figure 4.24.

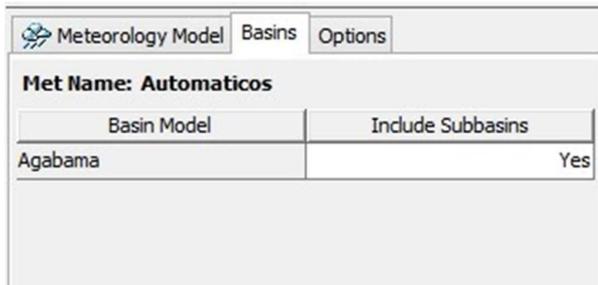


Figure 4.24. "Basins" tab of the component editor for the weather model.

- In the "Options" tab, the search radius ("Search (KM)") will be defined for the calculation. For each sub-basin or for the basin, as appropriate, the rainfall average will be calculated only with the rain gauges whose distance to the centroid of the basin is less than the established radius. If this parameter is left blank, all rain gauges will be used.
- To parameterize the rain gauges and the sub-basins in the meteorological model, the same must be displayed by clicking on the addition sign on the left and then on the "Precipitation Gages" label. See figure 4.25.

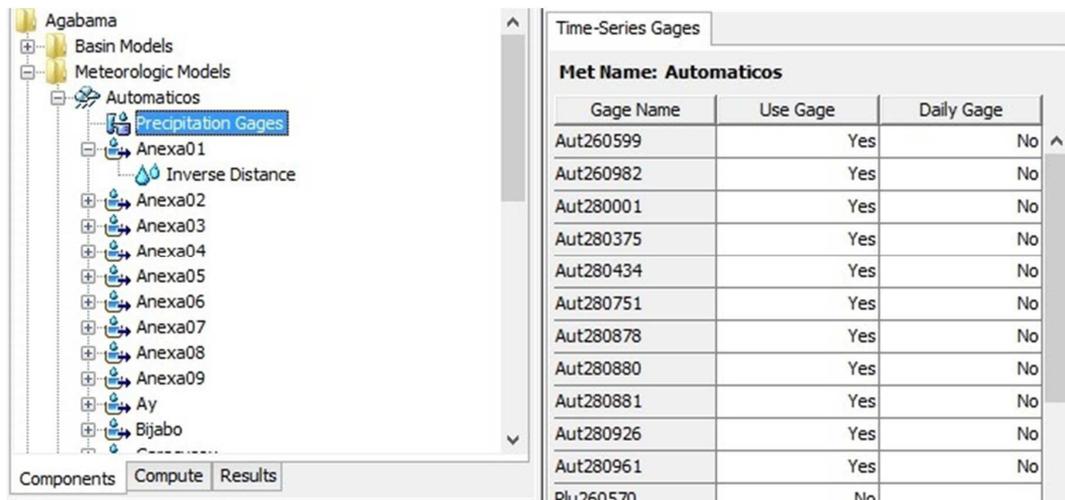


Figure 4.25. Selection of rain gauges for the meteorological model.

- In the lower panel of the component editor, a list of all the rain gauges available for the model will be displayed, which have been previously defined in the component destined for the time series ("Time-Series Data", see section 4.3). In each of the rain gauges to be used, the "Use Gage" column

will be changed to "Yes" and in those that will only report accumulated rainfall for 24 hours, the column "Daily Gage" will also change to "Yes".

- The precipitation components of each sub-basin will be displayed by clicking on the addition sign to the left. Then click on the "Inverse Distance" label. A lower panel will appear automatically for the parameterization of the sub-basin, as shown in figure 4.26.

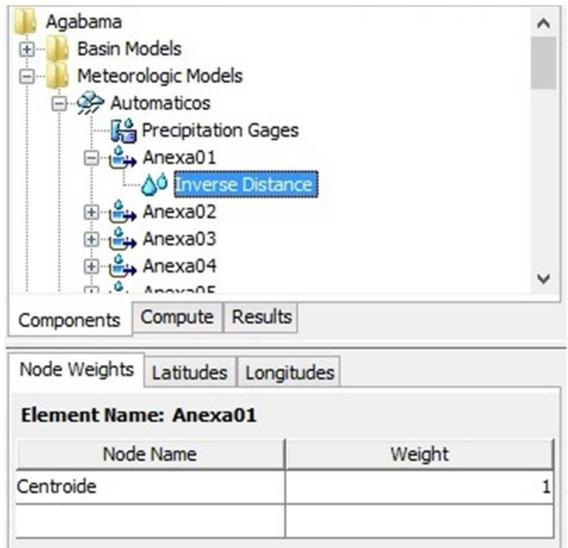


Figure 4.26. Parameterization of the precipitation component "Inverse Distance" of "Anexa01" sub-basin.

- In the "Node Weights" tab, a series of nodes or points that will represent the sub-basin and the weight that each node has in the calculation of rainfall will be defined. At least one node must be defined and the sum of the weights of all the nodes must be 1. In the tabs "Latitudes" and "Longitudes" the geographic coordinates of each node will be introduced in the format previously defined in the option " Program Settings ... "of the" Tools "menu.
- In the case of precipitation models distributed by grid cells, the parameterization process is much simpler. You only need to unfold the model components by clicking on the addition sign to your left and then clicking on the "Gridded Precipitation" label (see figure 4.27). Automatically a lower panel will be displayed where the grid to be used will be selected and the time difference between the data of the precipitation grid (UTC) and the local time will be declared. The grids to be selected must be previously defined in the component destined for this purpose ("Grid Data", see section 4.3).

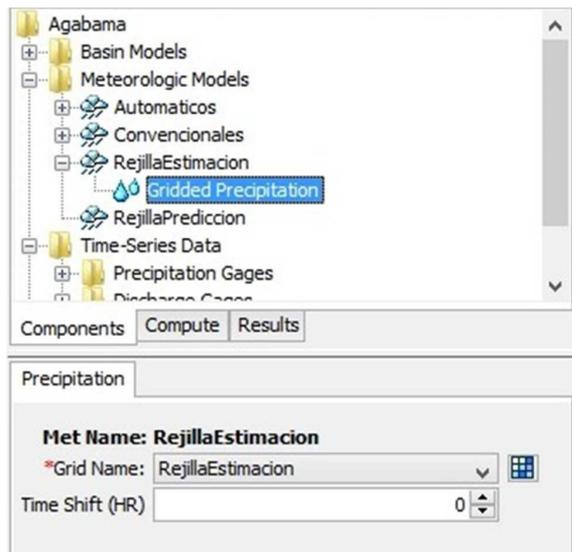


Figure 4.27. Parameterization of the meteorological model for rainfall data distributed by grid cells.

4.3 Introduction of time series, precipitation data grids and data pairs

The DSS file of the project stores all-time series and data pairs that are entered manually by the user. This data is automatically stored as a record in the file. When the data is edited, the record is updated automatically. The record is also automatically updated if the sensor to which the time series belongs to or if the function of the data pairs is renamed, copied or deleted. You can also access the registry through other applications that can read and write in the DSS format.

Any chronological series or data pairs that are not entered manually must be stored in an external DSS file. Grid data cannot be entered manually and therefore must be stored in external DSS files. The external DSS files are all those DSS files used in the project except for the DSS of the project that was created to store the model data and the results of the calculations. External files can store time series data with regular and irregular intervals, data pairs and grid data. They can be located anywhere on the computer or in the network and can be shared with other programs.

In the present modeling system, only external DSS files will be used for the storage of the precipitation, flow and level time series, while the project DSS file will be used for the storage of the data pairs (Level vs. Volume curves, Level vs Flow, cross sections, etc.).

4.3.1. Time series

Although only the process for the introduction of observed flow data will be explained in this section, in the case of rainfall data series or levels in surface streams, practically the same process is performed.

To enter observed flow data, which will be used for the calibration and validation of the model, proceed as follows:

- Click on the option "Time-Series Data Manager" in the "Components" menu, opening the window with the same name.

- In the "Time-Series Data Manager" window, open the "Data Type" combo box and select "Discharge Gage" (see figure 4.28).

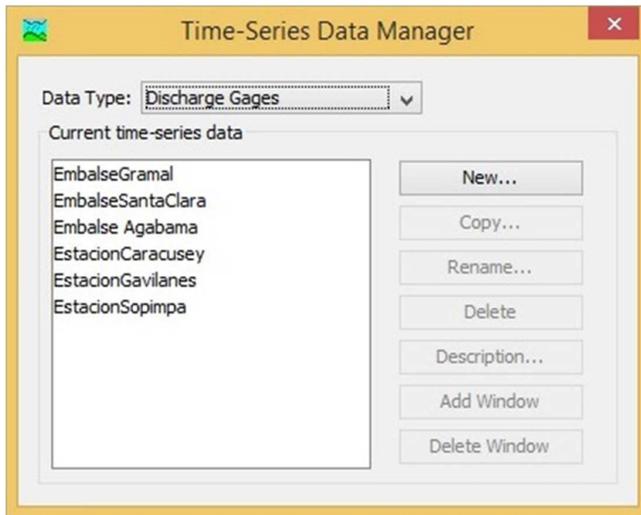


Figure 4.28. Management of gauging stations in the "Time-Series Data" window

- Clicking the "New" button will open the "Create A New Discharge Gage" window in which a name "Name" and a description "Description" will be assigned to the new gauging station that is being incorporated into the model (see figure 4.29). When finished, click on "Create".



Figure 4.29. Window "Create A New Discharge Gage"

- In case it is the first station with observed data of any hydro-meteorological variable that is created in the project, a folder "Time-Series Data" will automatically appear in the Explorer panel of the basin. Within this folder a sub-folder "Discharge Gage" containing the newly created station will also appear with an implicit time window or log for a time series (Figure 4.30.).
- Then close the window in the button in the upper right corner and repeat the process for as many stations as required. When finished, close the "Time-Series Data Manager" window by clicking the button in the upper right corner.

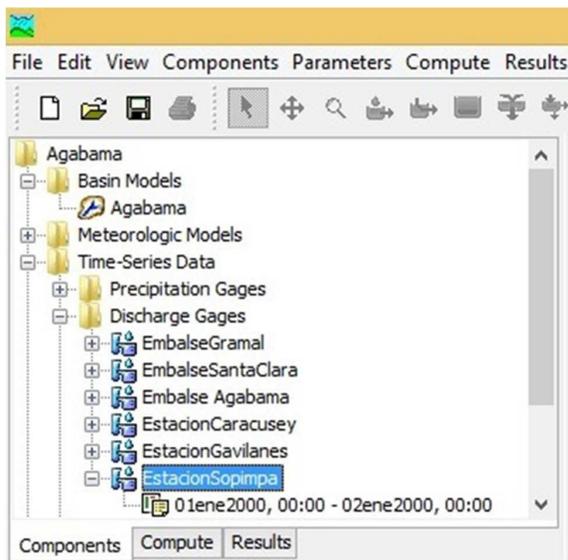


Figure 4.30. Gauging stations in the "Time-Series Data" component

- Once the stations have been created, each of them will be parameterized, selecting it in the basin explorer and specifying in the component editor window as shown below:

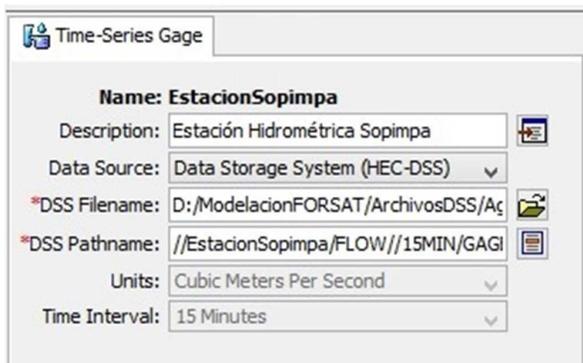


Figure 4.31. Parameterization of a gauging station.

- In the field "Data Source" select the way in which the flow data will be entered as manual input ("Manual Entry") or data storage system "Data Storage System (HEC-DSS)". For the purposes of this system, the latter option will be selected.
- In the field "DSS Filename" specify the DSS file that will contain the flow data and its location. It is recommended to store the file in the "SDS Files" folder of the working directory of the modeling system.
- In the field "DSS Pathname" specify the record inside the DSS file corresponding to the gauging station that is parameterized. When long series of data are stored, in a DSS file there may be several records for the same hydro-meteorological station which will have the same name except that they will be differentiated in the "D" part that indicates the start time of each record. You can select any of the records and the program will automatically extract the correct data depending on the selected time window.

- The "Units" and "Time Interval" fields are disabled when "Data Storage System (HEC-DSS)" is selected as the data source. In case of manual entry, their values would be selected in the respective drop-down lists.
- Once the time series have been defined and/or introduced, it is necessary to associate them with the hydrological element where they are measured or produced in reality. For this: the element in question will be clicked from the Explorer of the basin; In the component editor, click on the "Options" tab and the "Observed Flow" list will be displayed, for example, and the corresponding flow record will be selected.

4.3.2 Precipitation data grids

The process of incorporating precipitation data grids or any other hydro-meteorological variable (including descriptive data) is very similar to the introduction of external time series.

- Click on the "Grid Data Manager" option in the "Components" menu, opening the window with the same name.
- In the "Grid Data Manager" window, open the "Data Types" combo box and select "Precipitation Gridsets".
- Clicking the "New" button will open the "Create A New Precipitation Gridset" window in which a name "Name" and a description "Description" will be assigned to the new precipitation data grid that is being incorporated into the model. When finished, click on "Create".
- In case it is the first data grid of any hydro-meteorological variable that is created in the project, a "Grid Data" folder will automatically appear in the Explorer panel of the basin. A subfolder "Precipitation Gridsets" containing the newly created grid will also appear within this folder.
- Then close the window on the button in the upper right corner and repeat the process for as many grids as required. When finished, close the "Grid Data Manager" window by clicking on the button in the upper right corner.
- Once the grids have been created, each of them will be parameterized, selecting it in the basin explorer and specifying in the component editor window as shown below:

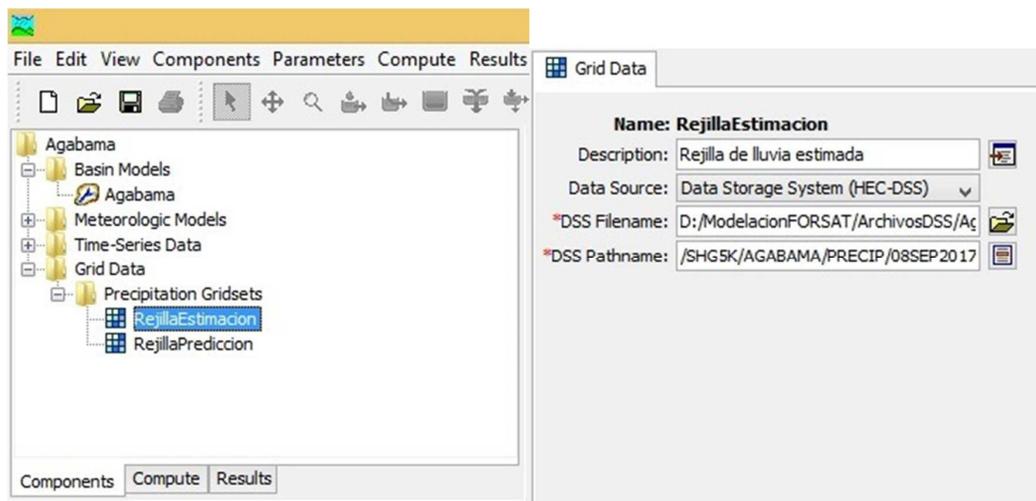


Figure 4.32. Parameterization of a grid data.

- In the field "Data Source" select the only possible way for the input of the grid data ("Data Storage System (HEC-DSS)").
- In the field "DSS Filename" specify the DSS file that will contain the rainfall data grids and their location. It is recommended to store the file in the "SDS Files" folder of the working directory of the modeling system.
- In the field "DSS Pathname" specify the record inside the DSS file corresponding to the rainfall data grid that is parameterized. The convention for storing series of data grids is different because a grid is required for each time interval. The different records in the DSS file will have the same except for the "D" and "E" parts that indicate the start and end time of each record. You can select any of the records and the program will automatically extract the correct data depending on the time window during the calculation.

4.3.3 Data pairs

For the generation of paired data of, for example, Level vs. Storage the following steps will be followed:

- Click on the "Paired Data Manager" option in the "Components" menu, opening the window with the same name.
- In the "Paired Data Manager" window, open the "Data Types" combo box and select "Elevation-Storage Functions".
- Clicking the "New" button will open the "Create A New Elevation-Storage Function" window in which a name "Name" and a description "Description" will be assigned to the table of paired data that is being incorporated in the model. When finished, click on "Create".
- In case they are the first paired data that are created in the project, a "Paired Data" folder will automatically appear in the Explorer panel of the basin. Within this folder will also appear a subfolder "Elevation-Storage Functions" containing the newly created table.
- Then close the window on the button in the upper right corner and repeat the process for as many grids as required. When finished, close the "Paired Data Manager" window by clicking on the button in the upper right corner.
- Once the tables have been created, each one of them will be parameterized, selecting it in the explorer of the basin and specifying in the window of the component editor as shown below:

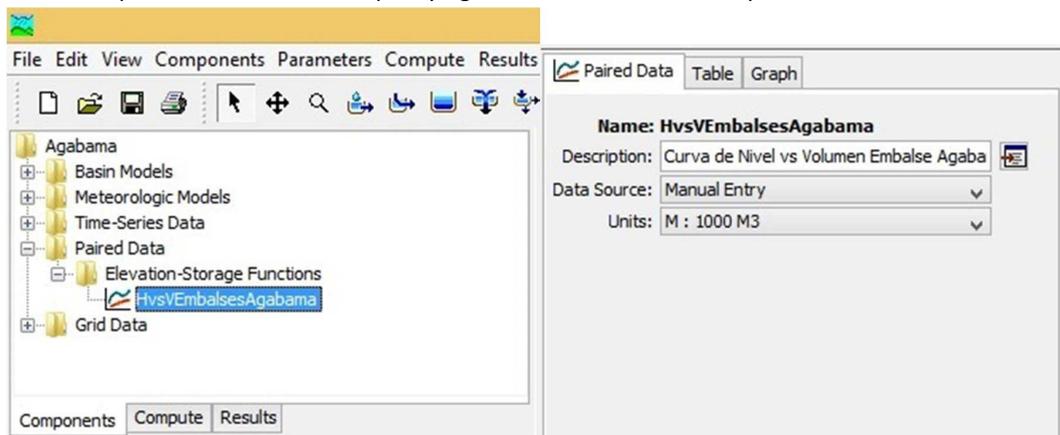


Figure 4.33. Parameterization of paired data of Level vs. Volume.

- In the field "Data Source" select "Manual Entry".
- In the field "Units" specify the units corresponding to that of the international system (M: 1000 M3).
- In the tab "Table" there will be a table to which will be introduced as many pairs of level and flow data as necessary.

4.4 Control specifications

The control specifications refer to the duration of the simulation, it is simply to indicate when to start and finish computing and the time increase ("Time interval").

- Click on the "Control Specifications Manager" option in the "Components" menu, opening the window with the same name.
- In the "Control Specifications Manager" window click on the "New" button. The "Create A New Control Specifications" window will open in which a name "Name" and a description "Description" will be assigned to the control specifications that are being incorporated into the model. When finished, click on "Create". The process can be repeated if more control specifications are required. For the prediction system it is recommended to create independent control specifications to be associated with each meteorological model in the simulation runs.
- A "Control Specifications" folder will appear in the explorer of the basin and inside this the icon of the specifications created. Clicking on this icon will show the following window in the component editor:

Figure 4.34. Editor of control specification components.

- Specifically, in this window the start and end dates and times of the simulation will be entered. Remember that in the fields with (*) red, data entry is mandatory. The simulation should last up to several hours after the rain has stopped, to allow the generated flow to reach the closure of the basin. That will depend on the time of concentration.
- Choose the increment of time or the temporary step with which the simulations will be carried out. This increment of time (Time interval) is to indicate how often between the initial and final dates of the simulation a result of the calculation must be obtained. This value should not be very large. If it is greater than 29% of the lag of the sub-basin, HEC-HMS reports an error.

4.5 Creation of simulation runs

Simulation runs are the primary method for calculating results. Each run is composed of a meteorological model, a basin model and a control specification. The results can be visualized as graphs, tables summaries and tables of chronological series both through the basin map and from the Basin Explorer. In addition to selecting the components, meteorological, basin and control, advanced elements are also included to control the run. To create a simulation run:

- Select "Create Compute" / "Simulation Run" in the "Compute" menu. The first step of the wizard for creation of simulation runs appears. Assign a name to the run and click on "Next".



Create a Simulation Run [Step 1 of 4]

A simulation run must have a name. You can give it a description after it has been created.

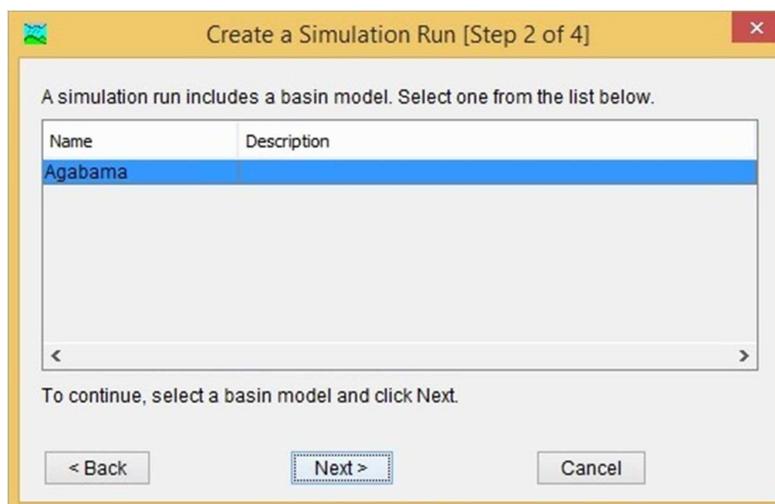
Name:

To continue, enter a name and click Next.

< Back Next > Cancel

Figure 4.35. Wizard for the creation of simulation runs (step 1).

- Select the base model that you want to simulate from the list. Click on "Next".



Create a Simulation Run [Step 2 of 4]

A simulation run includes a basin model. Select one from the list below.

Name	Description
Agabama	

To continue, select a basin model and click Next.

< Back Next > Cancel

Figure 4.36. Wizard for the creation of simulation runs (step 2).

- Select from the list the weather model with which you want to model. Click on "Next".

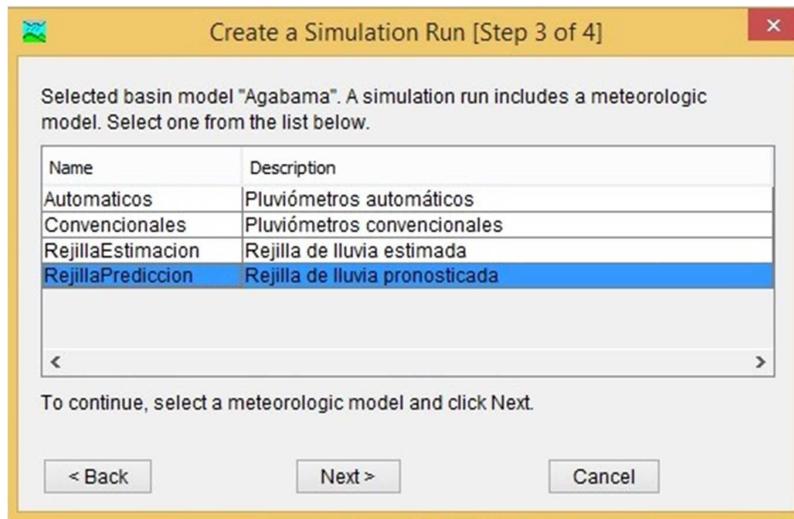


Figure 4.37. Wizard for the creation of simulation runs (step 3).

- Select the control specifications and then click on "Finish".

4.6 Calibration of the model

It is an indispensable requirement to generate an optimization, that the model of the basin is previously simulated, therefore the first action must be to run the model and verify that there are no errors. It is not possible to optimize, without a previous simulation.

- Execute the "Select Run" command in the "Compute" menu, select a simulation run as for example the one created in the previous section and execute it by clicking on the "Compute Run ..." option in the "Compute" menu. It is not necessary to create a new run.
- Execute the "Create Compute" / "Optimization Trial" option in the "Compute" menu. With this action a sequence of windows will be generated where the component elements for the optimization test are selected. This process is similar to that of the simulation.
- In the first window define the name that identifies the run p. ex. "Caracusey1".
- In the second window, select the simulation with which you want to perform the optimization test.
- In the third window select the element where the calibration will be carried out
- In the fourth and last window, select the meteorological model with which the calibration will be carried out.
- In the "Compute" tab of the Basin Explorer, select the created test ("Caracusey1") in the "Optimization trials" folder. Expand the tab and select "Objective Function" (Figure 4.38).

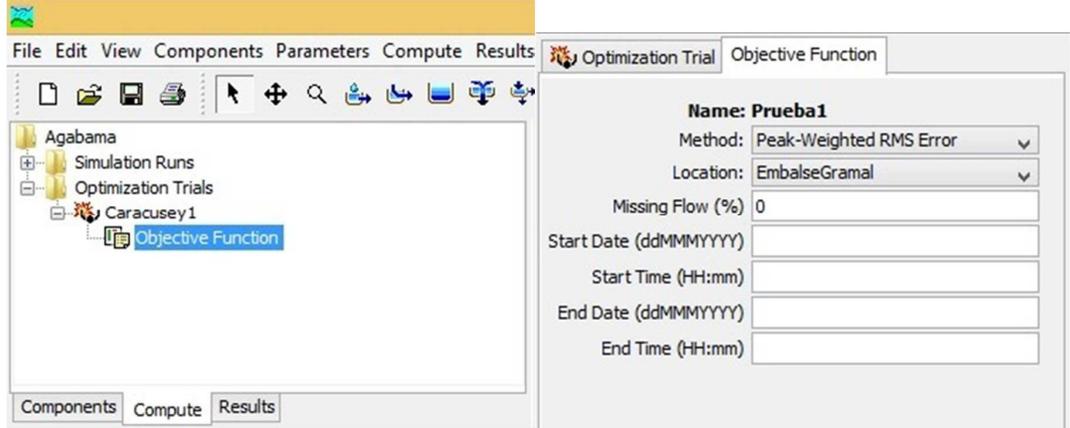


Figure 4.38. Selection and parameterization of the objective function of the optimization test.

- In the "Optimization Trial" tab of the lower panel, the tolerance values and maximum iterations that the software will use in the optimization process are predetermined by the program, these can be changed if the user wishes so.
- Click on the "Objective Function" tab to define the calibration method and the time interval to be calibrated.

Once the optimization is created, before executing it, indicate to the model the parameters that you want to calibrate for each element, in this case, the sub-basin of the Caracusey station. For it:

- In the "Compute" tab of the Basin Explorer, open the "Optimization trials" folder, right click on the "Caracusey1" test and select the "Add parameter" option. The parameter "Parameter 1" is automatically created in which the element to be calibrated will be defined, the proper parameter that is calibrated and the limits within which the iterations move.
- Clicking on the "Parameter 1" parameter in the Basin Explorer shows a window like the following:

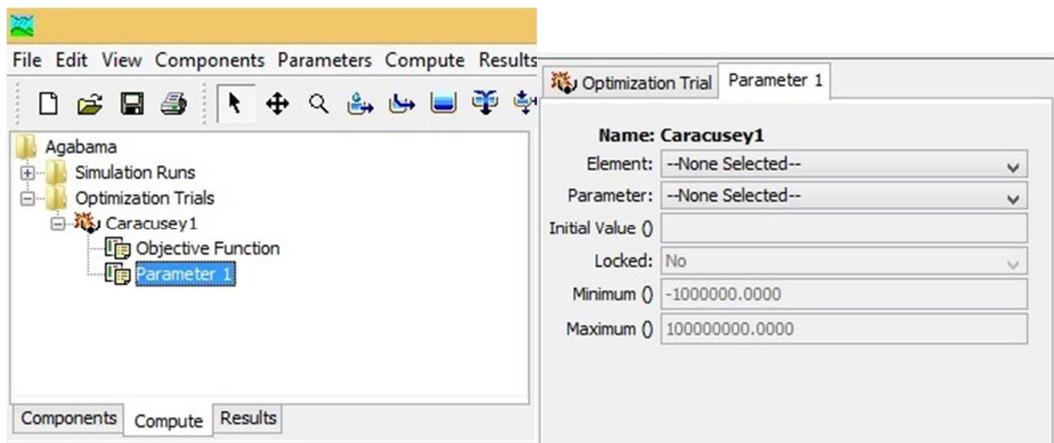


Figure 4.39. Parameters configuration of an optimization test

- In the "Element" box, it is where you select the element that represents the hydrological component where you want to perform the calibration (eg Sub-basin "Caracusey"). You can select a specific item or all of them.
- In the "Parameter" box, select the parameter you want to calibrate. In this case, the "Curve Number" is selected as parameter 1 but, if desired, you can repeat the previous process and define for the same element other parameters to calibrate, such as the "Lag time" of the "Transform" module.
- In addition, in the same window it is possible to modify the initial value of the parameter to be calibrated and the limit values that the set parameter can take.

5. Rain data assimilation

The amount of rain and the intensity with which it falls is important for the prediction of floods and for the management of agricultural and water resources. The intensity of the rain is measured in millimeters per hour and expresses how strong it is raining at the time of measurement. During a drizzle the intensity of the rain is low (less than 1.0 mm/h) but during a flood the intensity is high (50.0 mm/h or more). The surface rain gauges provide rain data but only for the exact place where they are located. However, the locations of rain gauges are limited and rainfall can vary greatly over relatively short distances. Weather radars offer better rain coverage than rain gauges but mountainous regions typically have little radar coverage and the oceans have no coverage at all. With the introduction of meteorological satellites in the 1970s, precipitation estimates remotely measured from satellites become a research topic. The satellite estimates provide important information on precipitation, especially in remote and mountainous regions.

For the simulation, automated flood prediction implemented within the framework of the FORSAT project, precipitation data will be obtained through four different routes: quantitative prediction by means of numerical forecast models; quantitative estimation; surface measurements by conventional rain gauges; and surface measurements by automatic rain gauges.

5.1. Rainfall data generated by quantitative estimation and by quantitative forecast

The Institute of Meteorology (INSMET) of the Ministry of Science, Technology and Environment has a satellite reception station since 2014, with LRIT system (English acronym for Low Rating Information Transmission), acquired by the project "Improvement" of Hydro-meteorological Early Warning System (EWS) of the most affected territories by Hurricane Sandy", with the support of the European Commission and UNDP.

The LRIT station receives data directly from the geostationary meteorological satellite GOES 13, and is accompanied by a processing software for the generation of different application products in meteorology, climatology, hydrology, etc. From measurements of cloud top temperature by infrared channel of 10.7 μm , rainfall intensity estimates are obtained in real time and permanently for the Caribbean area, with a spatial resolution of 4 kilometers and a temporary resolution of up to 15 minutes.

On the other hand, specialists of the Center of Atmosphere Physics (CFA) from INSMET have developed a forecast system of precipitation at very short term, by coupling different global and regional models of numerical time prediction, with data of stations in surface, probes, radars and meteorological satellites.

At present, the generation of the forecast is being developed through the ARPS regional models (Advanced Regional Prediction System) and MM5 (Fifth Generation Mesoscale Model) and the forecast is already concluded by the WRF (Weather Research and Forecast) model, based in the use of advanced numerical methods for solving systems of equations that describe the physical processes occurring in the atmosphere. The WRF works for three nested spatial domains with resolution of 27, 9 and 3 km; it is initialized based on the global GFS model (Global Forecast System), together with the assimilation of data from aerial surveys and surface stations; it reaches up to 72 hours of forecast time with a time resolution of up to one hour for domains 1 and 2 and up to 30 minutes for domain 3; and its operative configuration defines the update four times a day at 0000, 0600, 1200 and 1800 UTC hours.

The numerical rainfall estimation and forecasting data are obtained by the Hydrological Service offices of the National Institute of Hydraulic Resources through the use of the data and information exchange platform, also implemented within the framework of the project to strengthen the hydro-meteorological EWS affected by Hurricane Sandy. For this, you can contact them through the ftp address ftp://192.170.1.2 where they are organized as follows:

CFA

SPNOA

- XLAT_d02.ascii XLON_d02.ascii
- rain.wrfout_d02_2016-10-04_21.00.00.txt
- rain.wrfout_d02_2016-10-05_00.00.00.txt
- rain.wrfout_d02_2016-10-05_03.00.00.txt

...

...

CIMO

- LRIT Latitudes.txt

- LRIT Longitudes.txt

- Satellite rainfall

- 2016-09-09

- 2016-09-10

- 2016-09-11

- 2016-09-12

- 2016-09-13

...

...

- NORTH-IR Reprojected Caribe 1500x900x3 W Rainfall Estimation [07-15].dat

- NORTH-IR Reprojected Caribe 1500x900x3 W Rainfall Estimation [07-45].dat

- NORTH-IR Reprojected Caribe 1500x900x3 W Rainfall Estimation [08-15].dat

...
...
2016-09-14
2016-09-15

The "CFA\SPNOA" folder contains the quantitative forecast data. It presents the files XLAT_d02.ascii and XLON_d02.ascii with the data matrices of 279 columns by 144 rows with the geographical coordinates of latitude and longitude (in sexagesimal degrees with decimal notation and according to the coordinate system NAD27), respectively, of the lower left corner of each of the 6 km x 6 km cells into which the grid for domain 2 of the WRF is divided. Also included in this folder are files named according to the format "rain.wrfout_d02_aaaamm-dd_hh.nn.00.txt", containers of the same matrices of 279 columns per 144 rows with the accumulated rainfall data from the date/time of model initialization until the hh: nn UTC of the date dd/mm/yyyy indicated in the file name, with a frequency of one measurement every 3 hours.

For the data of the numerical estimates, the CIMO folder was assigned. The files "LRIT Latitudes.txt" and "LRIT Longitudes.txt" contained therein have data matrices of 1500 columns per 900 rows with the geographical coordinates of latitude and longitude (in sexagesimal degrees with decimal notation and according to the coordinate system NAD27), respectively, in the lower left corner of each of the 3 km x 3 km cells into which the grid for the Caribbean area is divided.

On the other hand, the files named "NORTH-IR Reprojected Caribbean 1500x900x3 W Rainfall Estimation [hh-mm].dat" have equal matrixes of 1500 columns per 900 rows with rainfall intensity data measured at hh-mm UTC for the day indicated in the name of the folder containing them, with a frequency of two to four measurements per hour. For example, the file "NORTH-IR Reprojected Caribbean 1500x900x3 W Rainfall Estimation [07-45].dat" of the scheme shown above, has the rainfall intensity values measured at 07:45 UTC on September 13, 2016, that is, at 02:45 normal time of Cuba from September 13, 2016.

Each of the folders named "yyyy-mm-dd", in which the rainfall intensity measurements are stored every 30 minutes, will be available only for seven days. In other words, the folder "2016-09-12", with the rain intensity data measured every 30 minutes on September 12, 2016, will remain on the platform until the beginning of September 19, 2016, time at which the "2016-09-19" folder will be available.

The INRH Hydrological Service designed and developed two applications for the assimilation of estimated and predicted precipitation matrices. These applications allow you to import batches of matrix files, store them in the form of chronological series indexed by cell, with temporary resolutions of one hour (numerical estimate) and three hours (numerical forecast); and to make pluvial generalizations for time windows defined by the user and for different spatial divisions (provinces, municipalities, fluvial basins, dam basins and underground basins). In addition, they allow to generate files with ASCII grid format of ArcInfo which are importable by the HEC data storage system (HEC-DSS) for the creation and entry of the HEC-HMS meteorological model.

5.1.1 Operation of precipitation matrix assimilation applications

Both systems of assimilation of precipitation matrices are organized in a similar way for easy use. They are located in the subdirectories "EstimacionNumLluvia" and "PronosticoNumLluvia" in the main

directory of the system ("ModelacionFORSAT") and they are composed of a set of five folders for storing data and information of different nature and origin:

- **BDatosAlfanumerica**, contains the alphanumeric database in .accdb format of Microsoft - Access, with which the process of capture, storage, processing and emission of data and precipitation information is performed.
- **BDatosEspacial**, contains the spatial database in support ESRI-ArcGIS version 10.2.2
- **Manejo** contains map documents in support (.mxd) ESRI-ArcGIS version 10.2.2 with predesigned spatial outputs as well as predesigned outputs (.txt) from the alphanumeric database, which feed the aforementioned map documents. It is also used for the temporary or definitive storage of other alphanumeric, graphic and spatial exits.
- **MatricesLRIT / MatricesWRF**, for the temporary or definitive storage of the LRIT or WRF matrices (depending on the case) downloaded from the INSMET FTP mailbox.
- **RejillasASCII** for the storage of ArcInfo ASCII grid outputs.

5.1.1.a. Data entry

According to the corresponding update frequency (it is recommended once a day for the predicted rain and every hour for the estimated rain) the application "LluviaSestimada.accdb" or "LluviaPronosticada.accdb" (depending on the system in question), located in the folder "BDatosAlfanumerica" is run. Upon opening, the application will display its main form which is basically composed of the tabs: "Data entry", for the import of rain matrices; "Predesigned queries", for the parameterization and selection/execution of basic queries configured and implemented by the developers, as well as the export of matrices with ArcInfo ASCII format for later introduction in HEC-DSS; and "Predesigned reports" for the parameterization and selection/execution of reports based on some of the predesigned queries.

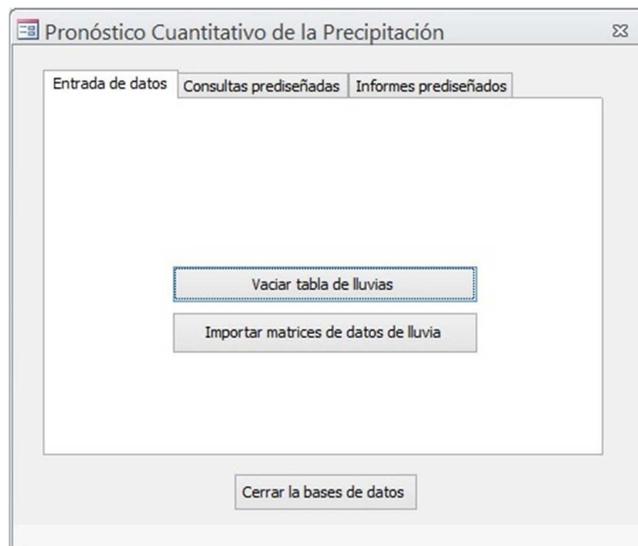


Figure 5.1. Main form of the application for the management of quantitative rainfall forecast data. "Data entry" tab.

In the data entry tab, you will find the "Empty rain table" button, which, as its name suggests, allows you to empty the database table in which rain data are stored, in case the records that it contains are no longer useful for the user (among other reasons because they belong to a rainy event unrelated to a new event to be evaluated), thus reducing the size of the database and the duration of the processing.

An operation for emptying rainfall data is justified because the function of these applications, more than storage, is the assimilation and processing of rain matrices supplied by the Institute of Meteorology for its use as an eventual input of hydrological and hydraulic simulation systems. For storage, it is recommended to keep the original matrices in the PC (MatricesLRIT/MatricesWRF folder) and/or an external storage device that can be imported again whenever required.

The specific import of the precipitation matrices is carried out using the "Import rain data matrices" command button incorporated into this tab. Pressing this button displays the dialog box for opening/writing standard files of Microsoft Office applications, to facilitate access to selection of the matrix files that will be imported (preferably stored in the MatricesLRIT/MatricesWRF folder). Multiple files (located in the same folder) can be selected at one time.

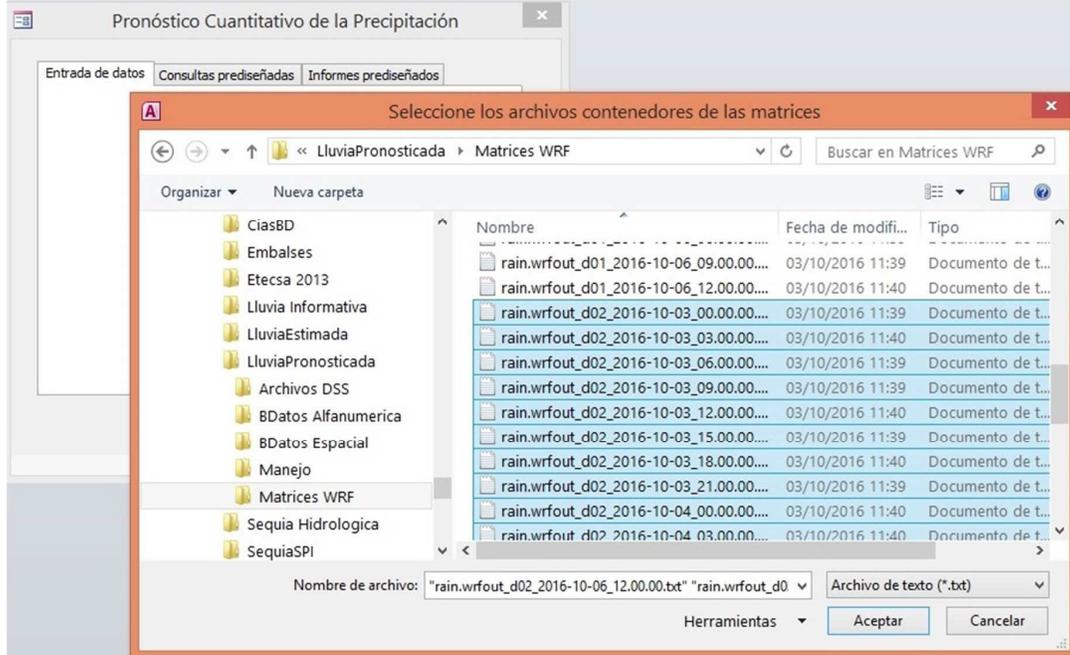


Figure 5.2. Dialog box for location, selection and import of rain matrix files.

In order to save space and processing time as well as to facilitate the synchronization between processes and applications, the rainfall intensity data imported by the numerical estimation application are converted into and stored as cumulative schedules; while the progressive accumulations imported by the numerical forecast application are converted into accumulated for three hour intervals.

5.1.1.b. Predesigned queries

The "Predesigned Queries" tab provides a list of the set of basic queries that were conceived and implemented by the developers of the application, which can be accessed once the estimated/predicted rainfall matrices have been entered. In general, they are queries to obtain chronological series and cumulative rainfall for different types of zoning (cells, municipalities, provinces, reservoir basins, river basins, underground basins) and for a time interval defined by the user. The query "Relation of reports" useful to display the list of entered data matrices that coincide with the time interval defined by the user is added to these.

To configure the time interval whose data you want to evaluate, press the "Define period to consult" button located in the upper left corner of the record, after which the form "Criteria for predesigned queries" will be displayed (Figure 5.3).

In this form there are two pairs of text boxes in which the user will write the dates (in dd/mm/yyyy format) and time (in hh: mm UTC format) at the beginning and end of the period to be evaluated. For the correct operation of the application, especially in relation to the operations using dates and times, it is required that the regional configuration of the PC operating system is in Spanish (Mexico) format.

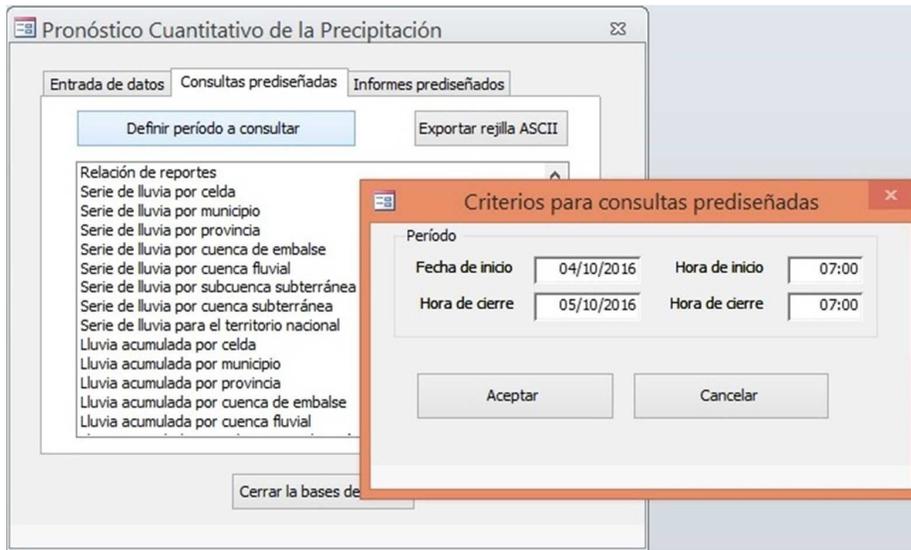


Figure 5.3. View of the "Predesigned Queries" tab and the form for the definition of the analysis interval.

After entering this data, pressing the "Accept" button will close the form, all queries will be updated and you can, by double clicking the lines of the queries list, display the desired information. Figure 5.4 shows the query "Accumulated rainfall by provinces" selected in the list and its results in the attached table.

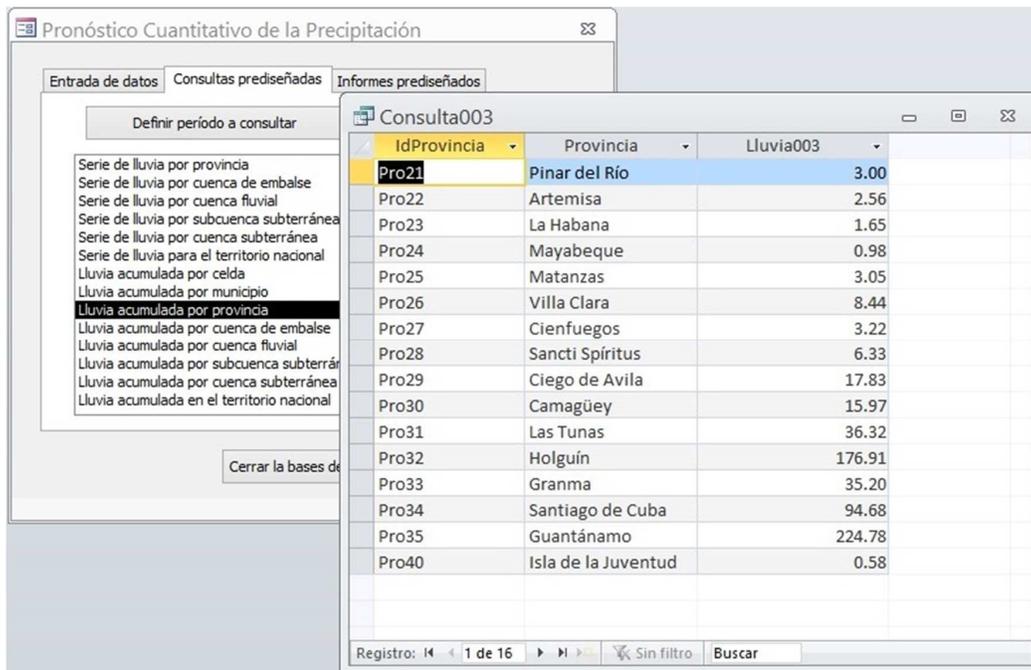


Figure 5.4. Output of a query "Rain accumulated by provinces"

The rainfall accumulation queries, besides being presented in tabulated form, can be visualized in the form of maps. For this, once the table is presented:

- "Text file" is selected in the "Export" section of the "External data" ribbon of the MS-Access (Figure 5.5).
- In the text file export wizard that will appear below, press the "Browse" button, to display the standard "Save file" dialog box.
- Surf to the folder "...Management" and select the text file whose name corresponds to the information that is being exported (ex.: "AccumulatedRainProvinces.txt"). **Special care must be paid to this step because both the names and the formats of each one of the rain accumulation queries are linked to the configurations of the corresponding map documents (.mxd) of ArcGIS.**
- Press the "Accept" button
- The warning that the file already exists and the Do you want to replace it? question will display Press "Yes".
- Go through the other sections of the wizard by pressing "Next" and selecting the options: "Delimited-characters such as tabulation ...", in the second section; "Comma", "Include field names in the first row" and "Text qualifier:" " in the third section (Figure 5.6 and Figure 5.7).
- Once the text file is exported, execute it by double-clicking or opening it from ArcGIS, the corresponding map document, located in the "Management" folder itself. A map similar to the one in Figure 5.8 will be automatically displayed in ArcGIS.

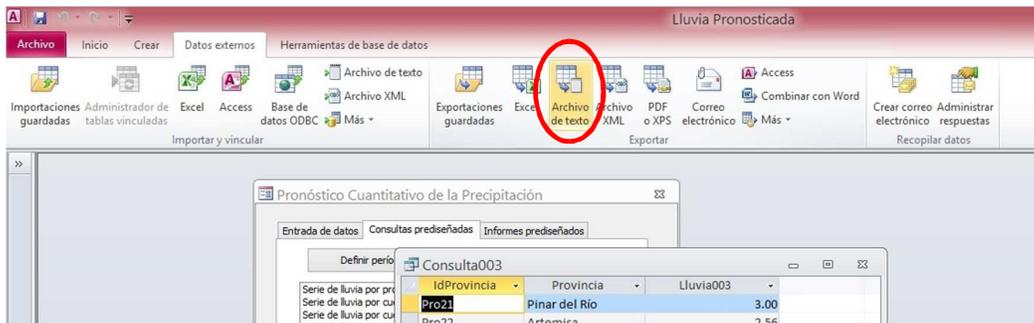


Figure 5.5 Wizard for exporting text files in "External data" ribbon

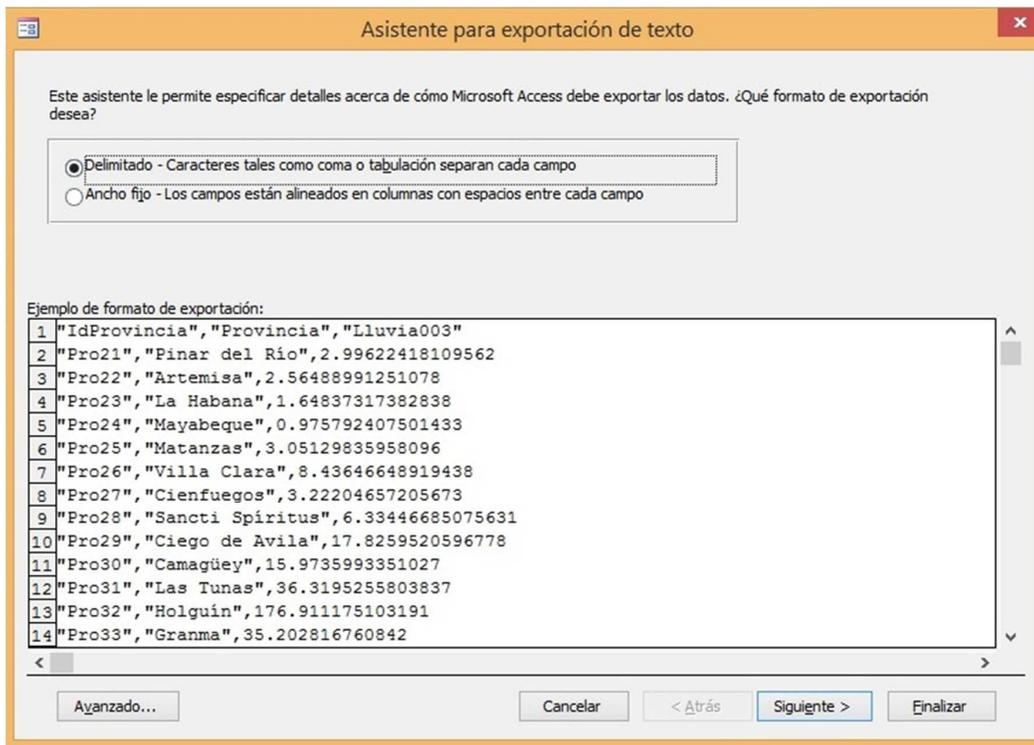


Figure 5.6. Wizard for exporting text files, second section.

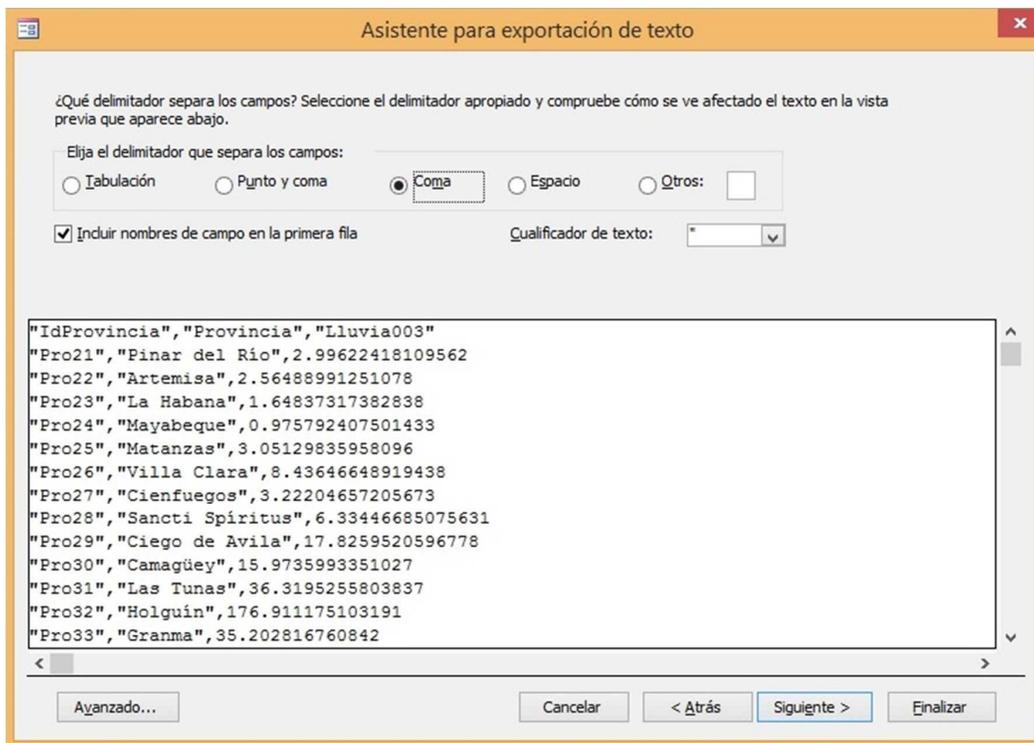


Figure 5.7. Wizard for exporting text files, third section.

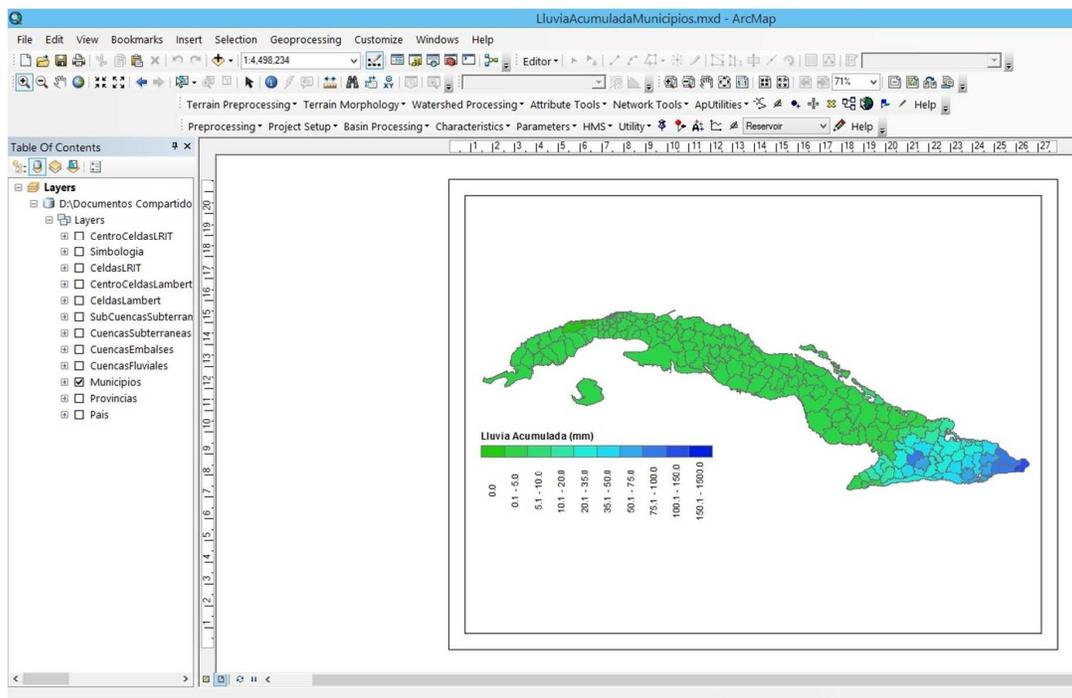


Figure 5.8. Rain accumulated map by municipalities.

5.1.1.c. Exporting ArcInfo ASCII grid

In the upper right corner of the "Predesigned Queries" tab, the "Export ASCII grid" button has been placed. This is the tool for exporting files with ASCII grid format (.asc) for ArcInfo, with rain accumulations for regular intervals of one hour or three hours (depending on whether it is estimated rainfall or predicted rainfall) included in the query period defined by the user, files that will be later assimilated by HEC-DSS. The .asc files will be generated only for independent delimitations of river basins, that is, one for each basin.

Once the query period has been defined, pressing the "Export ASCII grid" button will display the form for the selection of one or more basins for which the .asc files will be exported (Figure 5.9). The list of river basins defined in the Decimal Classification of Rivers and Waters of Cuba will appear on the form, each with a selection box on its right which will be checked or unchecked at the user's discretion. To speed up the process, two buttons have been enabled to select/deselect all basins.

After selection of just the basins for which you want to export the files and pressing the "Accept" button, a dialog box will be displayed for the selection of the folder in which the files will be stored (recommended ...\\ASCII grids). When accepting, the files with the formatted name of the form "CueCC.CCC aaaammdd hhnn - aaaammdd hhmnn.asc" will be created sequentially, being CC.CCC the decimal code of the basin and yyymmdd hhnn the date-time (UTC) of start and end of each regular interval of one or three hours.

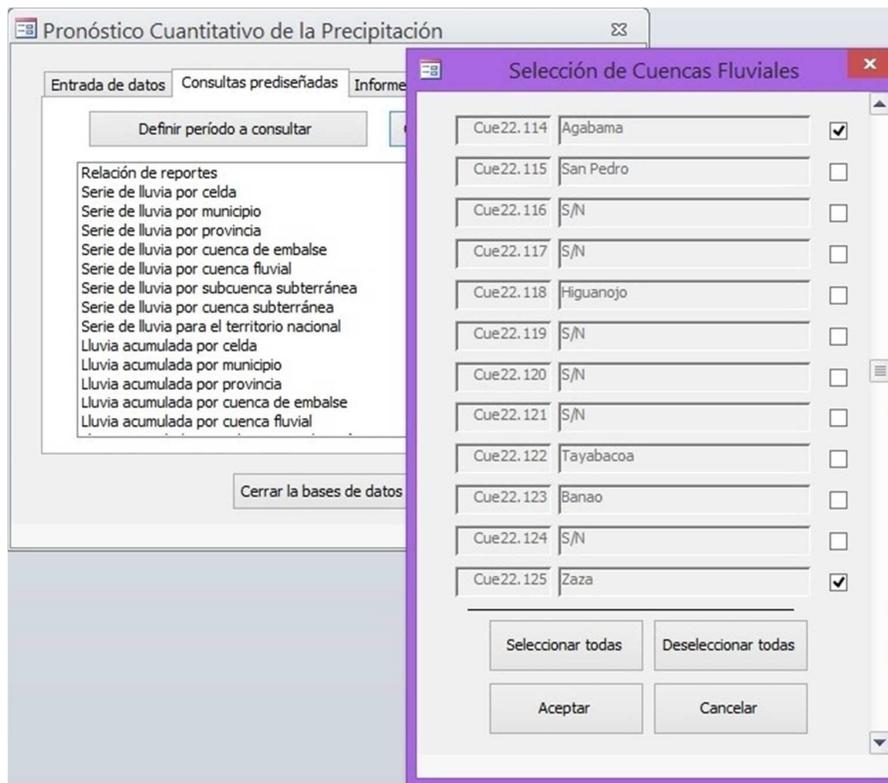


Figure 5.9. Form for the selection of river basins during the export of .asc files

The .asc files are composed of a six-line header followed by an group of sorted values as an image of the grid. The parameters of the six lines of the header are presented below:

- NCOLS; number of grid columns; whole.
- NROWS; number of grid rows; whole.
- XLLCORNER; X coordinate in meters (Lambert North projection for Cuba) from the lower left corner; actual.
- YLLCORNER; Y coordinate in meters (Lambert North projection for Cuba) from the lower left corner; actual.
- CELLSIZE; cell size in meters; actual.
- NODATA_VALUE; missing data indicator; implied -9999.

Each grid contained in a .asc file will be a portion of a general grid for all Cuba with 5 km x 5 km cells arranged in 76 rows and 277 columns, whose lower left corner is located at coordinates North 3000.00 m; East 88500.00 m, according to the Lambert North projection for Cuba. The assumed spatial resolution is conditioned by the resolutions accepted by HEC (GRIDUtil, DSSVue, .dss) for the grids of the "Standard Hydrologic Grid" system.

5.1.1.d. Predesigned reports

The predesigned reports are nothing more than complements or improvements from the visual point of view of the predesigned outputs, in such a way that their understanding, distribution and printing

are facilitated. Up to now, there are outputs for rain accumulations by municipality, province, reservoir basin, river basin, basin and underground sub-basin.

For the presentation of predesigned reports, we proceed in a similar way to the predesigned queries but in the tab provided for that purpose ("Predesigned reports") in the main form. It has the "Define period to inform" button that performs exactly the same function as the "Define period to query" button (both buttons can be used instinctively). Once defined the period, the desired report is selected and opened by double clicking on the list of reports.

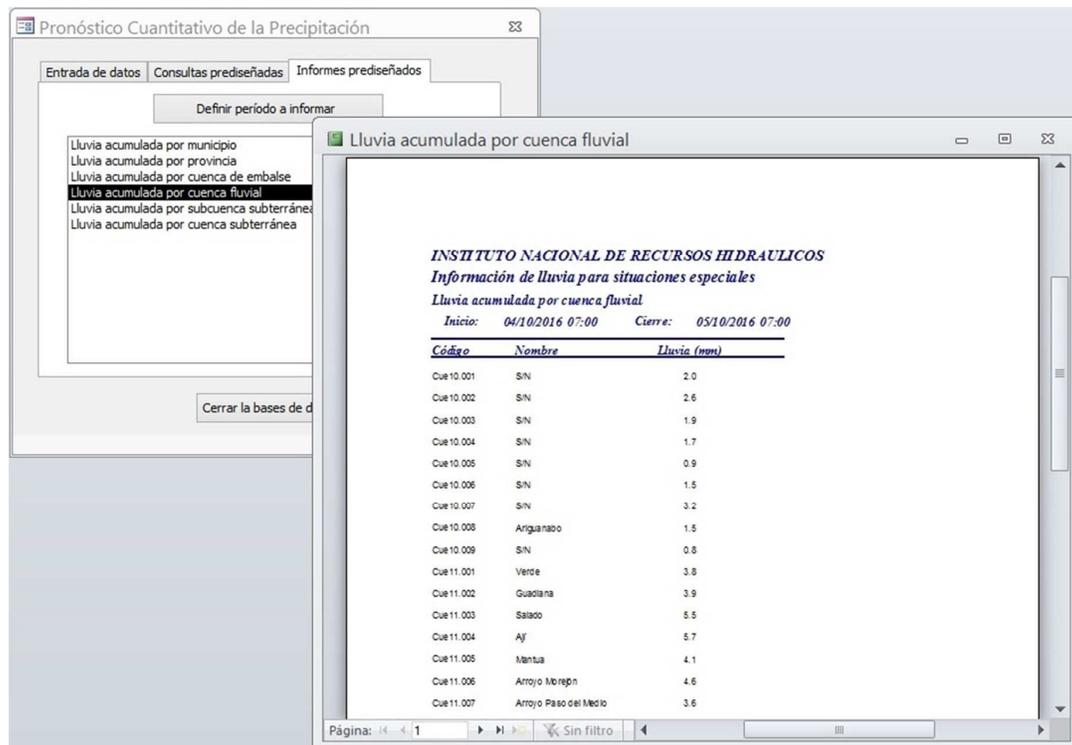


Figure 5.10. View of the "Predesigned reports" tab and example of an accumulated rainfall report by river basin.

5.1.2. Importing rain grids in HEC-DSS

Time chronological series of spatial information have become increasingly important for providing hydrological applications, but they pose a challenge in terms of standardized storage and indexing. The data structure with grid or grid format in HEC-DSS provides a very efficient storage of and access to data sets of the same parameter, expressed in the same units, which cover the same cells of the grid (in terms of spatial extension or definition of coordinates) through a recurrent constant time interval.

Each HEC-DSS file is a database-independent file and can be easily exchanged among users and applications that recognize HEC-DSS, without platform conversions or external dependencies such as schema definitions. HEC-DSS is mainly designed to facilitate the use of time series of data such as

hourly water levels or monthly average expenses. The main tool for data management of HEC-DSS is the HEC-DSSVue application (Visual Utility Engine of the Data Storage System of the Hydrological Engineering Center).

HEC-GridUtil is the program developed to facilitate the visualization, processing and basic analysis of data sets with grid format in HEC-DSS, although many other tasks of ordinary management, such as the copying of data between HEC-DSS files or renaming records can be made using HEC-DSSVue. Grid sequences typically approximate the variation in space of a measurement that varies for fixed time intervals at fixed locations. The predominant types of grid data in DSS are time series with regular intervals of hydrological variables distributed over a fixed geographical area such as radar estimated precipitation, or average daily temperatures over a basin. Storage in HE-DSS first facilitates the use of data by the HEC-HMS model (Hydrological Modeling System of the Hydrological Engineering Center), but also offers advantages in terms of access speed, data organization, file size, portability, etc.

HEC-DSS stores the grids data as records in a database to which it references according to descriptive identifiers or "names-routes". A pathname consists of up to 391 characters and, by convention, is separated into six parts of up to 64 characters each (delimited by slashes "/"), labeled "A" through "F" in the following way:

1. Part A refers to the coordinate system of the grid. The two main spatial reference definitions are known as the Hydrological Rain Analysis Project (HRAP) and the Standard Hydrological Grid (SHG).
2. Part B describes the area covered by gridded data such as a basin, a region, etc.
3. Part C refers to the parameter represented by the grid such as precipitation (PRECIP) or temperature (TEMP)
4. Part D contains the initial moment of the period represented by the data in the grid, such as 04OCT2016: 0700.
5. Part E contains the final time of the period represented.
6. Part F contains identification information specified by the user that distinguishes one set of grids from another.

In addition to the descriptors contained in the pathname, the HEC-DSS records include header information. The header identifies the units, data type, spatial definitions and statistics on the values of the cell data.

For the insertion of the precipitation matrices into a .dss file using the GridUtil application, it is required, in addition to the .dss file (be it new, existing) and the ASCII matrices, a project or "basin" of GridUtil. This "basin", for the purposes of the modeling system, will have as main utility the enabling of menus, options and tools in the GridUtil application.

To create a new basin, run the GridUtil application, select "Create New Watershed" from the "File" menu, the "Create New Watershed" dialog box will open (Figure 5.11). In the "Name" field, enter the name of the new GridUtil project. A subdirectory with this name will be created to store the files for the basin, so the use of characters with special meaning for the operating system should be avoided. You can enter a description of the basin or important characteristics in the "Description" field.



Figure 5.11. "Create New Watershed" dialog box

Click on "Select Location" to select the folder in which the GridUtil project folder will be stored (the "DSS Files" folder of the modeling system working directory is recommended), the "Select Watershed Folder" browser will open. (Figure 5.12). Surf to the container folder. Alternatively, you can paste the full path in the "File Name" field. Click on "Open".

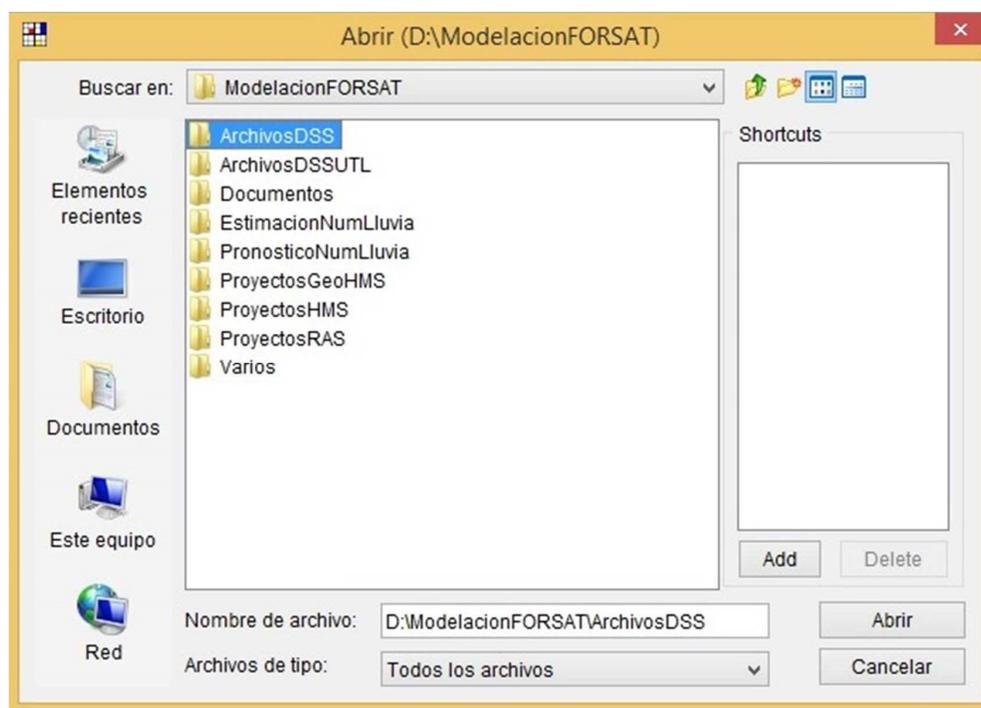


Figure 5.12. Browser "Select Watershed Folder"

Then, select the system of units (SI) and the time zone of the project (International Time Zones, GMT -5: 00 Cuba). Click on "OK". A summary dialog box will appear showing the name, description, system of units and time zone of the new basin. If everything is fine, click on "OK". A new project folder will be created and filled with the basic information that describes the new basin.

Once the project is created and opened, to proceed with the import of the ASCII matrices, you must select "ArclInfo Ascii ..." from the "Import" submenu of the "Single Grid" menu. The "Import ArclInfo ASCII Files" dialog box will be displayed (Figure 5.13), click on "Add File", in the "Open File" dialog box it will appear (Figure 5.14) go to the folder where the matrix files are stored ASCII (the "ASCII Grids" folder of the subdirectories for rain forecast and numerical estimation is recommended). Select the file to be imported and click on "OK".

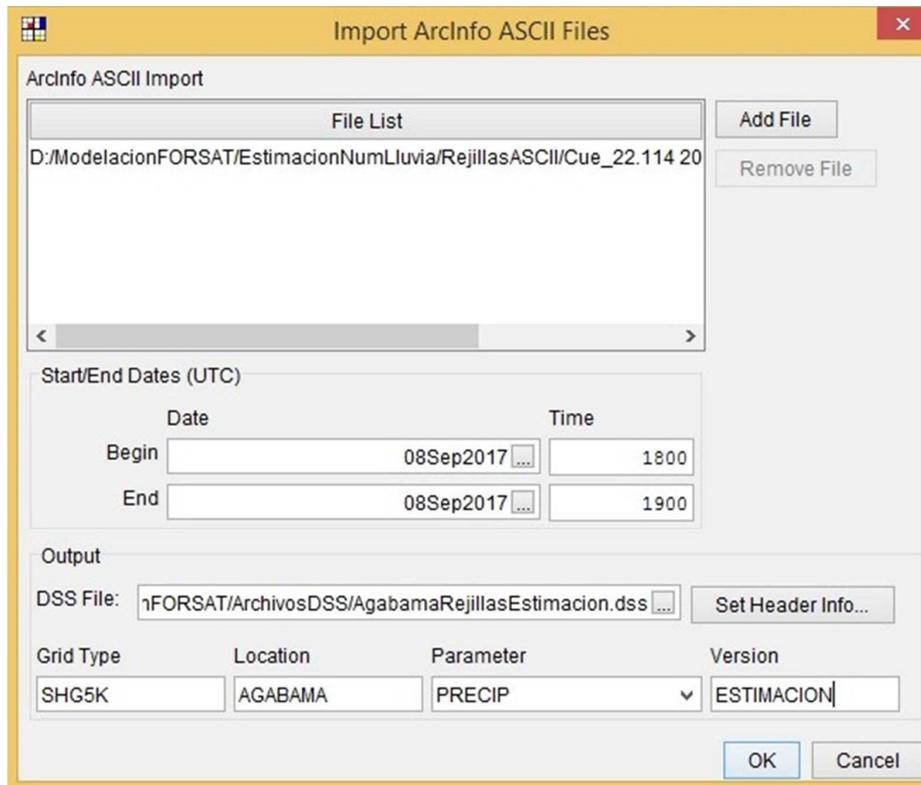


Figure 5.13. " Import ArclInfo ASCII Files " dialog box.

In the "Grid Type" field for the definition of the grid type, write "SHG5K" indicating the grid system "Standard Hydrologic Grid" with spatial resolution of 5 km. In the field "Location" the physical space that represents the imported grid will be defined (the name of the river basin is recommended) while in the "Parameter" field the hydrological variable registered in the grid ("PRECIP") will be selected. In the field "Version" write "PRONOSTICO" or "ESTIMACION" according to the case. Click "OK"

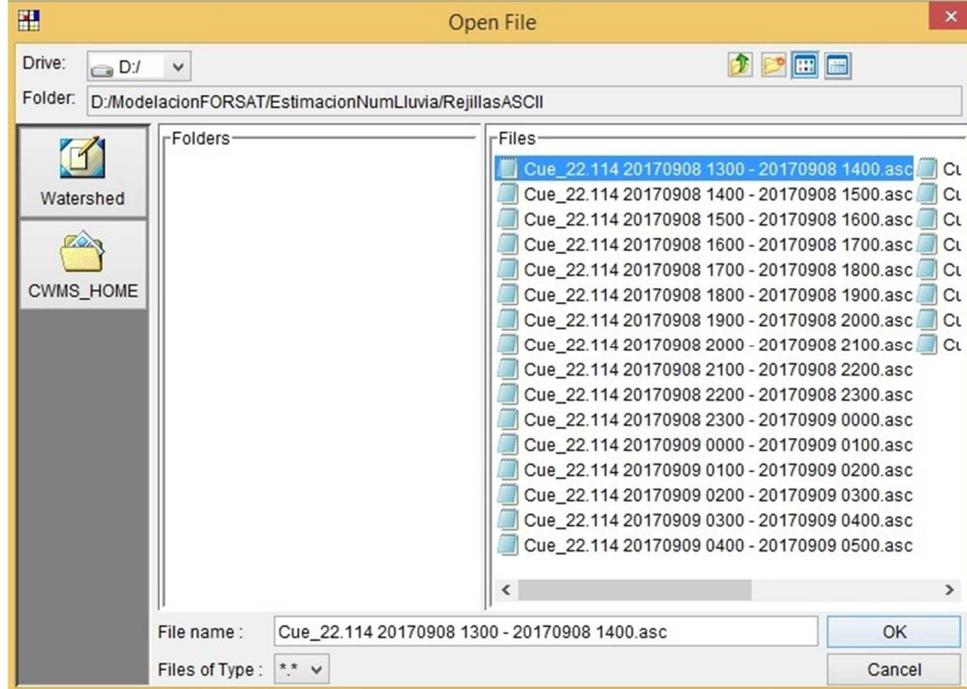


Figure 5.14. "Open File" dialog box for the selection of ASCII matrix files.

In the "Start/End Dates (UTC)" section, the date/time combinations of start and end of rain registered in the grid that is imported will be entered. As shown in Figure 5.13, the dates will have the format "DDMMMAAAA" with the months represented by the first three letters in English while the format of the hours will be hhmm.

In the "Output" section choose the .dss file for the storage of the matrices by clicking on the button located on the far right inside the "DSS File" field. An "Open File" dialog box will appear (Figure 5.15) in which you will surf to the folder of the .dss files (the folder "DSS Files" of the working directory of the modeling system is recommended). In the case of an existing file, select it from the list of files and otherwise write the name of the new file in the "File Name" field. Click on "OK".

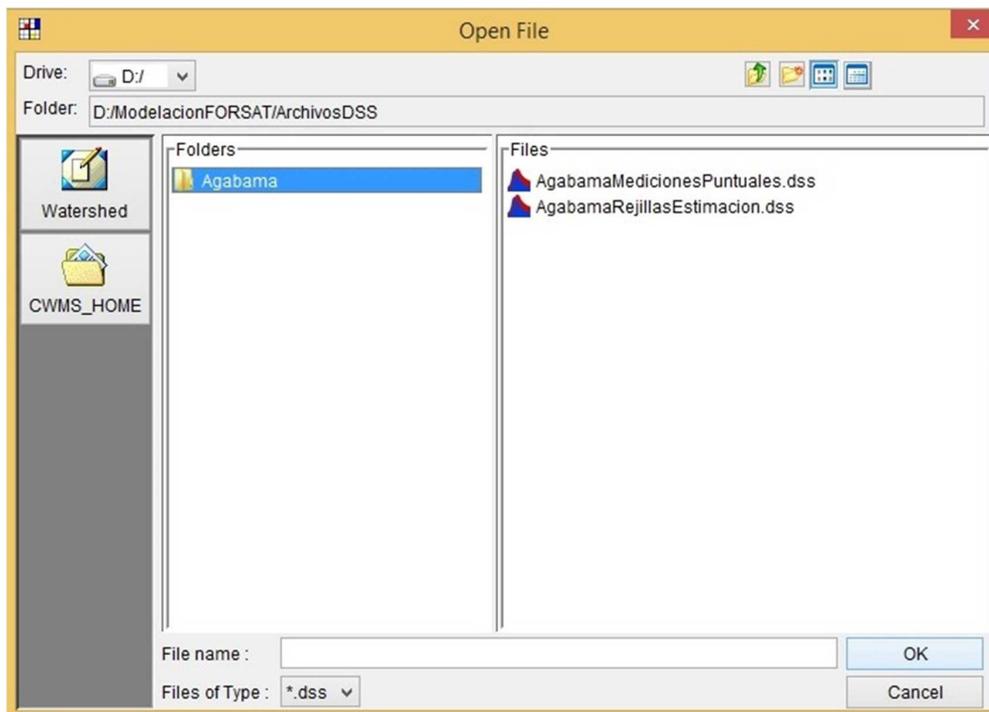


Figure 5.15. "Open File" dialog box for the selection of .dss files.

5.2. Rain data measured in conventional rainfall stations

At present the Hydrological Service of the National Institute of Hydraulic Resources has a Special Informative Rainfall Network for Exceptional Situations, composed of more than 700 stations throughout the country in which, from when the Information Phase is decreed by the General Staff National Civil Defense, manual measurements and oral data transmissions are made to the INRH Provincial Office Posts, every eight hours, four hours or two hours depending on the imminence of the threat.

For the reception, storage, processing and emission of rain observations and the generated information, we have the MS-Access application "Hourly Information Rain" to which a data export tool has been added for data imported into a database file of HEC-DSS, a more practical solution for the management of external time series of hydrological variables in the HEC-HMS hydrological modeling system.

Similar to the applications for the processing of the numerical forecast and rainfall matrices, the application for the special information network for exceptional situations presents in its main window a data entry form, one for predesigned queries and one for the predesigned reports.

To export files in DSSUTL format, access the "Predesigned Queries" tab and click on the "Define period and provinces to be consulted" button, the "Criteria for predesigned queries" form will appear (Figure 5.16) where the beginning Start and end times of the period to be exported will be entered (the selection of provinces in this form is not useful for export to DSSUTL). Finally click on the "Accept" button.

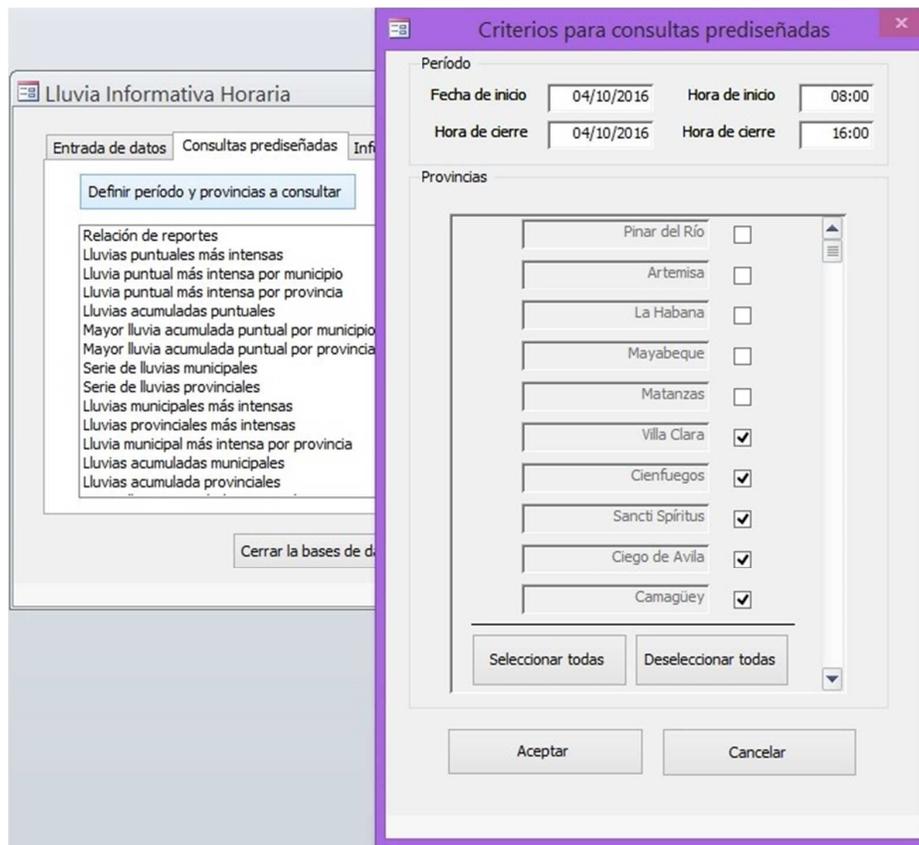


Figure 5.16. Criteria for predesigned queries of the Special Informative Pluviometric Network for Exceptional Situations database.

Once the time interval is defined, click on the "Export DSSUTL" button, the form will appear to select the specific stations whose measurements for the time interval defined above will be exported (Figure 5.17), select the stations of interest (the "Select all" and "Deselect all" buttons have been incorporated to speed up the selection), click "Accept".

The station selection form will be automatically closed and the standard Windows dialog box will appear to save files "Save DSSUTL file in ..." (Figure 5.18), go to the folder where the file will be saved ("DSSUTL files" working directory of the modeling system is recommended), type the name of the file to be saved by adding the extension ".utl" or select it from the list (in case it already exists), click on the "Accept" button.

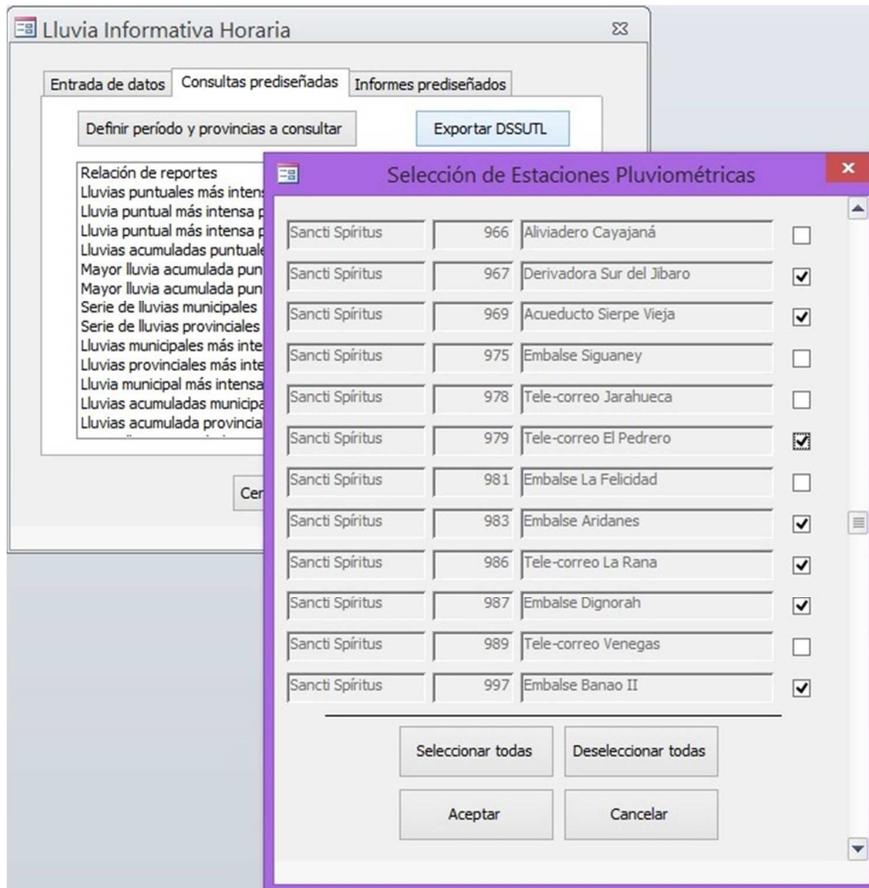


Figure 5.17. Form for the selection of stations for export to DSSUTL

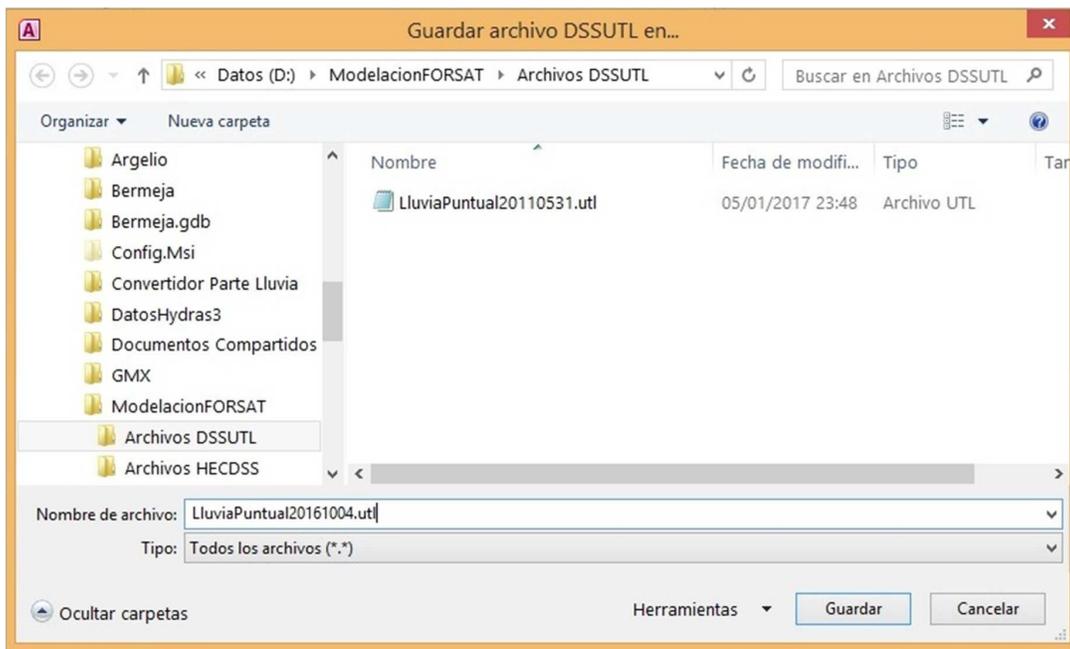


Figure 5.18. Dialog box "Save DSSUTL file"

The exported DSSUTL format file is ready to fill an existing database file with HEC-DSS support. In case a HEC-DSS file is not available, it must be created using the HEC-DSSVue application as follows:

Run the HEC-DSSVue application and from the "File" menu, click on "New". When the "Create new HEC-DSS File" dialog box is opened (Figure 5.19), select where you want to create the file (the "DSS Files" folder of the working directory of the modeling system is recommended) using the "Search" list in "or file icons. Type a name for the new file in the "File name" text box and then click on the "Create" button. A new HEC-DSSVue file will be created in the selected location. The data can then be added using the tools located under the "Data Entry" menu, copied through the different available plug-ins, or copied from other DSS files.

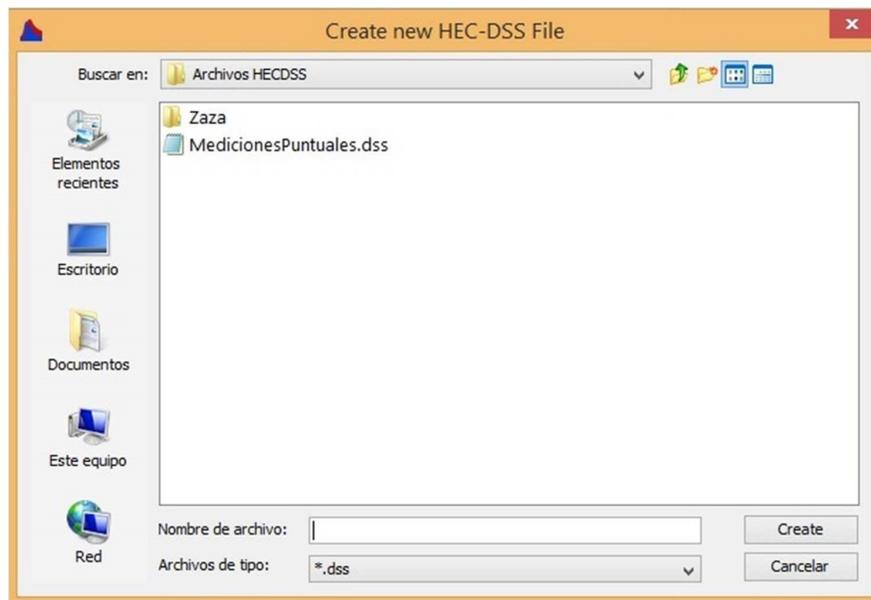


Figure 5.19. Dialog box "Create new DSS file".

When you have a DSS file, with the DSSVue application, you must first open it and then import the data from the DSSUTL file:

From the "File" menu, click on "Open". The "Open HEC-DSS File" browser will be displayed (Figure 5.20).

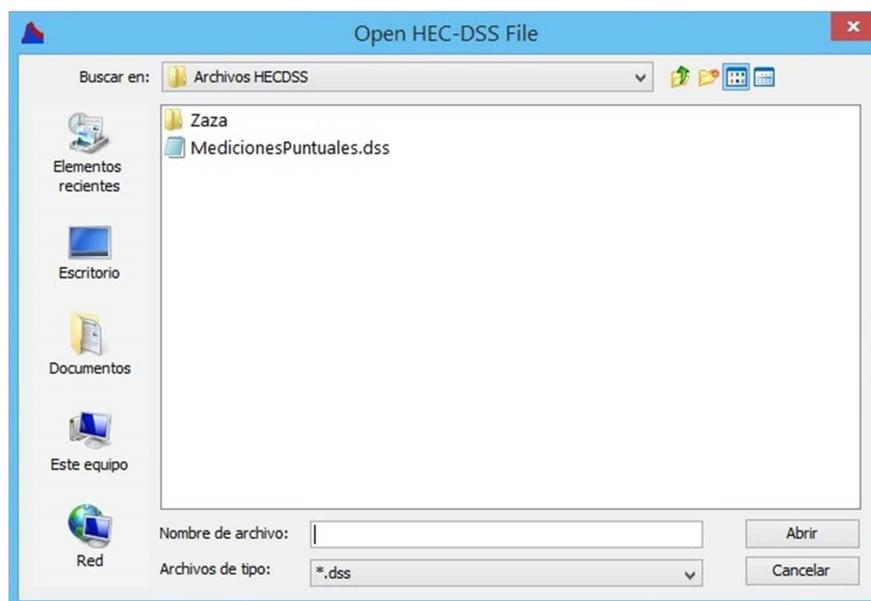


Figure 5.20. Browser "Open HEC-DSS File".

From the browser, use the standard Windows controls to navigate to the HECDSS file that you want to open, click on "Open".

The name of the file you selected will appear in the "File name" text box of the HEC-DSSVue main window (see Figure 5.21) and the names of the records contained in the file will be displayed in the list of names-routes HEC-DSS.

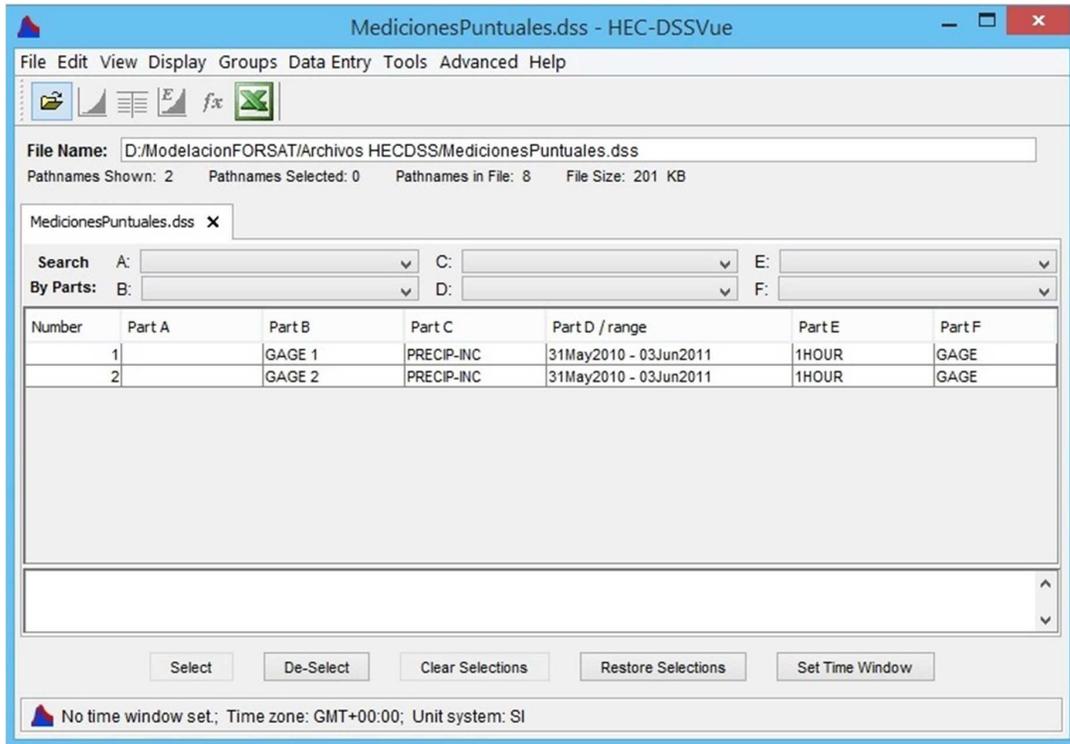


Figure 5.21. Main window of HEC-DSSVue.

From the "Data entry" menu point to "Import" and click on "Dssutl Write Data File", the "Enter DSSUTL data file to import" browser will open (Figure 5.22), navigate to the location of the created .utl file (the "UTL Files" folder of the modeling system working directory is recommended), select the file and click on "ok".

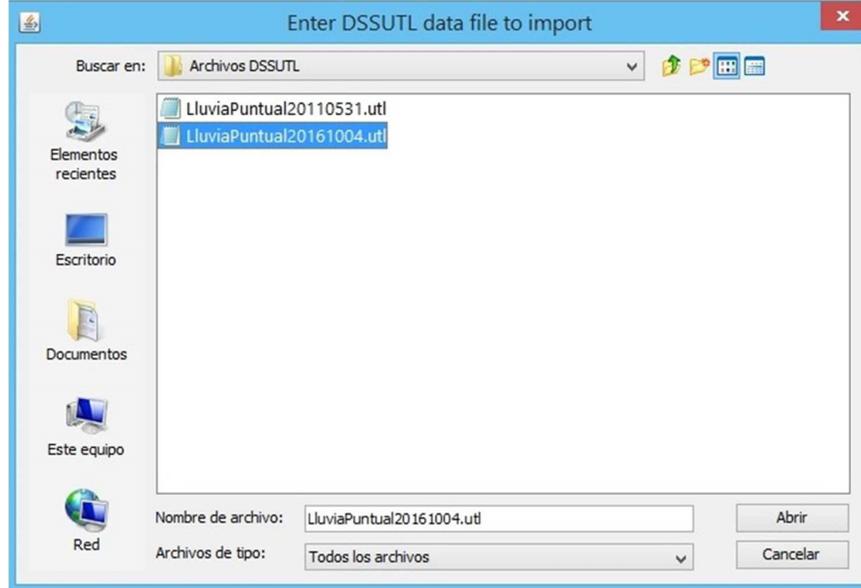


Figure 5.22. Select DSSUTL file to import.

5.3. Rain data measured in automatic rainfall stations

Analogous to the tools developed for the management of the data of the conventional pluviometric stations, an application has been developed for the extraction of accumulated rainfall hours and instantaneous water level values, from the database DEMASDB, conceived for the storage of data generated by the automatic hydro-meteorological stations, and create the files for DSSUTL with them. The rest of the process is identical to that of conventional stations.

5.4. Estimation of regional Precipitation-Duration-Frequency curves from 24-hour-accumulated precipitation sheets.

Although the hydrological prediction system proposed is designed to simulate the rain-runoff transformation process from simple real events or even short-term continuous events (just over 24 hours), it will sometimes be necessary to use the system to the simulation based on synthetic rains obtained by statistical analysis of rainfall data. The most common way to do this is to use a design storm that involves a relationship between rainfall intensity, duration, and proper frequencies or return periods, known as intensity-duration-frequency (IDF) curves.

In order to obtain the rain intensity values required for the preparation of these curves, continuous records of rainfall and duration sheet pairs obtained mainly by means of rain gauges are required. However, in Cuba the information with which the rainfall variable is actually counted, is the one collected by totalizing rain gauges for 24 hours, so it is proposed to substitute the IFD curves for precipitation (plate) -duration-frequency (PDF) curves using the methodology proposed by Campos Aranda (1992), which is based on the following equations:

$$P_T^t = (0,21LnT + 0,52)(0,54t^{0,25} - 0,50) P_{10}^{60} \begin{cases} 2 \leq T \leq 100 \text{ years} \\ 5 \leq t \leq 120 \text{ min} \end{cases} \quad (5.1)$$

being:

P_T^t : precipitation of 60 min duration and 10-year return period T; mm

P_{10}^{60} : precipitation of 60 min duration and 10-year return period; mm

Then, this same author presents the following equation, which relates the precipitation of duration one hour and return period 2 years:

$$P_T^t = (0,35LnT + 0,76)(0,54t^{0,25} - 0,50) P_2^{60} \begin{cases} 2 \leq T \leq 100 \text{ years} \\ 5 \leq t \leq 120 \text{ min} \end{cases} \quad (5.2)$$

being:

P_2^{60} : precipitation of 60 min duration and return period 2 years, mm

These equations are in function of small duration sheets, as is the case of 60 minutes. This is a problem to be solved because the rainfall information usually counted is daily, so the behavior of the rainfall for a duration of one hour is unlikely to be known. Due to this difficulty, several criteria are presented to select the quotient between the precipitation in one hour and 24 hours, both with return period of 2 years. Its use is based on the information available, which will indicate which one to use.

Finally, the methodology proposed by Campos Aranda (1992) for obtaining the PDF curves is as follows:

- Select the return periods that the curves will have.
- Calculate the representative values of 24-hours maximum rain for the basin under study, for the return periods of the curves and for the 2-year period.
- Select the quotient between the rain of 1 h and 2 years of return period and the rain of 24 h, also for 2-year return period (P1hour/P24hours).
- Obtain the PDF curves from equations 5.1 and 5.2.
- Finally, draw the curves.

Summarizing the above, Rodríguez (2011) proposed a regional analysis of the series of annual maximum daily rainfall obtained from the rainfall information (see Annex I) and then apply the proposed methodology by Campos Aranda (1992) for obtaining regional PDF curves.

5.4.1. Obtaining PDF curves

Once the representative rainfall stations have been defined for the basin in general or for each of the sub-regions in which the basin is divided as shown in the example in Annex I, the regional rainfall series

are obtained in maximum 24-hour annual basis in regard to arithmetic averages of the punctual values of annual daily maximums.

To determine the coefficient between the rain of 1 hour and a day, for a return period of two years, the method proposed by the World Meteorological Organization (2011) is used, which has to do with the number of rainy days per year. According to the study by Trusov et al. (1983), the average annual number of rainy days for the different regions of the country (western, central and eastern) is above 50, so the quotient between rain of 1 hour and a day for a return period of two years, in all cases can be considered as 0.5.

Using the proposed methodology, the PDF curves of the four sub-regions were drawn up, based on the results of the regional analysis. Figure 5.1 shows the PDF curves for the 100-year return period (probability of annual exceedance of 1%) for the four sub-regions. Tables 5.1 to 5.4 show the curves for return periods of 2, 5, 10, 25, 50, 100 and 1000 years in numerical form and for each sub-region. The PDF curves obtained from the regional analysis represent the behavior of the maximum daily rainfall in the basin, where the higher values occur in the lower area of the same (in terms of topographic level).

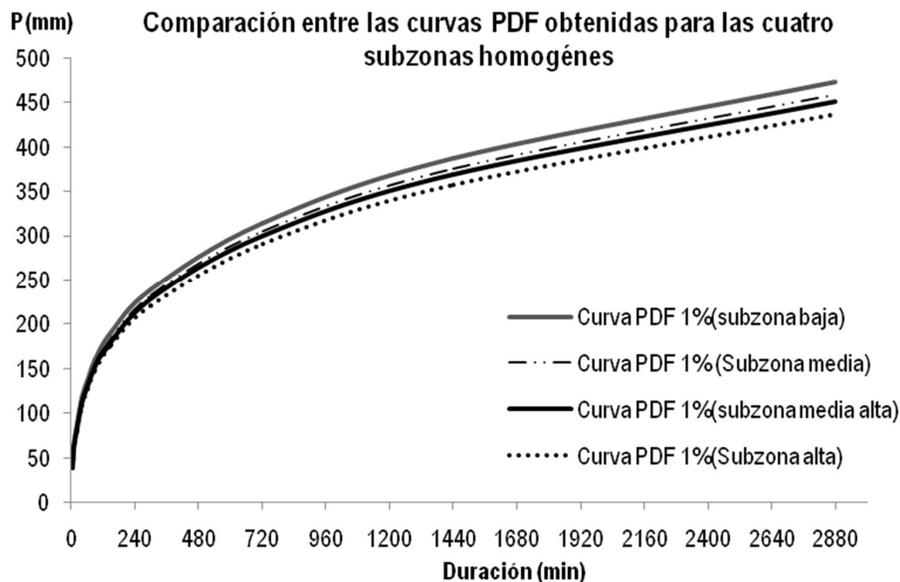


Figure 5.1: PDF curves for the four sub-regions, for a return period of 100 years (probability of annual exceedance of 1%).

Table 5.1: PDF curves for the low sub-region

Duration (min)	Rain sheet (mm) for stated return period						
	2 years	5 years	10 years	25 years	50 years	100 years	1000 years
5	17,8	23,5	27,8	33,5	37,8	42,1	56,5
10	26,7	35,2	41,6	50,2	56,6	63,1	84,5
20	37,2	49,1	58,1	70,0	79,0	88,0	117,9
40	49,7	65,6	77,6	93,5	105,5	117,6	157,5
60	58,1	76,7	90,7	109,3	123,4	137,4	184,1
90	67,4	88,9	105,2	126,8	143,1	159,4	213,6
150	80,5	106,3	125,7	151,5	171,0	190,4	255,2
300	101,2	133,6	158,1	190,5	214,9	239,4	320,8
720	133,1	175,6	207,8	250,4	282,6	314,8	421,7
1440	163,7	216,1	255,7	308,1	347,7	387,3	518,9
2880	200,2	264,2	312,6	376,7	425,1	473,5	634,5

Table 5.2: PDF curves for the medium sub-region

Duration (min)	Rain sheet (mm) for stated return period						
	2 years	5 years	10 years	25 years	50 years	100 years	1000 years
5	17,3	22,8	27,0	32,5	36,7	40,8	54,7
10	25,8	34,1	40,4	48,6	54,9	61,1	81,9
20	36,0	47,6	56,3	67,8	76,5	85,3	114,2
40	48,2	63,6	75,2	90,7	102,3	114,0	152,7
60	56,3	74,3	87,9	106,0	119,6	133,2	178,5
90	65,3	86,2	102,0	122,9	138,7	154,5	207,0
150	72,3	95,4	112,9	136,0	153,5	171,0	229,1
300	98,1	129,5	153,2	184,6	208,3	232,1	310,9
720	129,0	170,2	201,4	242,7	273,9	305,1	408,8
1440	158,7	209,5	247,9	298,6	337,0	375,4	503,0
2880	194,0	256,1	303,0	365,1	412,1	459,0	615,0

Table 5.3: PDF curves for the medium-high sub-region

Duration (min)	Rain sheet (mm) for stated return period						
	2 years	5 years	10 years	25 years	50 years	100 years	1000 years
5	17,0	22,4	26,5	31,9	36,0	40,1	53,7
10	25,4	33,5	39,6	47,8	53,9	60,0	80,4
20	35,4	46,7	55,3	66,6	75,2	83,7	112,2
40	47,3	62,4	73,9	89,0	100,5	111,9	150,0
60	55,3	73,0	86,4	104,1	117,4	130,8	175,3
90	64,1	84,7	100,2	120,7	136,2	151,7	203,3
150	71,0	93,7	110,9	133,6	150,7	167,9	225,0
300	96,4	127,2	150,5	181,3	204,6	227,9	305,4
720	126,7	167,2	197,8	238,4	269,0	299,7	401,5
1440	155,9	205,7	243,4	293,3	331,0	368,7	494,0
2880	190,6	251,5	297,6	358,6	404,7	450,8	604,0

Table 5.4: PDF curves for the high sub-region

Duration (min)	Rain sheet (mm) for stated return period						
	2 years	5 years	10 years	25 years	50 years	100 years	1000 years
5	16,4	21,7	25,7	30,9	34,9	38,9	52,1
10	24,6	32,5	38,5	46,3	52,3	58,2	78,0
20	34,3	45,3	53,6	64,6	72,9	81,2	108,8
40	45,9	60,6	71,7	86,4	97,5	108,6	145,5
60	53,6	70,8	83,8	100,9	113,9	126,9	170,0
90	62,2	82,1	97,2	117,1	132,1	147,2	197,2
150	74,3	98,1	116,1	139,9	157,9	175,9	235,6
300	93,5	123,4	146,0	175,9	198,5	221,1	296,2
720	122,9	162,2	191,9	231,2	261,0	290,7	389,5
1440	151,2	199,5	236,1	284,5	321,1	357,7	479,2
2880	184,9	244,0	288,7	347,8	392,6	437,3	585,9

6. System operation for flood hazard assessment (contribution to outputs from the flood hazard study due to heavy rains from HVR studies).

In the existing methodology for the determination of the flood hazards due to heavy rains, from the combination of rainfall spatial distribution maps with different occurrence probabilities and those with spatial distribution of indicators of multiple elements behavior conditioning the runoff (relief, vegetable cover, soil grouping, land use, etc.), we obtain the spatial distribution of the susceptibility to flooding or, better, of the water response in the study territory.

In order to improve the scope of the resulting hazard information, the application of automated hydraulic and hydrological simulation models will be incorporated into these studies, based on the process known as the "study of flood frequencies". This process will result in: the runoff volumes (and/or flood volumes) generated by different probabilities rain events of annual overrun (50%, 20%, 10%, 4%, 2%, 1% and 0, 1 year); and the levels above the mean sea level of the water surface in the river network, that is, the strains in the main current sections of the basin added to the bottom of the channel (topographic level) obtained from the Digital Model of Elevation, from which the floodplains will be drawn for maximum flows of different probabilities.

As a general rule, the functions of annual maximum flow frequency obtained from statistical analysis of maximum annual flows big records, are the most reliable frequency functions. However, long series of flow data are available only in a few basins, while in many basins no series is available at all. Even when a long series is available, basin conditions may have changed dramatically due to urbanization or other non-stationary processes, or large events may not have occurred during the record period. Therefore, an accurate function of flow frequency may not be obtained only from historical data. A calibrated basin model with precipitation events of known frequencies is often used to develop a flow frequency function and compare with other estimates. The calibration of the model is typically based on available historical events of similar frequencies.

In addition, frequency functions for current development conditions and hydraulic works must be developed without statistical analysis. Gauging records do not exist for these altered future regime conditions. A commonly used method for this is based on the application of a basin model, such as the HEC-HMS with the hypothesis of the so-called design storm. Pilgrim and Cordery (1975) describe this hypothesis as follows:

"In the normal approach to estimating the design flow rate, the intention is to estimate the flow rate of a frequency selected from a rainfall design of the same frequency ... The basic premise (of this approach) is that if the average or medium values of all other parameters are used, the frequency of the calculated flows should be approximately equal to the frequency of the design rain ".

To develop an expense frequency function with this procedure, the next steps are followed:

1. Develop a rain-runoff-transit model that shows the characteristics of the basin and the currents for the case of corresponding interest: current conditions of development and without hydraulic works; current conditions of development and with hydraulic works; future conditions of development and without hydraulic works; and future conditions of development and with hydraulic works. The current

development model without works must be calibrated with observed data if they are available, or verified using regional equations or flow estimates.

2. Collect rainfall data, perform statistical analysis and define rainfall sheets of known frequency for the basin. The results of the statistical analysis can be presented as:

- an Intensity-Duration-Frequency (IDF) function
- a Precipitation (sheet) -Duration-Frequency (PDF) function
- a batch of isohyet maps
- a batch of equations that define sheets for specified frequencies and durations.

Of these, storm hyetograph can be developed directly. In addition, a series of annual maximum daily rains can be obtained based on the probability of annual overrun.

3. For a selected frequency or probability of annual overrun (PSA), use the IDF or PDF information to define a precipitation hyetograph, then use the rainfall-runoff-transit model to calculate the peak expense, level or volume. Assign the probability of annual exceedance of the precipitation to the peak expense, level or volume obtained, following the hypothesis of the design storm described above.

4. Repeat the process for a range of frequency events.

5. Group the results to produce a full runoff frequency function.

6. Use sensitivity analysis to determine the most important parameters in case more adjustments of the frequency curve are needed.

7. Compare these results of the hydrological storm frequency model with other methods (eg if available, flow statistics and regional regression equations) to determine the best estimate of the cost frequency curve for current development conditions (with or without hydraulic works).

Once the flows for different probabilities of annual overpasses are obtained in the selected closures within the basin, the corresponding hydraulic simulations could be carried out for downstream river sections in order to obtain the heights of water above the riverbed and with these, and the help of digital elevation model, get the fringes or floodplains. To reinforce this process, it is possible to define one (or several) threshold value of height above the level of the ground from which considerable damage is generated (eg: 1.20 m above the ground level) and identify the areas where these thresholds are surpassed by the water levels obtained for each of the probabilities.

Starting from the concept of hazard equivalent to probability or occurrence frequency, the levels of hazard (no hazard, low hazard, medium hazard and high hazard) would be identified based on the values of annual overrun probability used for the definition of the rain risk patterns and obtaining the respective runoff. In this sense, the flood zone for 50% probability represents the area that can be flooded from a precipitation value that is exceeded 50 times in 100 years (once every two years) or very frequently, while the fringe Flood for 4% probability represents the area that is flooded with accumulated precipitation exceeded once every 25 years (infrequently).

The high hazard could then be associated to probabilities greater than 20% (return period under 5 years); the average hazard could be limited between the probabilities of 20% and 10% (return period between 5 and 10 years); the low hazard, for probabilities between 10% and 4%; and without hazard for the probabilities lower than 4%.

For the practical application of the activities described above related to the obtaining of the hypothetical storms and the maximum costs associated or generated by these storms, the next procedure would be followed:

a) Calculation of precipitation (sheet) -duration-frequency relationships for return periods of 2, 5, 10, 25, 50, 100 and 1000 years.

The results of the methodology application proposed by Campos Aranda (1992), for the calculation of the precipitation sheets for the indicated return periods and duration of up to 48 hours, as well as the process to obtain these frequency distributions, are the ones presented in section 5.4 and Annex I.

b) Calculation of maximum expenditure from hypothetical storms.

The process of working with the HEC-HMS to calculate the maximum expenditure from hypothetical storms based on frequencies requires, in advance, a model of the basin prepared as indicated in the previous section.

Once this is done, it is then necessary to create the meteorological models necessary to calculate the maximum expenses from hypothetical storms based on frequencies. Seven meteorological models must be created for each of the sub-regions in which the basin under study is divided.

The models correspond to the return periods of 2, 5, 10, 25, 50, 100 and 1000 years. The following describes how to create the meteorological model for a return period of 50 years in HEC-HMS.

- Select "Meteorologic Model Manager" in the "Components" menu.
- Enter a weather model name and description in the "Create a New Meteorologic Model" window. The name of the model, ex. Met0050Subregion1, this means that it is the meteorological model for sub-region 1 and a return period of 50 years. The description is optional; in it you can register information of interest, eg. Meteorological subregion 1 T 50 years.
- Click on the "Meteorologic Model" tab. In the window that is shown, define the type of precipitation that is introduced to the model by selecting "Frequency Storm".
- There is no data of evapotranspiration ("Evapotranpiration") or de-icing ("Snowmelt"), therefore for both the option "None" is accepted, the system of units also accepts the metric ("Metric").
- In this panel, click on the "Basin" tab. In the "Include Subbasin" column (include sub-basins) click and unfold to select Yes.
- In the Basin Explorer panel, click on "Frequency Storm". Enter the information specified below in this window:

- o Probability (Exceeding probability) 2 Percent.
- o Input Type: Partial duration or annual duration can be selected.
- o Output Type: Partial duration or annual duration can be selected.

- o Intensity Duration: for this case, 5 min duration of the maximum intensity is placed.
- o Storm Duration: for this case a 48-hour storm has been generated.
- o Intensity Position (position of the intensity of the maximum intensity during the storm): you can choose 50%.
- o Storm Area: (area of the storm): it is used to automatically calculate the reduction factor of the precipitation sheet depending on the area. If the storm is considered to cover the entire basin, then the sub-region area will be introduced. If left blank, each sub-basin will have a different hietogram calculated using the area of the sub-basin as the area of the storm.

Enter the precipitation height data, for durations of 5 min, 10 min, 20 min, ..., 2880 for a return period of 50 years.

c) Control Specifications.

In this case the time interval that is simulated is the same as that of the storm, it but is considered that the precipitation falling on the basin is 2% probability, therefore the control specifications are the same and they were already imported at the beginning of this section.

d) Create simulation

To create the simulation protocol, the command "Create Compute"/"Simulation Run" of the "Compute" menu is executed.

When executing, the four windows presented in section 4.5 are displayed one after the other, where the combination of the components to be simulated is selected.

7. Real-time system operation (hydrological prediction process).

During the process of real-time system operation, two simultaneous activities will be carried out: (1) simulate the runoff that will occur in the basin during the 24 hours between the date- current time+48 hours and the date- current time + 72 hours; and (2) simulate the runoff that the rainfall will produce in the basin during the 24 hours between the current date-time - 24 hours and the current date-time moment. For the first case, the quantitative prediction of precipitation will be used and runs will be made every six hours, while for the second, the quantitative precipitation estimation and rainfall observations will be used in surface rainfall stations, being conventional or automatic, and the runs could be done up to every two hours if the hydro-meteorological situation requires so.

For the case (1) we proceed as follows:

- Compile quantitative precipitation prediction grids for the period between date- current time + 48 hours and date- current time + 72 hours. For example, if the simulation is performed on June 4th, 2018 at 08:00 hours, then the quantitative prediction grids for precipitation are collected for the period 06/06/2018 08:00 - 07/06/2018 08:00. To do this, proceed as indicated in section 5.1.1.

- o Access the FTP mailbox where the rainfall numerical forecast matrices are deposited.
 - o Access the subdirectory "PronosticoNumLluvia" of the main directory of the "ModelacionFORSAT" system.
 - o Run the application "LluviaPronosticada.accdb".
 - o Perform the process of importing rain data matrices from the FTP mailbox to the database.
- Obtain accumulated rainfall in 24 hours for the study basin through consultation or through the report "Accumulated rain by river basin" as indicated in 5.1.1.b or in 5.1.1.d.
 - o Define period to consult.
 - o Execute the query "Rain accumulated by river basin".
 - o Enter the rain value corresponding to the basin that is being evaluated.
- Identify to what period of return, frequency, or occurrence probability corresponds the obtained rain accumulated in 24 hours.
 - o Access the table or graph with the Probability-Duration-Frequency curves obtained as described in section 5.4.
 - o Compare predicted accumulated rainfall with rainfall values for the different probabilities and duration equal to 1440 minutes (24 hours) of the PDF curves.
 - o Select the probability whose rain for 24 hours is closer to the forecast accumulated.
- From the study of Hazard, Vulnerability and Risk of the basin, obtain the flood hazard map for the probability of rain identified in the previous step. This hazard map constitutes the preliminary flood forecast for the period "date current time + 48 hours" - "date- current time + 72 hours". It is supported by the premise that the frequency of the calculated flows should be approximately equal to the frequency of design rainfall if the average or average values of all other parameters are used.
- Export the predicted rain with ASCII grid format (.asc) for ArcInfo, as detailed in section 5.1.1.c.
 - Close the "LluviaPronosticada.accdb" application.
- Import the predicted rainfall grids in HEC-DSS as detailed in section 5.1.2.
 - o Run the HEC-Gridutil application.
 - o Open the corresponding GridUtil project or basin.
 - o Import the grids one at a time ("Single Grid / Import / ArcInfo ASCII" menu)
 - o Close the HEC-GridUtil application
- Carry out the simulation
 - o Run the HEC-HMS application
 - o Open the corresponding project or model
 - o Update (define the start and end of the simulation run to be performed) the existing control specifications for simulation runs with a meteorological model based on predicted rainfall grids. To do this, select the control specifications in the basin explorer and modify the values in the component editor window.
 - o Select the "Compute" tab of the basin explorer.
 - o Select the "Simulation Runs" folder. The created simulation runs will be displayed (see figure 7.1).

o Click on the corresponding simulation run ("Predicted Rain"). The component editor for this simulation will open. Change the description so that it adjusts, for example, to the new control conditions.

o Right click on the name of the simulation run in the explorer of the basin and select the option "Compute" in the contextual menu that will be displayed. A window showing the progress of the simulation will appear. Once finished, close the window.

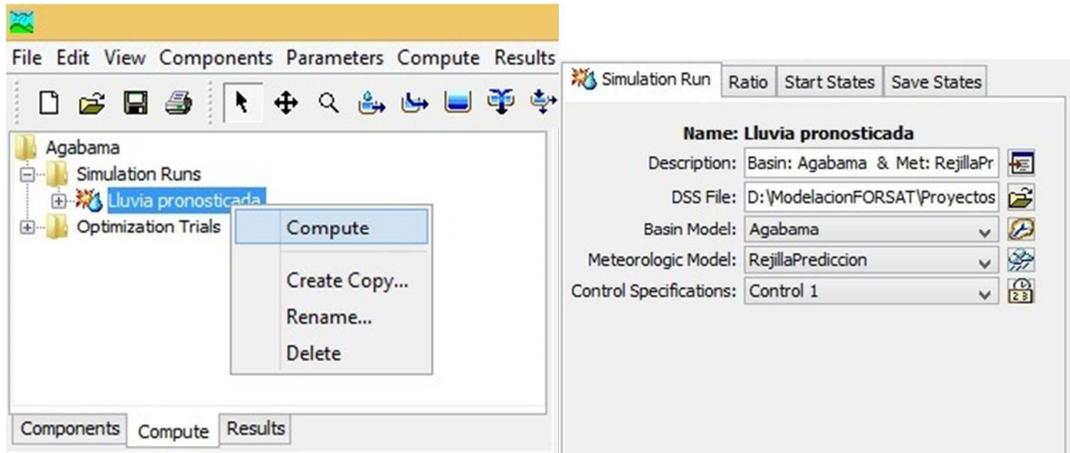


Figure 7.1: Selection and execution of a simulation run

- Show and analyze the results. Once the run of the simulation is finished, four buttons will be activated in the toolbar to show different types and scales of results.

o Select the "Global Summary Table" tool to see a summary of peak flow results for all the elements in the basin model. You can print the table or write down the peak flow for the elements you want.

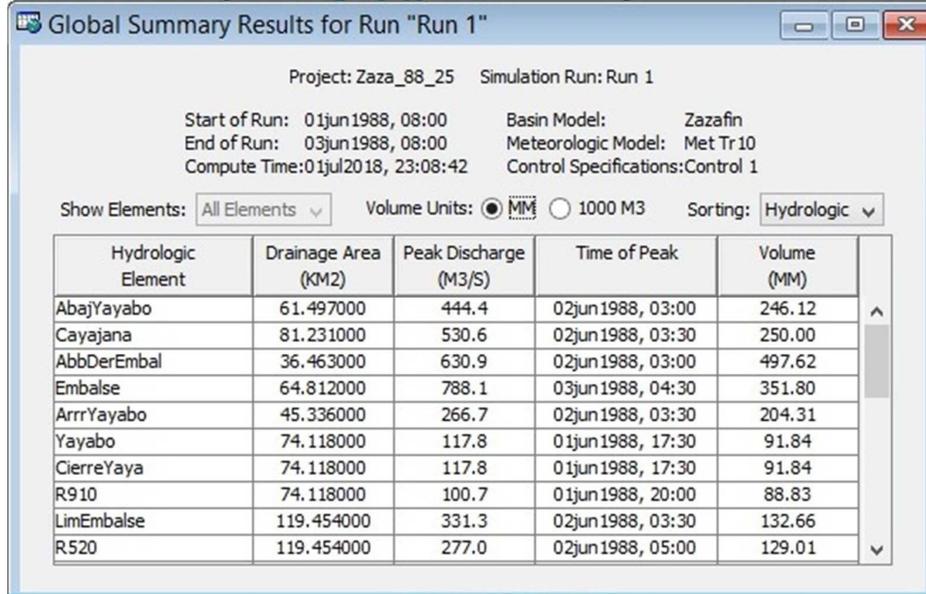


Figure 7.2: "Global Summary Table" window

o To see graphical or tabular results of a certain element of the model, select the element in the basin explorer and then select in the toolbar "View Graph for Selected Element (s)" or "View Summary Table for Selected Element (s)".

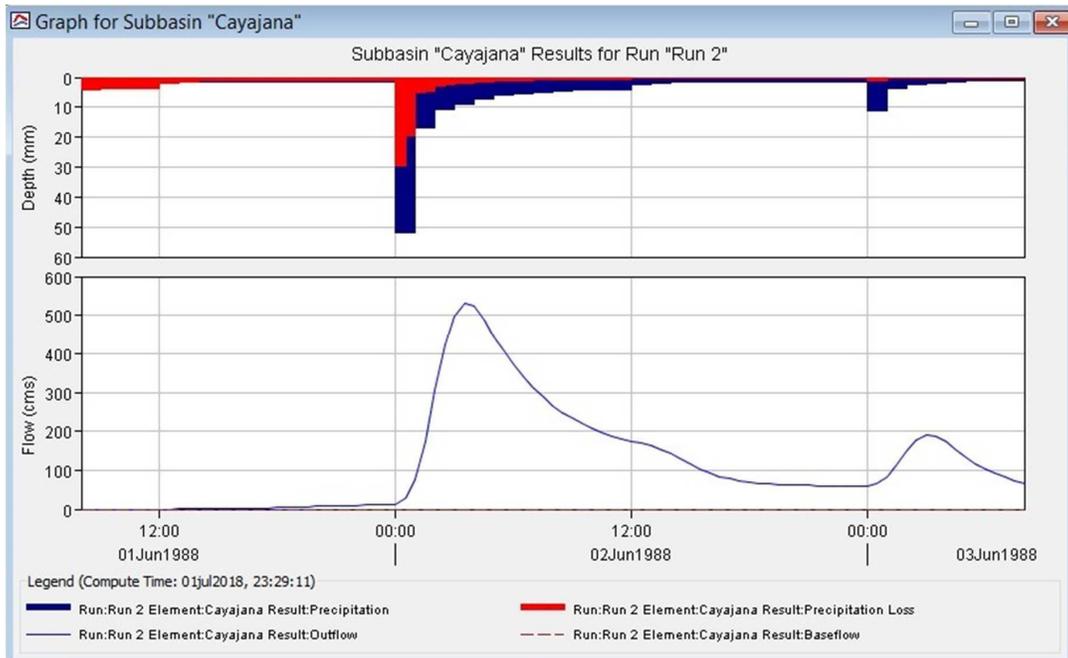


Figure 7.3: "Graph for Selected Element (s)" window

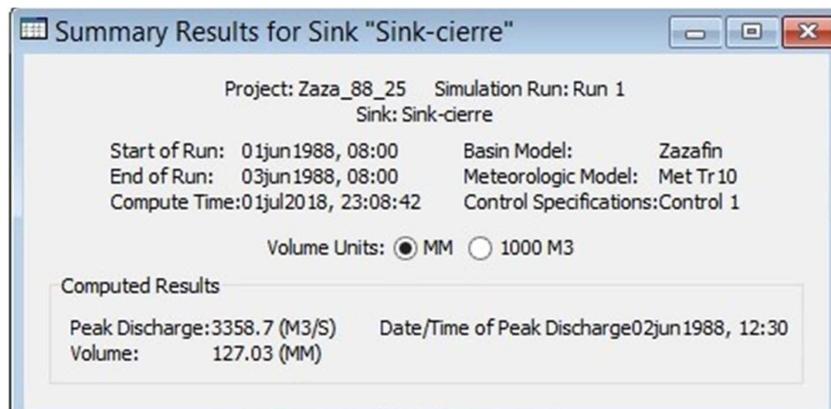


Figure 7.4: "Summary Table for Selected Element (s)" window

o Select in the toolbar "View Time-Series Table for Selected Element (s)" to obtain the chronological series of the run for the selected element.

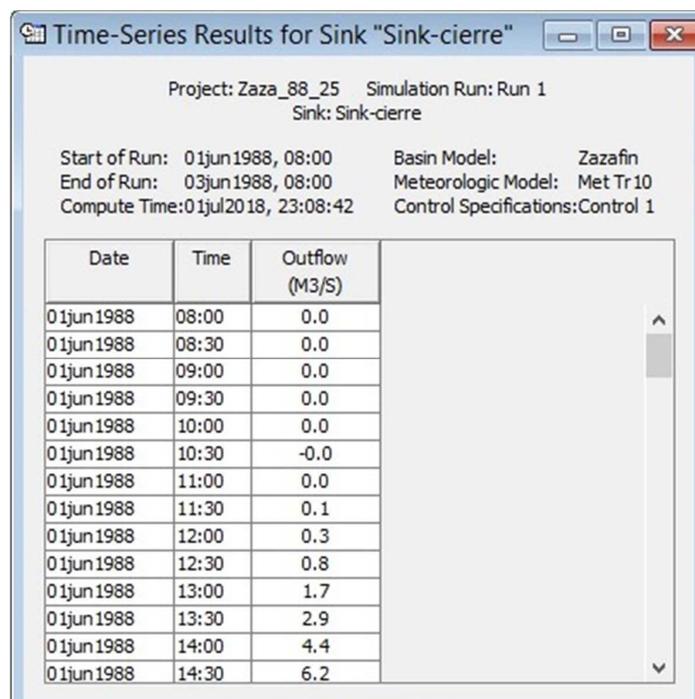


Figure 7.5: "Time-Series Table for Selected Element (s)" window

- Define the flood plain. It can be achieved by several routes among which are:
 - o Hydraulic modeling using the HEC-RAS and HEC-GeoRAS computer applications, using as input data the results of hydrological modeling using HEC-HMS.
 - o "Semi-automated" calculation of tie rods (water height) and surface width, using previously prepared Excel books containing Tabulated Curves of Strain - Surface Width - Expense for the sections of interest defined in the hydrological model. Once the surface widths are obtained,

these can be mapped and interconnected to generate the flood plain with the help of a digital elevation model.

o Satellite images or flood maps cataloged for different flows or probabilities of occurrence.

For the case (2) with a quantitative estimate of rainfall, the procedure is very similar to that of case (1):

- Collect quantitative precipitation estimation grids for the period between date- current time - 24 hours and current date-time. For example, if the simulation is performed on June 4, 2018 at 08:00 hours, then the quantitative prediction grid for precipitation is collected for the period 03/06/2018 08:00 - 04/06/2018 08:00. To do this, proceed as indicated in section 5.1.1.

o Access the FTP mailbox where the rain estimation numerical matrices are deposited.

o Access the subdirectory "EstimacionNumLluvia" of the main directory of the "ModelacionFORSAT" system.

o Run the application "LluviaEstimada.accdb".

o Perform the process of importing rain data matrices from the FTP mailbox to the database.

- Obtain accumulated rainfall in 24 hours for the study basin through consultation or through the report "Accumulated rain by river basin" as indicated in 5.1.1.b or 5.1.1.d.

- Identify to what period of return, frequency, or probability of occurrence corresponds the rain accumulated in 24 hours obtained.

- From the study of Hazard, Vulnerability and Risk of the basin, obtain the flood hazard map for the probability of rain identified in the previous step. This hazard map constitutes the preliminary flood forecast for the period "current date" - "current date-time + 24 hours".

- Export the predicted rain with ASCII grid format (.asc) for ArcInfo, as detailed in section 5.1.1.c.

- Close the "LluviaPronosticada.accdb" application.

- Import the predicted rainfall grids in HEC-DSS as detailed in section 5.1.2.

- Carry out the simulation

- o Execute the HEC-HMS application

- o Open the corresponding project or model

- o Update (define the start and end of the simulation run to be performed) the existing control specifications for simulation runs with a meteorological model based on predicted rainfall grids.

- o Select the "Compute" tab of the basin explorer.

- o Select the "Simulation Runs" folder. The created simulation runs will be displayed (see figure 7.1).

- o Click on the corresponding simulation run ("Predicted Rain"). The component editor for this simulation will open. Change the description so that it adjusts, for example, to the new control conditions.

- o Right click on the name of the simulation run in the explorer of the basin and select the option "Compute" in the contextual menu that will be displayed. A window showing the progress of the simulation will appear. Once finished, close the window.

- Show and analyze the results.

- Define the flood plain.

For the case (2) with rainfall data measured in surface rainfall stations, proceed as follows:

- Collect the rainfall data measured for the period between current date-time - T (24, 8, 4 or 2 hours) and current date-time. To do this, proceed as indicated in sections 5.2 and 5.3.
 - Run the application "LluvialInformativaHoraria.mdb".
 - Carry out the process of manual introduction or import of punctual rainfall data.
- Obtain accumulated rainfall in 24 hours for the study basin through consultation or through the report "Rain accumulated by river basin".
- Identify to what period of return, frequency, or probability of occurrence corresponds the rain accumulated in 24 hours obtained.
- From the study of Hazard, Vulnerability and Risk of the basin, obtain the flood hazard map for the probability of rain identified in the previous step. This hazard map constitutes the preliminary flood forecast for the period "current date time" - "current date-time + 24 hours".
- Export the rain measured in DSSUTL format, as detailed in section 5.2.
- Close the application "LluvialInformativaHoraia.mdb".
- Import the rain file measured in HEC-DSS as detailed in section 5.2.
 - Run the HEC-DSSVue application or Open the corresponding DSS file ("File / Open" menu)
 - Import the file (Data Entry / Import / Dssutl Write Data File menu)
- Carry out the simulation or Execute the HEC-HMS application
 - Open the corresponding project or model
 - Update (define the start and end of the simulation run to be performed) the existing control specifications for simulation runs with meteorological model based on rainfall stations ("Automatic" and "Conventional").
 - Select the "Compute" tab of the basin explorer.
 - Select the "Simulation Runs" folder. The created simulation runs will be displayed (see figure 7.1).
 - Click on the corresponding simulation run ("Automatic Pluviometers" or "Conventional Pluviometers"). The component editor for this simulation will open. Change the description so that it adjusts, for example, to the new control conditions.
 - Right click on the name of the simulation run in the explorer of the basin and select the option "Compute" in the contextual menu that will be displayed. A window showing the progress of the simulation will appear. Once finished, close the window.
- Show and analyze the results.
- Define the flood plain.

8. References and bibliography

1. Arias Lastre, P. P. (2015). "Application Guide of HEC-HMS in Cuban watersheds. Practical examples. "Thesis in option to the title of Hydraulic Engineer, Higher Polytechnic Institute José Antonio Echeverría, CUJAE.
2. Campos Aranda, D. F. (1992). "Processes of the Hydrological Cycle". Autonomous University of San Luis Potosí, Mexico, 2nd reprint. 524pp.

3. Carreras Flores, L. (2013). "Methodology for distributed modeling with HEC/HMS software." Thesis in option to the title of Hydraulic Engineer, José Antonio Echeverría Higher Polytechnic Institute, CUJAE.
4. World Meteorological Organization (2011). "Guide to Hydrological Practices": Vol. II - Management of water resources and application of hydrological practices, WMO-No. 168. Geneva, Switzerland.
5. Pilgrim, D. H., and Cordery, I. (1975). "Rainfall Temporal Patterns for Design Floods." Journal of the Hydraulics Division, ASCE, 101 (HY1), 81-85.
6. Rodríguez López, Y. (2009). "Hydrological simulation of extreme events. Case study: Zaza river basin. Thesis in option to the title of Master in Technical Sciences. Hydraulic Research Center., José Antonio Echeverría Higher Polytechnic Institute, CUJAE. Havana, Cuba.107pp.
7. Rodríguez López, Y. (2011). "Hydrological modeling of avenues. Case study: Zaza river basin. "Thesis in option to the scientific degree of Doctor of Technical Sciences, José Antonio Echeverría Polytechnic Institute, CUJAE.
8. Trusov, I., Izquierdo, A. and Diaz, L. R. (1983). "Spatial and temporal characteristics of atmospheric precipitation in Cuba". Editor of the Academy of Sciences of Cuba. Havana, Editorial Academia.
9. USACE (2000). HEC-HMS Technical Reference Manual. Hydrologic Engineering Center, Davis, CA.
10. USACE (2009). HEC-DSSVueUser's Manual. Hydrologic Engineering Center, Davis, CA.
11. USACE (2010). HEC-RAS River Analysis System Applications Guide. Hydrologic Engineering Center, Davis, CA.
12. USACE (2010). HEC-RAS River Analysis System Technical Reference Manual. Hydrologic Engineering Center, Davis, CA.
13. USACE (2010). HEC-RAS River Analysis System User's Manual. Hydrologic Engineering Center, Davis, CA.
14. USACE (2011). HEC-GeoRAS GIS Tools for Support of HEC-RAS Using ArcGIS User's Manual. Hydrologic Engineering Center, Davis, CA.
15. USACE (2011). Grid Utility Program HEC-GridUtil User's Manual. Hydrologic Engineering Center, Davis, CA.
16. USACE (2013). HEC-GeoHMS Geospatial Hydrologic Modeling Extension User's Manual. Hydrologic Engineering Center, Davis, CA.
17. USACE (2015). HEC-HMS Applications Guide. Hydrologic Engineering Center, Davis, CA..
18. USACE (2016). Hydrologic Modeling System HEC-HMS User's Manual. Hydrologic Engineering Center, Davis, CA.

Annex I. Regional analysis of the annual maximum daily rainfall series. Study case: Zaza river basin.

For the study of the maximum rains it is necessary to use statistical tools that allow the analysis of the available data in an area, managing to homogenize this information and obtaining conclusions from it.

In recent times the use of regional analysis has taken a big boom, which is based on the series analysis of annual maximums from the stations that are in a region, which can be considered as homogeneous, depending on the characteristics statistics of the series of annual maximums of both daily rains and instantaneous flows. The regional analysis has the following advantages:

- ✓ Their results are applicable to non-instrumented localities (which have no measurement).
- ✓ Their results are more reliable than those of the local analysis when the lengths of the series are less than 25 data.
- ✓ It can replace the short records of observations with a wide space distribution of measuring equipment.
- ✓ It increases the length of available records by transferring information from the different stations that make up a region.
- ✓ It allows to deal the problem of two different populations superposition in the set of rains, which can be caused by different precipitation mechanisms: convective, orographic or cyclonic rains, allowing to gather databases with different origins.

The parameters of a distribution, for example the shape, do not vary much through a specific area or region.

The regional analysis complies with the following stages:

1. Analysis and filtering of the primary observations data.
2. Selection of equipment for regional analysis.
3. Identification of the equipment that make up homogeneous regions.
4. Selection of the regional frequency distribution.
5. Estimation of regional frequency quantiles.

The techniques for hydrological regional analysis can be used in a complementary way and are the following:

- Technique of the seasons-year.
- Correlation technique and multiple regression.
- Method of Dalrymple, 1960.
- Regional application of the Box-Cox transformation.
- Method of the f weighted probability standardized moments.
- Method of extreme values multivariate estimation.

As previously stated, one of the stages of the regional analysis is the selection of equipment to be used in the study, which determines from the quality, length and location of the stations, which of them

should be taken into account in the analysis. In the case of precipitation series, the criteria listed below should be considered:

Criterion 1. Length of the series to be used (N).

The series used in the regional analysis will be the annual maximums series (AMS), of which it is proposed that the minimum length limit of the record to be used will be 10 years.

The minimum number of values is obtained which generates an arithmetic mean of the series that is representative or stable. For this, the number of observation years is plotted with the value of the average for the number of years observed, that is, the average is recalculated each time an observation corresponding to a new year is considered. Figure I.1 shows an example of how the graph would look for a series of annual maximum daily rains, establishing as 13 the minimum value of observations, where greater stability in the value of the mean is reached.

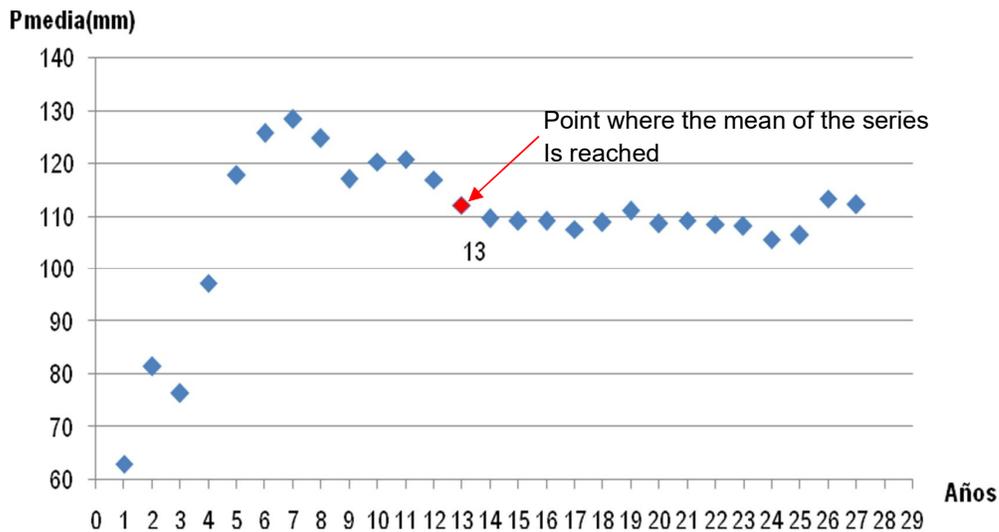


Figure I.1: Example of the graphical method applied to a series of annual maximum daily rains to determine the year's minimum number of records needed to obtain greater stability in the average of the series.

Criterion 2. Quality of the annual maximum series.

For the results of the probabilistic analysis to be theoretically valid, the series of historical data must meet certain statistical criteria: randomness, independence, homogeneity and seasonality. Randomness means that the fluctuations of the variable are caused by natural causes; Independence refers to the fact that no data of the series is influenced by previous values, or that it does not influence subsequent ones; homogeneity implies that the data come from the same population and, finally, seasonality means that the statistical properties of the data do not change over time.

Criterion 3. Influence of the equipment in the study area.

It is important to determine the influence of the equipment in the study area. It is recommended to apply some method to determine if the equipment located at short distances, outside the drainage basin, has influence or not in the study area. The method of the Thiessen polygons (although it is advisable to apply it in relatively flat regions, where the effect of the topography does not affect the behavior of the precipitations) is the most used for this purpose.

The rainfall information available for the study was daily rainfall data for 70 equipment located in Villa Clara and Sancti Spíritus provinces, which collected rainfall data for the period between 1923 and 2007 (Figure I.2).



Figure I.2: Location of the rain gauges and the hydrometric stations available for the study.

As previously stated, the series of annual maxima must be independent, random and homogeneous, essential requirements to proceed with a statistical or probabilistic modeling; that is why an examination was carried out in each of the 70 series corresponding to each equipment, after using the Johnson transform, with the aim of normalizing these series and being able to apply both the parametric and nonparametric tests. The result of the homogeneity analysis of all the series is shown in Table I.1.

Analyzing the results of table I.1, it can be concluded that the series of stations SS-454, SS-463 and SS-869 are homogeneous according to three tests of the six examined and the equipment SS-865 and VC-449 they are only homogeneous by two of the tests. The rest of the stations in most tests are homogeneous so it can be considered that their values belong to the same location.

Equip.	F	T	C	Spearman	Hel.	S	Equip.	F	T	C	Spearman	Hel.	S
SS-406	H	H	H	PLP	NH	H	SS-867	H	H	H	No PLP		H
SS-422	H	H	H	PLP	H	H	SS-868	H	NH	H	No PLP	NH	H
SS-423	NH	H	H	No PLP	H	H	SS-869	NH	H	H	No PLP	NH	NH
SS-432	H	H	H	No PLP		H	SS-875	H	H	H	No PLP	H	H
SS-433	NH	H	H	No PLP	H	H	SS-897	H	NH	H	No PLP	H	H
SS-435	NH	H	H	No PLP	NH	H	SS-918	NH	H	H	No PLP	NH	H
SS-436	NH	H	H	No PLP	NH	H	SS-919	H	H	H	No PLP		H
SS-443	H	H	H	No PLP	H	H	SS-920	H	H	H	No PLP		H
SS-450	NH	H	H	No PLP		NH	SS-932	NH	H	H	No PLP	H	H
SS-451	H	H	H	No PLP	H	H	SS-934	NH	H	H	No PLP	H	H
SS-454	NH	H	H	PLP	NH	H	SS-935	H	H	H	No PLP		H
SS-463	H	NH	H	PLP	NH	H	SS-936	H	H	H	No PLP		H
SS-502	NH	H	H	PLP	H	H	SS-937	NH	H	H	No PLP	H	H
SS-614	NH	H	H	No PLP	NH	H	SS-939	H	H	H	No PLP	H	H
SS-765	H	H	H	No PLP	H	H	SS-953	H	H	H	No PLP	H	H
SS-766	NH	H	H	PLP	H	H	SS-954	NH	H	H	No PLP	H	H
SS-768	H	H	H	No PLP		H	SS-966	NH	H	H	No PLP		NH
SS-769	H	H	H	No PLP	NH	H	SS-975	H	H	H	No PLP	H	NH
SS-772	NH	H	H	No PLP	H	H	SS-976	H	H	H	No PLP	NH	NH
SS-775	H	H	H	No PLP	H	H	SS-978	H	H	H	No PLP	H	H
SS-778	H	H	H	PLP	NH	H	SS-986	H	H	H	No PLP	H	H
SS-779	H	H	H	No PLP	H	H	VC-402	H	H	H	No PLP	NH	H
SS-780	H	H	H	No PLP		H	VC-403	H	H	H	No PLP	H	H
SS-781	H	H	H	No PLP	H	H	VC-410	NH	H	H	No PLP		H

SS-783	H	H	H	No PLP		H	VC-411	H	H	NH	No PLP	NH	H
SS-784	H	H	H	No PLP		H	VC-414	H	H	H	No PLP		H
SS-788	H	H	H	No PLP	H	H	VC-415	NH	H	H	No PLP	NH	H
SS-795	H	H	H	No PLP	H	H	VC-417	H	H	H	No PLP		H
SS-796	NH	H	H	No PLP		H	VC-420	H	H	H	No PLP	H	H
SS-844	NH	H	H	No PLP		NH	VC-421	H	H	NH	No PLP		H
SS-862	NH	H	H	PLP	H	H	VC-428	H	H	H	No PLP	H	H
SS-863	NH	H	H	No PLP		H	VC-429	H	H	H	No PLP	H	H
SS-864	NH	H	H	No PLP		H	VC-445	NH	H	H	No PLP	H	H
SS-865	NH	H	H	PLP		NH	VC-447	NH	H	H	No PLP		H
Equip.	F	T	C	Spearman	Hel.	S	Equip.	F	T	C	Spearman	Hel.	S
SS-866	NH	H	H	No PLP	H	H	VC-449	NH	H	H	PLP	NH	NH

Table I.1. Results of the homogeneity statistical tests for each of the annual maximum series.

Remarks: The three parametric tests used are: F: Fisher, T: Student's T, C: Cramer and the three nonparametric tests: Spearman, Hel: Helmer, S: Sequences. The acronyms of the results are: H: Homogeneous, NH: Non-homogeneous, PLP: Long-term persistence. The blanks in the Helmer test indicate that for the series used, the number of changes is greater than the number of sequences and the software is not programmed for negative differences between the number of sequences and the number of changes.

Taking into account that the lack of homogeneity does not necessarily imply the impossibility of processing the data by statistical means, but a restriction of the volume of information, since one must select a subseries (preferentially, the oldest or original) within the total sample, these five series mentioned in the previous paragraph, were re-examined, eliminating the values registered from 1993 onwards (this criterion was taken because as of this year the recorded observations are not very reliable, as stated by part of the INRH officials). From this analysis it was obtained that in the first four stations, all the homogeneity tests show that the series are homogeneous (in none of the cases the series was reduced to less than 10 values), while in the last station the tests of Spearman and the sequences are still showing that the series is not homogeneous, but it is not discarded because it is homogeneous by the Fisher parametric tests and Student's T test, which are very significant.

Regarding the results of the first-order serial autocorrelation coefficient, their values oscillate between -0.459 and 0.487, values that are a little bit high, but due to the nature of the phenomenon being analyzed, this result does not matter, since the Maximum daily rainfall for one year is not related at all, with the one recorded the following year, so the series can be considered independent and random.

As a first decision for the conformation of the sub-regions, the equipment that have 10 or less values are eliminated, in this case the equipment SS-953 and SS-954 are found. In the case of the second criterion, the series of annual maximum daily rainfall, the 70 equipment analyzed in the study, reach

the stability of the average in the range of 8 to 14 values, so the limit value of 10 corresponds to the lower value of the interval mean.

After eliminating the two equipment from the 70 stations, the sub-regions were formed, with the information from the 68 rain gauges, using the GIS, ArcMap v.10.2, obtaining maps showing the behavior of the average rain (this variable is determined from the series of maximum daily rainfall of the rain gauges per year), and the height corresponding to each equipment.

Figure I.3 shows the representation of the behavior in the GIS of the average annual maximum rainfall values, combined with the corresponding heights of each equipment, resulting in four well-defined regions, where each color range represents the division of the basin into zones for regional analysis.

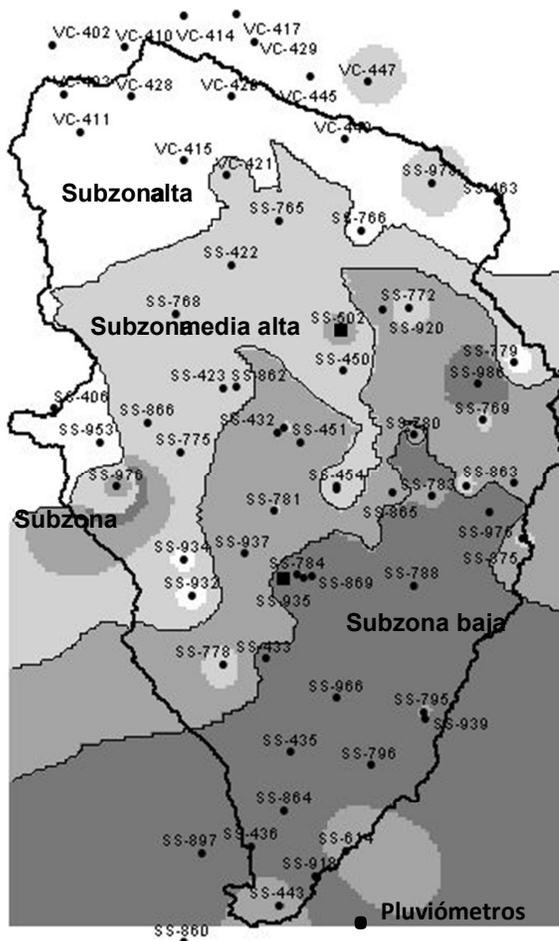


Figure I.3: Representation of the areas in which the basin is divided for regional analysis.

Table I.2 lists the equipment that make up each sub-region for the regional analysis study of the annual maxima series in Zaza basin.

Table I.2. List of equipment that make up each sub-region.

N	Low	Medium	Medium high	high
1	SS-433	SS-432	SS-422	SS-766
2	SS-435	SS-451	SS-423	SS-953
3	SS-436	SS-502	SS-450	SS-406
4	SS-614	SS-769	SS-454	SS-463
5	SS-784	SS-772	SS-765	SS-978
6	SS-788	SS-778	SS-768	VC-402
7	SS-795	SS-780	SS-775	VC-403
N	Low	Medium	Medium high	high
8	SS-796	SS-781	SS-779	VC-410
9	SS-860	SS-783	SS-862	VC-411
10	SS-864	SS-863	SS-866	VC-414
11	SS-869	SS-865	SS-868	VC-415
12	SS-897	SS-867	SS-932	VC-417
13	SS-918	SS-875	SS-934	VC-420
14	SS-935	SS-919	SS-976	VC-428
15	SS-936	SS-920	VC-421	VC-429
16	SS-939	SS-937		VC-445
17	SS-966	SS-986		VC-447
18	SS-443			VC-449
19	SS-975			

To support the analysis of the equipment corresponding to each subzone, the technique of the statistically homogeneous zone (SHZ) was used, using the average of each subzone as parameters. An example of the result of this test is shown in Figure I.4 for the low subzone.

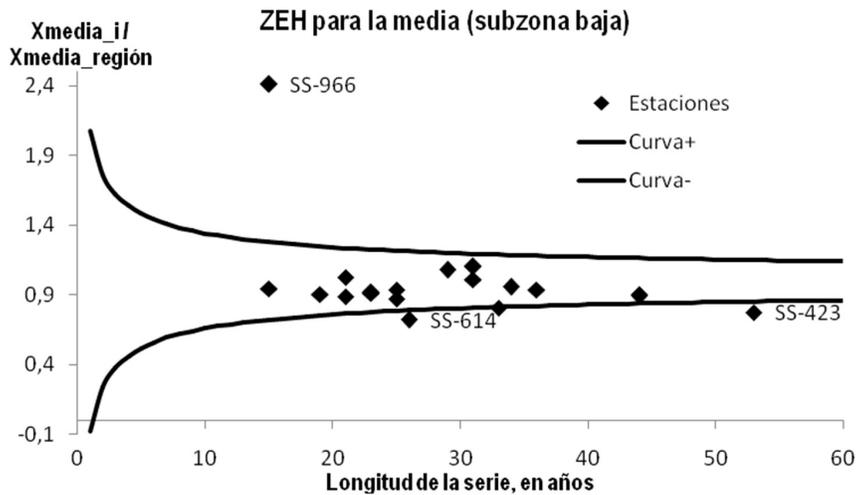


Figure I.4: Statistically homogeneous zone for the low sub-region, according to the average.

By applying the Index flood method, with the help of the Xtest program, to the stations contained in each of the regions, the four sub-regions are homogeneous. The details of these results can be seen in table I.3.

Table I.3. Summary of the results of the regional analysis for the 4 delimited sub-regions.

Subzone	Nb initial equipment	Nb final equipment	H value	Criteria for the elimination of equipment from the sub-region
Low	19	16	0,55	Faulty equipment (SS-939 and SS-966) and equipment that perform similar to another sub-region (SS-614)
Medium	17	16	0,79	Equipment that perform similar to another sub-region (SS-502)
Medium high	15	11	1,00	Faulty equipment (SS-775), equipment near the region boundary (VC-421) and equipment that worsens the value of H (SS-768, SS-765)
High	18	15	0,83	Equipment near and outside the drainage basin (VC-403, VC-445 and VC-402)