Quick start guide

"Chaak: Urban Hydrological Impact Modeling"

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Requeriments and installation

The Chaak: Urban Hydrological Impact Modeling software is a simulation, analysis, and modeling tool for stormwater drainage networks developed in the technical computing language MATLAB. Its main objective is to analyze the UHI of a watershed and assess its approach to ZHI through the implementation of SUDS provide a user-friendly environment.

The latest iteration was crafted to seamlessly function within the Windows 11 operating system. Developed using the MATLAB® technical computing language, this software necessitates a standard MATLAB installation with the Mapping Toolbox. Rigorous testing has been conducted to ensure optimal performance across MATLAB versions from R2017b onwards.

The software does not need any installation. To initialize Chaak, users need to navigate to the source code folder (*src*) in MATLAB and execute it from that directory. Once located in the directory, the execution continues by entering the command "Chaak" in the MATLAB command window.

Tutorial description

In order to demonstrate the functionality and capabilities of Chaak, this tutorial presents a simulation of drainage network operations, the determination of urban hydrological impact (UHI), and the effect of incorporating Sustainable Urban Drainage Systems (SUDS). The analysis area is located in Toluca, Mexico, within the Verdiguel River basin, delineated by extreme coordinates: 19°18'32"N - 99°39'53"W and 19°15'48"N - 99°38'01"W (Figure 1). This basin exhibits a sub-humid temperate climate with summer rainfall and an average elevation of 2670 meters above sea level.

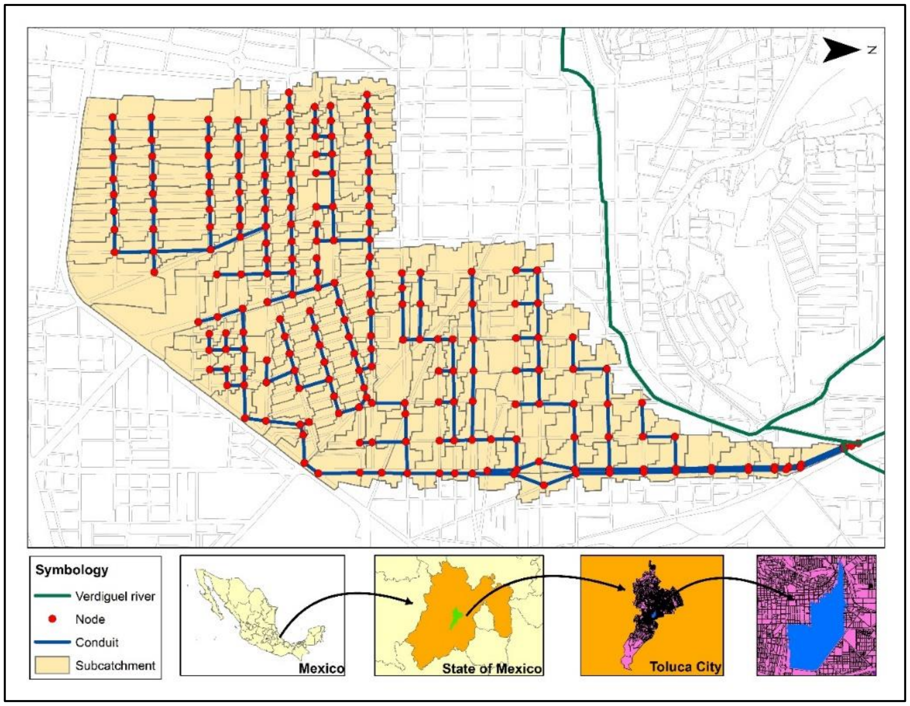

Figure 1. Partial drainage network of Toluca city

The Verdiguel River is one of the most significant drainage systems in the region, originating in the foothills of the Nevado de Toluca. It traverses the city center and eventually merges with the Lerma river several kilometers downstream. Throughout its course within the city, this watercourse has been modified to become part of the drainage network, receiving both sanitary and stormwater inputs collected through a combined sewer system. This, coupled with urban growth, has led to recurrent issues of ponding and flooding.

In summary, for the evaluation of UHI in Chaak, the following sections must be completed:

- Model creation.
- Configuration of simulation options.
- Estimation of urban and natural hydrological response (UHR).
- Estimation of SUDS hydrological response (NHR).
- Estimation of urban hydrological impact (UHI).
- Results analysis.

All files and information necessary for replicating the application example are located within the *Example_Files* folder, which contains three subfolders named *Stormwater_SHP_files*, *Runoff*, and *SUDS*, with the required files for the creation of the drainage network, parameters for estimating surface runoff, and creation of SUDS respectively (Figure 2).

The *Stormwater_SHP_files* folder contains all the necessary files for constructing the drainage network, where the information for each node, pipe, and basin element is distributed in Shapefiles. The Runoff folder contains three files named *Infiltration_data, Runoff_data,* and *Storm*. The *Infiltration_data* file contains the data required to estimate infiltration using the Soil Conservation Service Curve Number method. On the other hand, the *Runoff_data* file contains the information needed to estimate surface runoff using the kinematic wave method, and finally, the *Storm file* contains a design storm hyetograph with a 10-year return period.

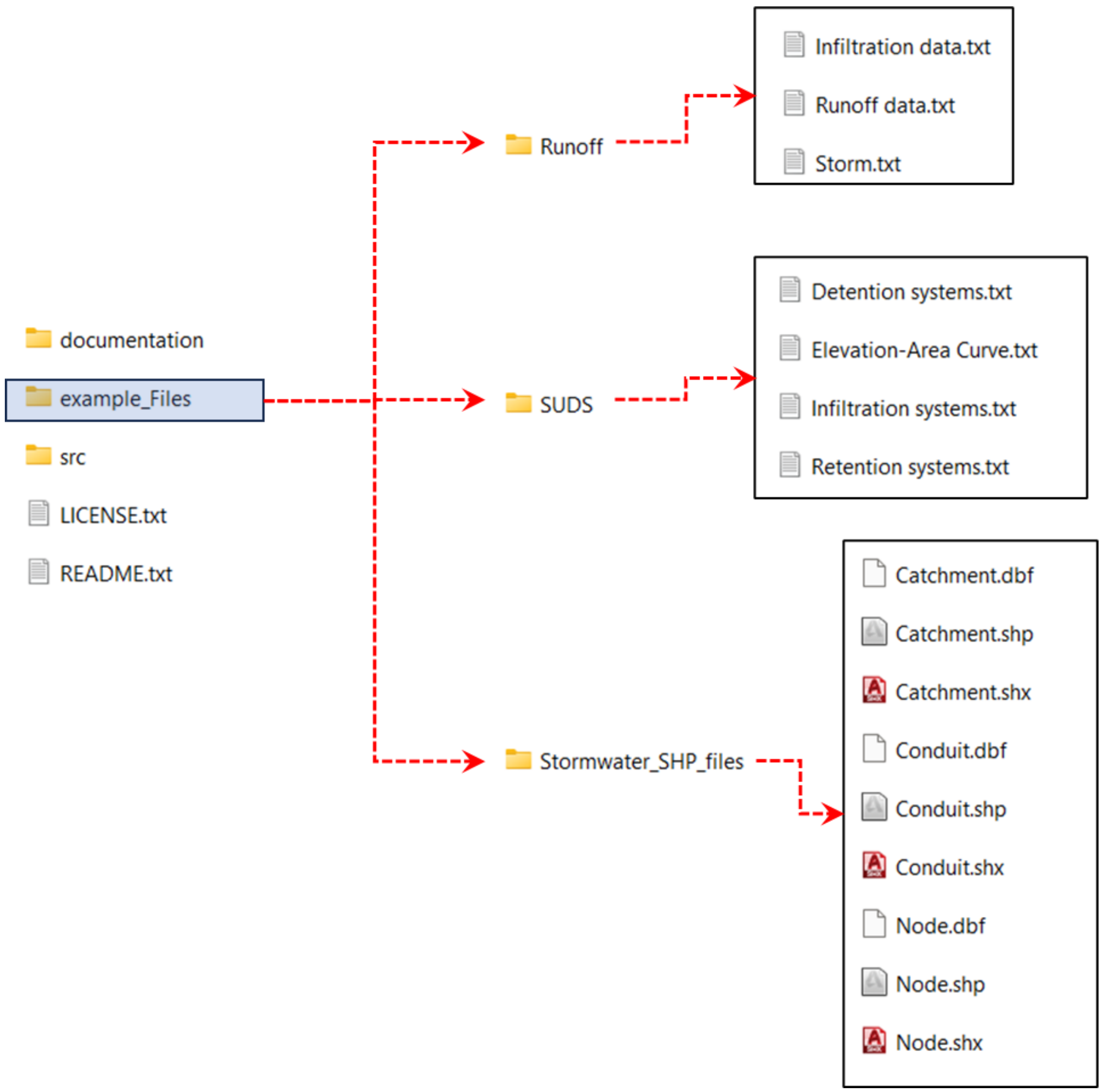

Figure 2. Required files for the simulation of the drainage network of Toluca city

Initialization of Chaak: Urban Hydrological Impact Modeling

To initialize Chaak_IHU correctly, it is necessary to locate the source code folder in MATLAB and execute it from that directory. To perform a successful execution, type the command *"Chaak"* in the MATLAB command window (Figure 3). Once Chaak is executed, an initial screen will appear as shown in Figure 4, from where access to the main workspace window is obtained.

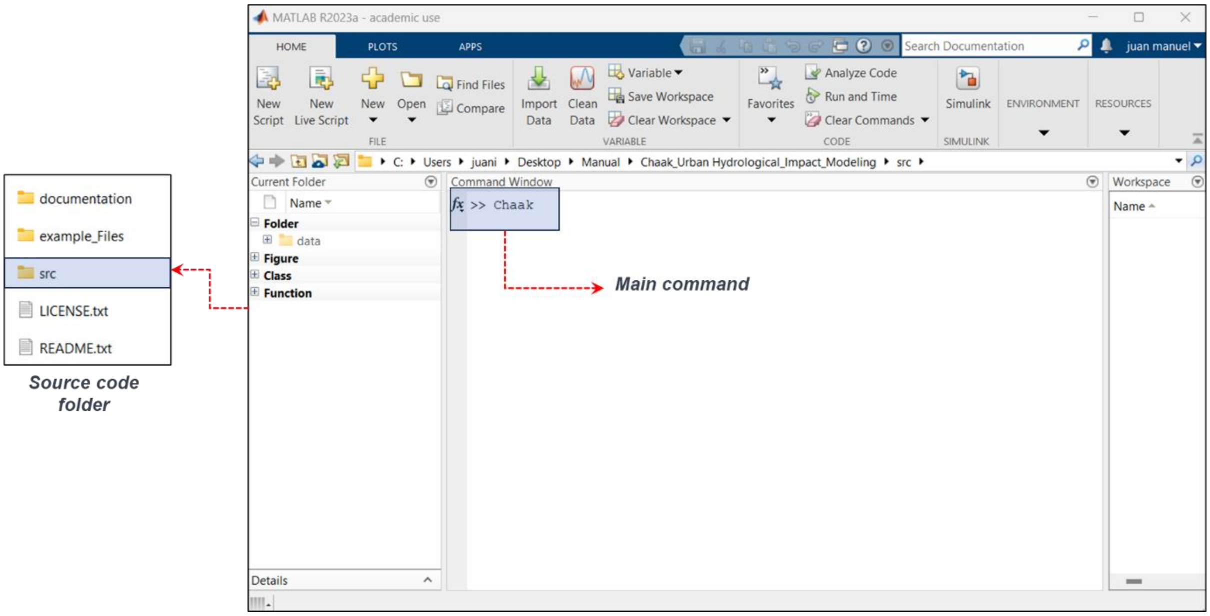

Figure 3. Setting up the MATLAB environment to run Chaak

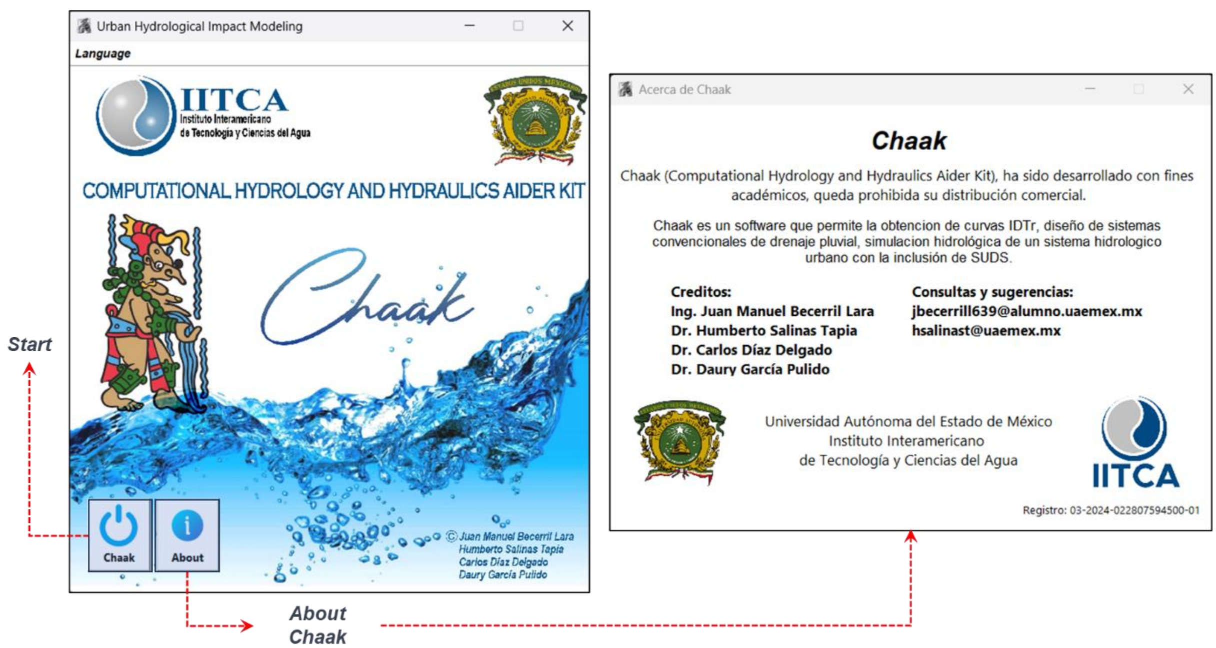

Figure 4. Initial window of Chaak: Urban Hydrological Impact Modeling

Create a new project

The main window of Chaak allows for managing the creation and opening of projects. Figure 5 illustrates the process of creating a new project, for which it is necessary to enter a name and saving path. In the selected path, a main folder with the project name will be generated, along with a MAT file containing the project name, enabling the opening of the project in subsequent work sessions. The information generated in each of the simulations performed will also be stored at this path.

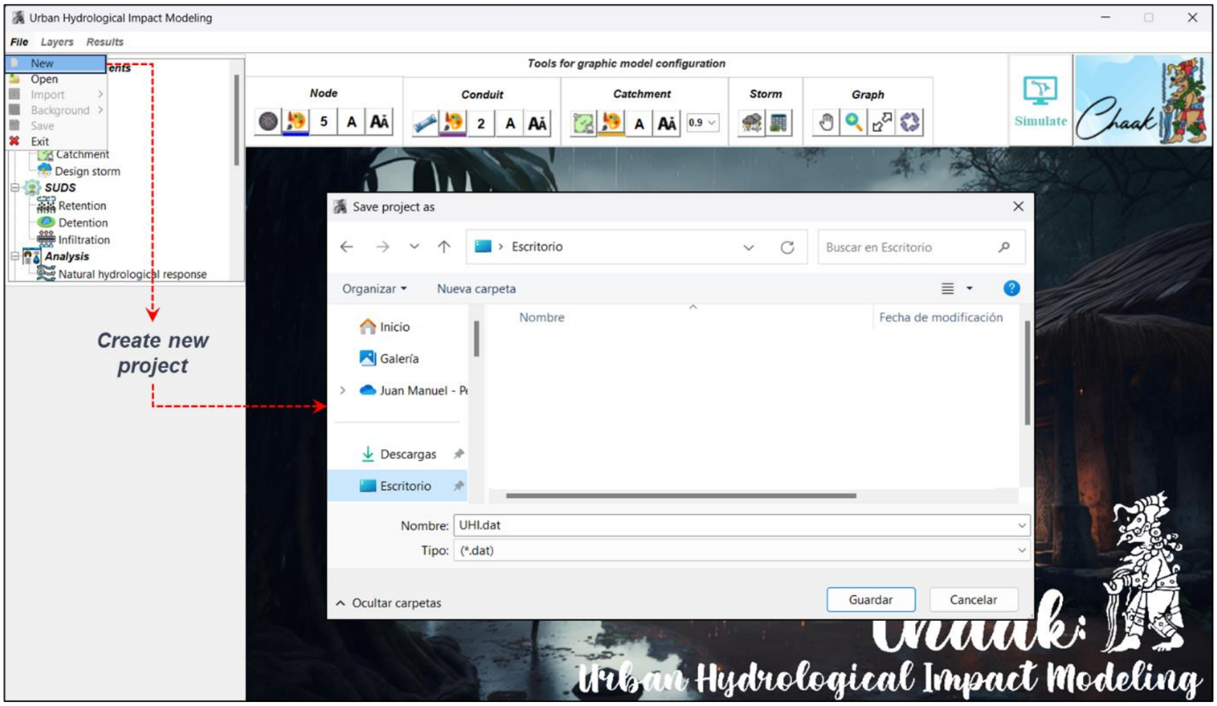

Figure 5. Main window of Chaak: Urban Hydrological Impact Modeling

When a project is created/opened, all available tools in the main interface are activated, allowing for the modeling and simulation of an urban drainage system. Figure 6 presents the main components of the user interface.

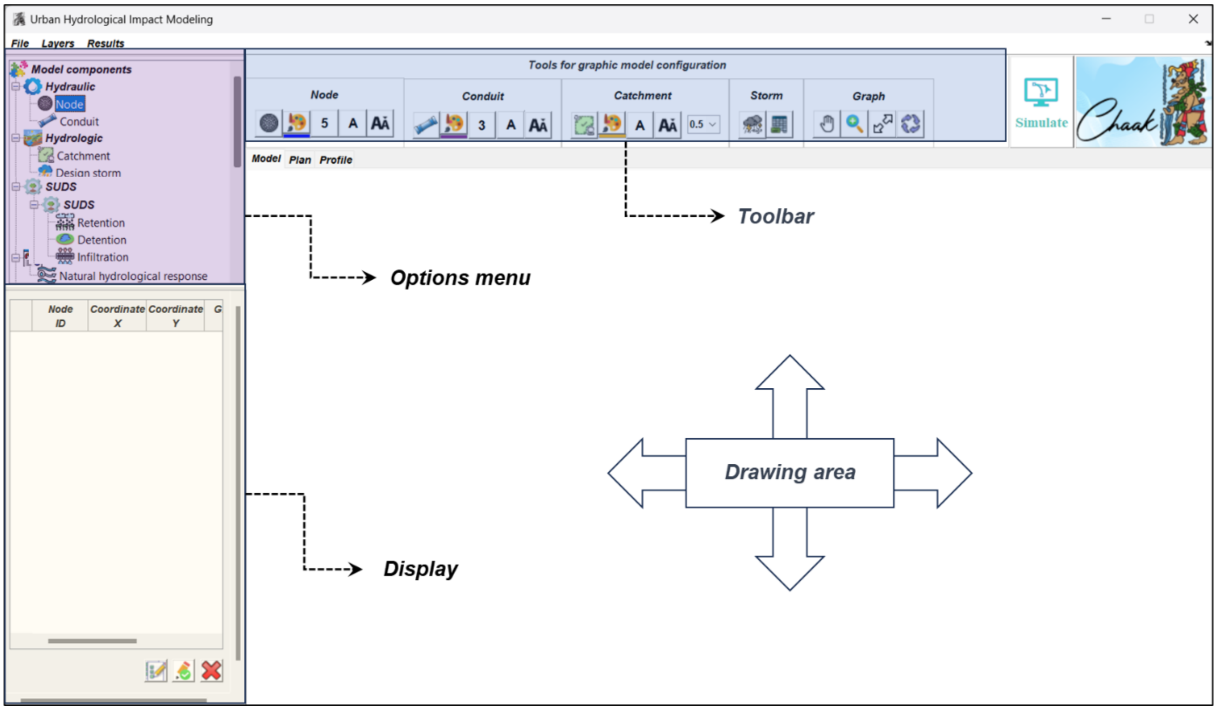

Figure 6. Components of the main window of Chaak: Urban Hydrological Impact Modeling

Construction and configuration of the drainage network

The tool features a graphical user interface for the interactive creation and configuration of a conventional urban drainage system. However, as an alternative to this manual process, importing the model via Shapefiles is allowed. Figure 7 illustrates the outlined process for constructing a drainage network by importing the files contained in the *Stormwater_SHP_files* folder. Once the process is completed successfully, the imported stormwater system will be displayed on the screen as shown in Figure 8.

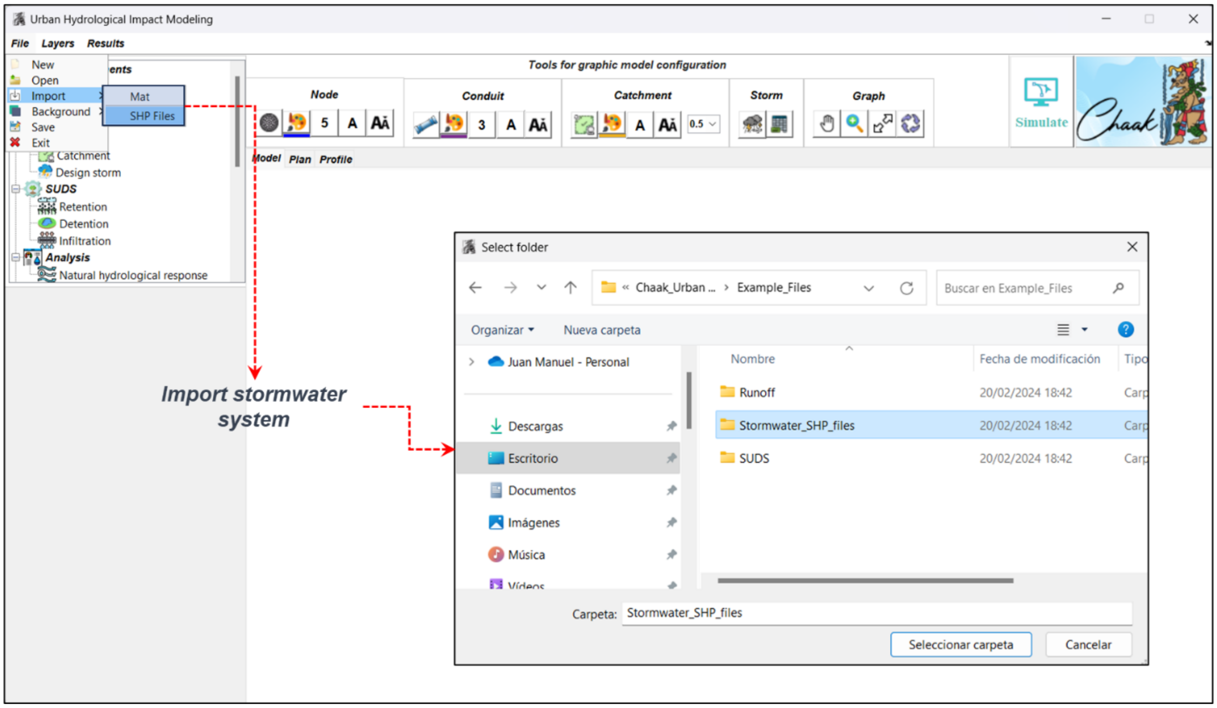

Figure 7. Construction of a stormwater system using SHP files in Chaak: UHI

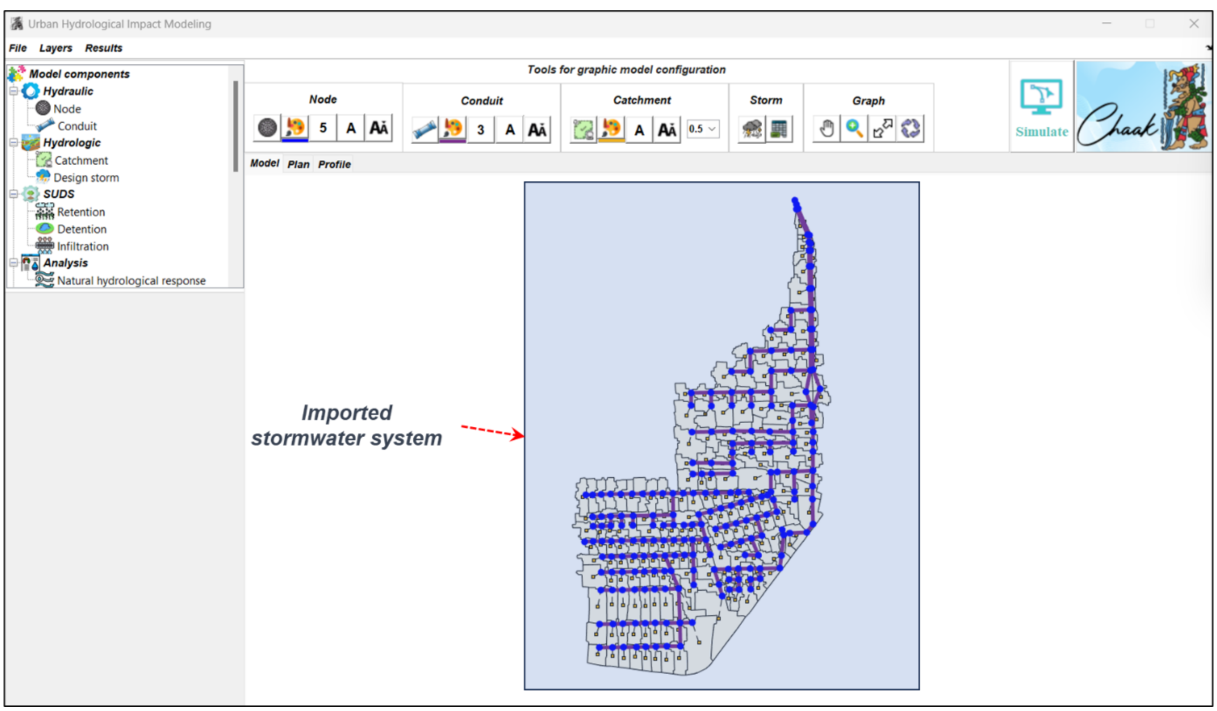

Figure 8. Representation of the drainage network of Toluca city in Chaak: UHI

The topology of the sewer network consists of 220 nodes, each representing a common manhole, i.e., points of flow entry into the drainage network. These elements are modeled through their topographic elevation levels and allow for the construction of Conduit-type elements. Figure 9 illustrates a diagram with the available options for edit and visualize Node-type elements.

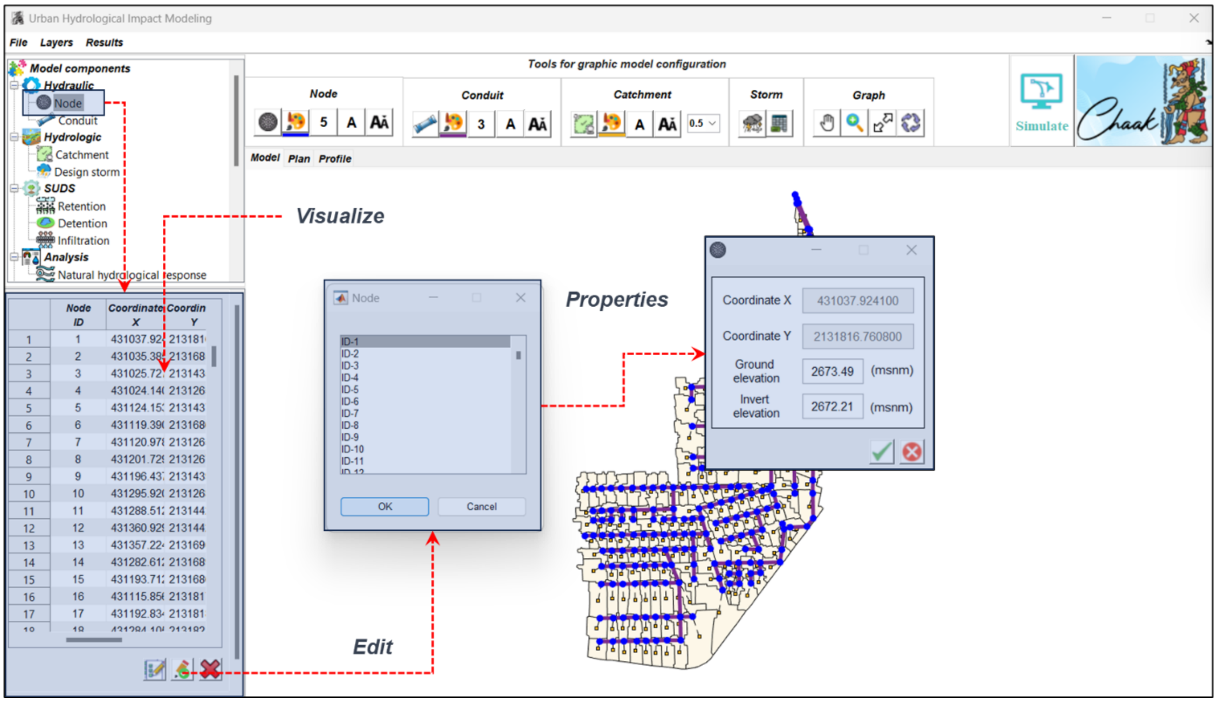

Figure 9. Visualize and edit options for Node-type element properties in Chaak: UHI

Similarly, the network comprises 221 pipes responsible for connecting each of the nodes, with a total length summing up to 21.49 km and presenting a circular cross-sectional area with diameters ranging from 0.3 to 1.98 m. These elements are tasked with transporting the drained rainwater to each node until its final discharge (Node ID-220). Figure 10 illustrates a schematic with the available options for edit and visualize Conduit-type elements.

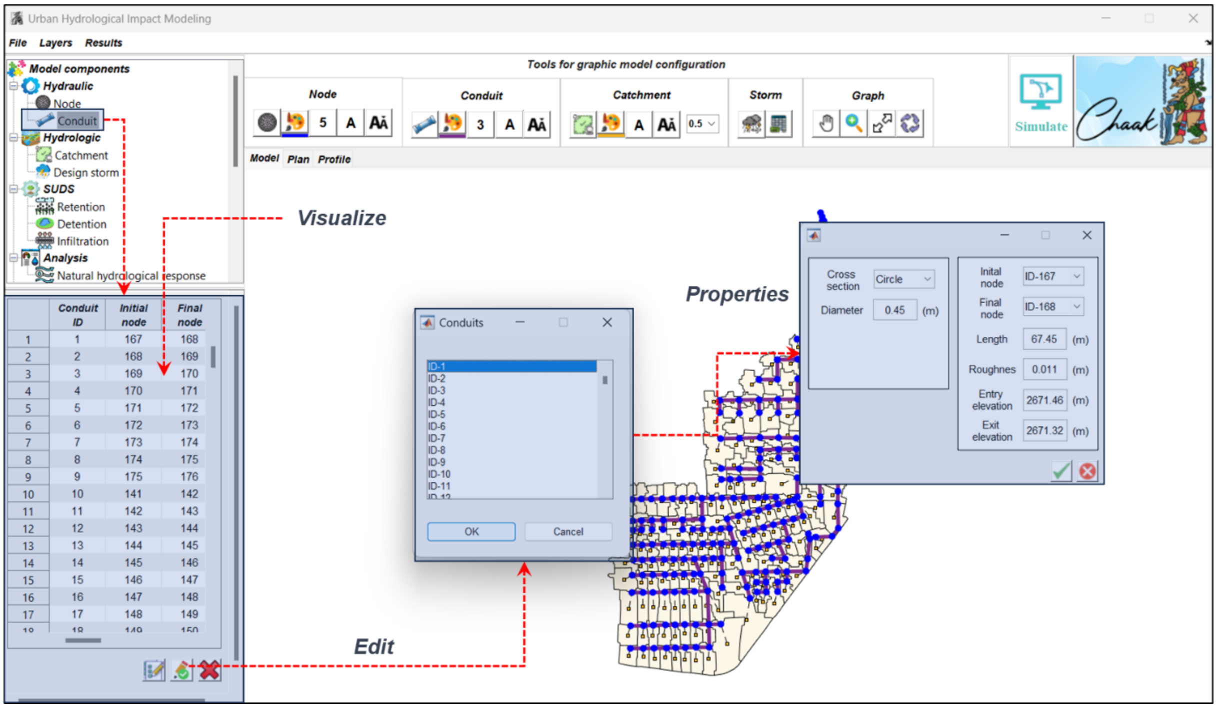

Figure 10. Visualize and edit options for Conduit-type element properties in Chaak: UHI

The study area has a catchment area equivalent to 372.22 hectares and is subdivided into 215 sub-catchments. This component is the main unit upon which surface runoff is modeled, which is subsequently drained to a node in the system. For its modeling, it is necessary to know the physical characteristics of the site so that the required information for the conceptualization of surface runoff and infiltration processes can be extracted. Figure 11 illustrates a diagram of how to import the parameters required for conceptualizing infiltration processes (*Infiltration_data*) and runoff (*Runoff_data*). On the other hand, Figure 12 presents a schematic with the available options for edit and visualize Catchment-type elements.

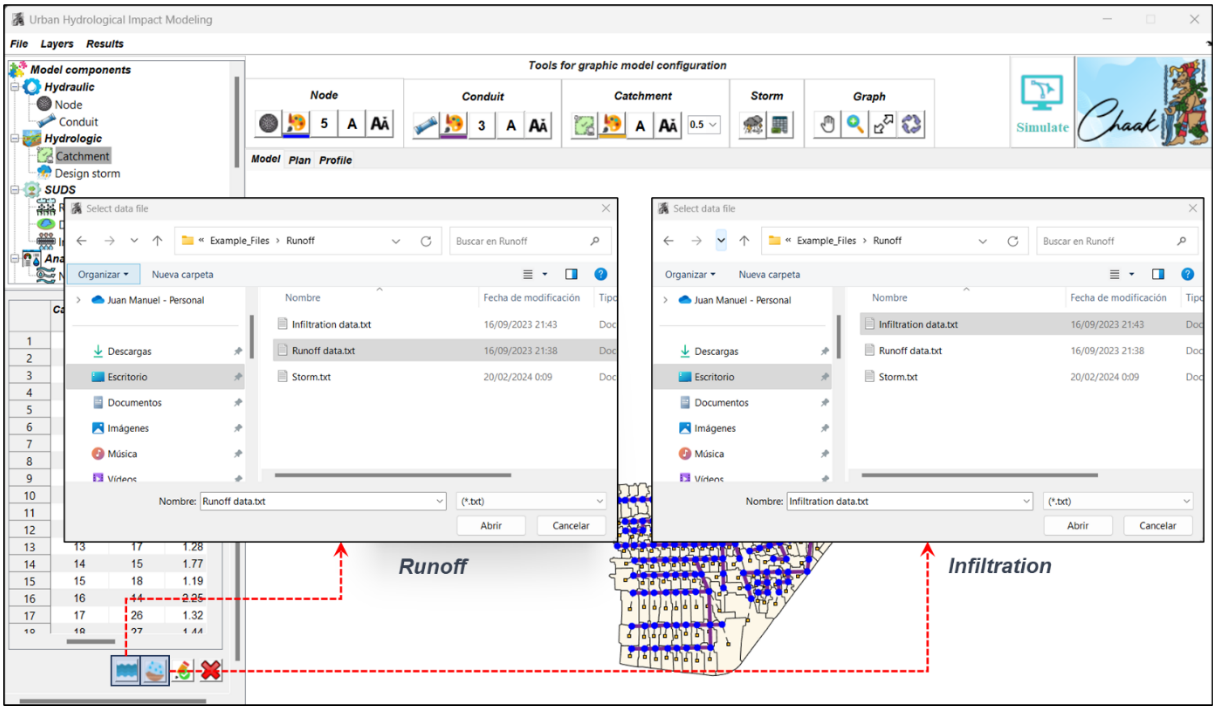

Figure 11. Import of infiltration and runoff parameters for Catchment-type elements in Chaak: UHI

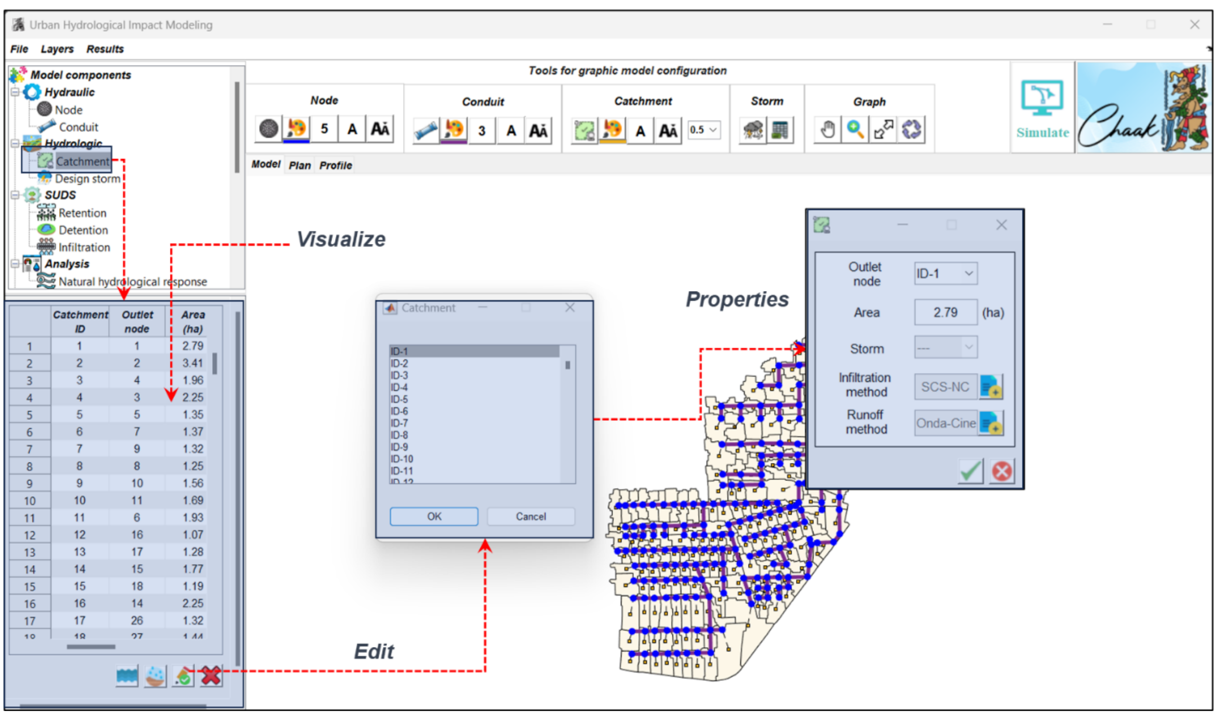

Figure 12. Visualize and edit options of Catchment-type element properties in Chaak: UHI

Creation of design storm

The last component of the model is the design storm, which allows representing the spatial and temporal distribution of a precipitation event. For the application example, a design storm with a return period of 10 years was considered, with a total duration of one hour, temporally distributed using a symmetric hyetograph with 5-minute blocks and with a total precipitation of 24.55 mm. Each storm can be created as shown in Figure 13 or by importing the data contained in the Storm file from the Runoff folder.

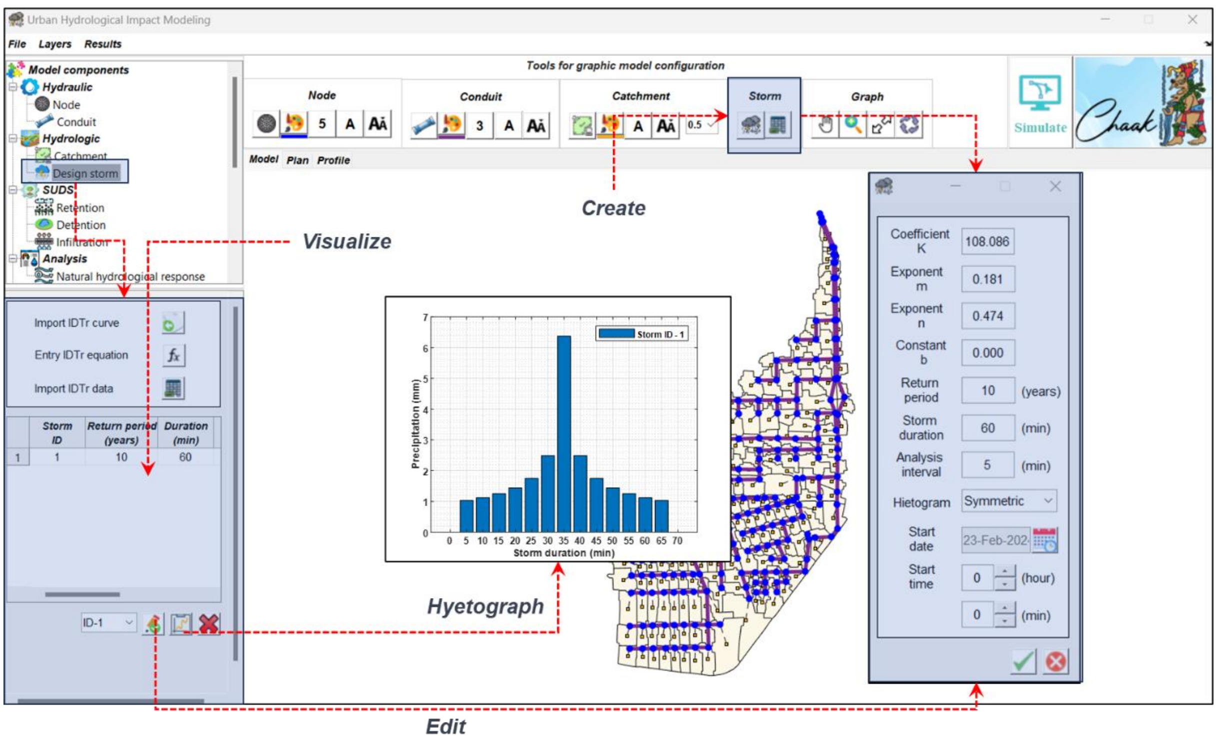

Figure 13. Creation, visualization, and editing of Storm-type elements in Chaak: UHI

Each catchment in the system must be associated with a design storm. To carry out this process, it is necessary to link the storm with each catchment, as shown in Figure 14. Chaak allows for the creation of multiple design storms in order to establish different analysis scenarios and improve the spatial distribution of precipitation.

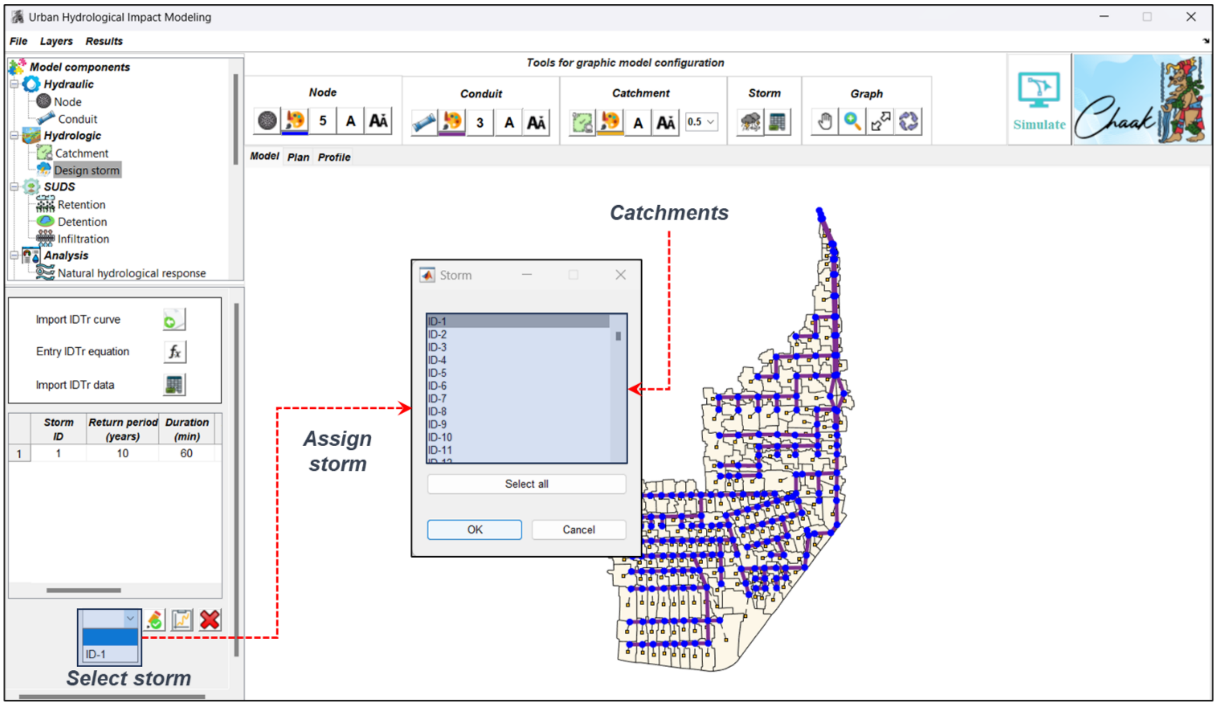

Figure 14. Assignment of design storm to Catchmen-type elements in Chaak: UHI

Conceptualization of natural hydrological response

The conceptualization of the NHR estimates how a watershed would behave if there were no urbanization within it. This provides a reference point for analyzing the hydrological changes undergone by the urbanization process. To represent the natural hydrological condition of the case study, the synthetic unit hydrograph from the Soil Conservation Service (SCS) was used, considering an area equivalent to 327.22 hectares, a concentration time of 80 minutes, and a curve number (CN) equal to 88 (Figure 15).

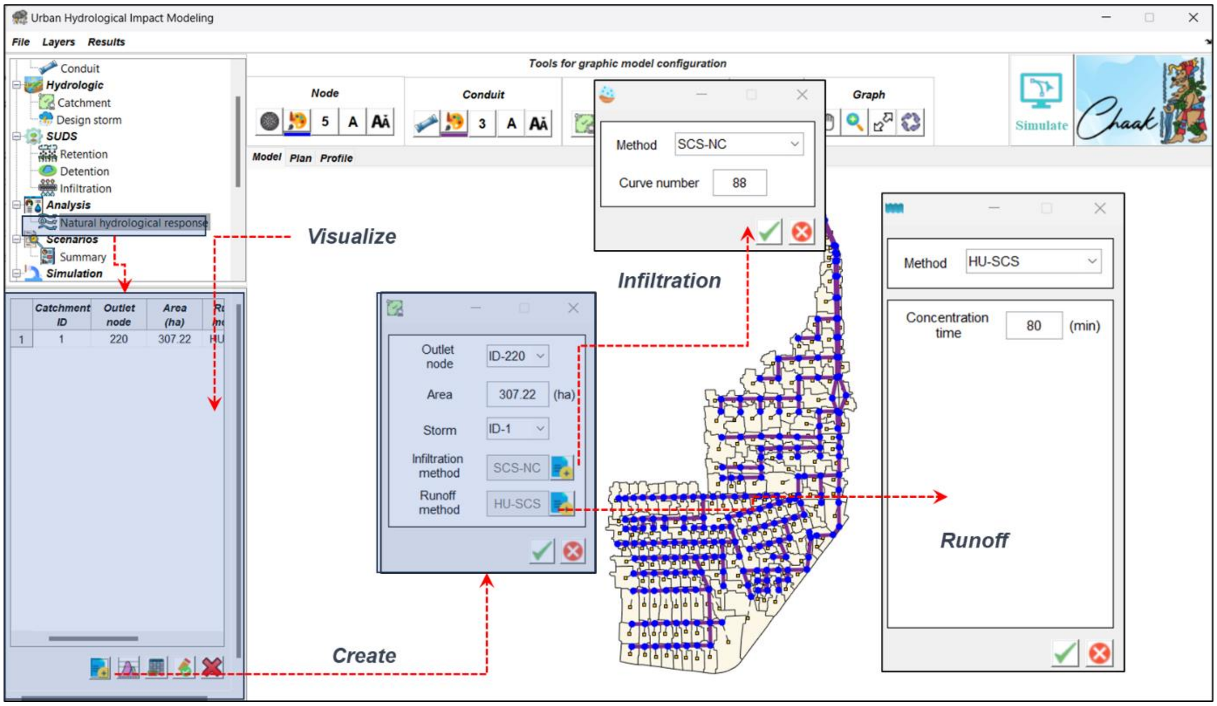

Figure 15. Creation, visualization, and editing of NHR in Chaak: UHI

Construction of sustainable urban drainage systems

SUDS are proposed as necessary measures to recover and/or reduce the hydrological processes lost during the urbanization process. In this way, it is assumed that achieving sustainable development is possible by safeguarding the site's hydrological conditions and associated benefits, such as reducing the number and potential damage caused by urban floods. The SUDS available for analysis are grouped into retention, detention, and infiltration typologies, and are generally constructed following the steps shown in Figure 16

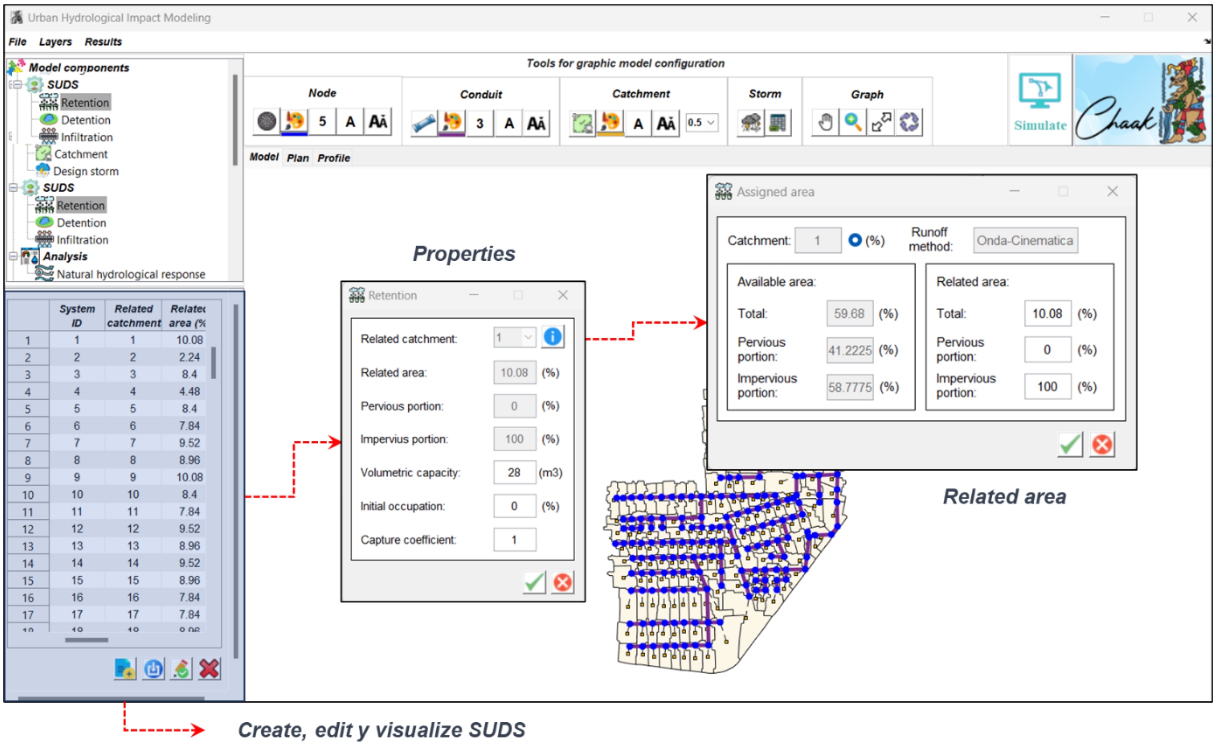

Figure 16. SUDS retention modeling in Chaak: UHI

The modeling of each SUDS depends on the needs and characteristics of the watershed on which it is to be implemented. The amount of specific information required to realistically analyze the planned system is considerable, and its description and theory are beyond the scope of this application example. However, in order to demonstrate the implementation of each SUDS typology in the case analysis, those sub-catchments with a high degree of urbanization were identified and assumed favorable conditions for the implementation of each system.

For retention systems, catchments with available space were identified, establishing a total drained area limit of 1 hectare, while proposing a retention potential of 1 m^3 of storage for every 1000 m^2 of area directly drained by the device (Figure 17).

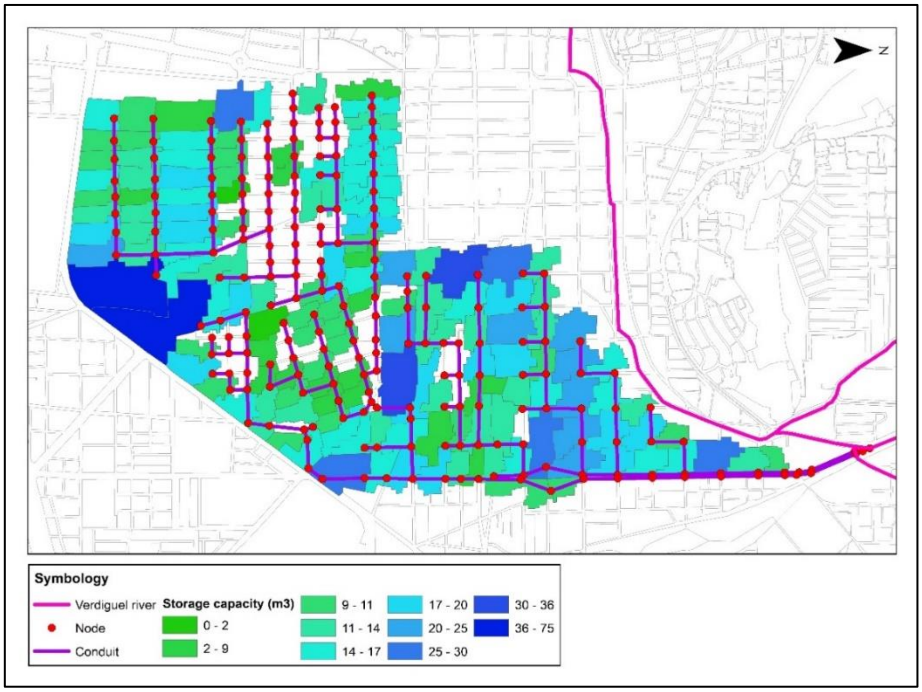

Figure 17. Location and storage capacity associated with the different retention systems incorporated in the study area

Regarding detention systems, 75 systems were defined (Figure 18) with a rectangular prism shape, considering a ratio of 50 to 1 of the catchment area to the device's plan area, with a maximum elevation of 1 m and circular orifice discharge control with a diameter of 5 cm and a discharge coefficient of 0.9. Finally, the incorporation of 68 infiltration systems (Figure 19) was conceptualized, considering the same catchment area to plan area ratio as the infiltration systems, with a storage of 0.5 m and a constant infiltration rate of 360 mm/h.

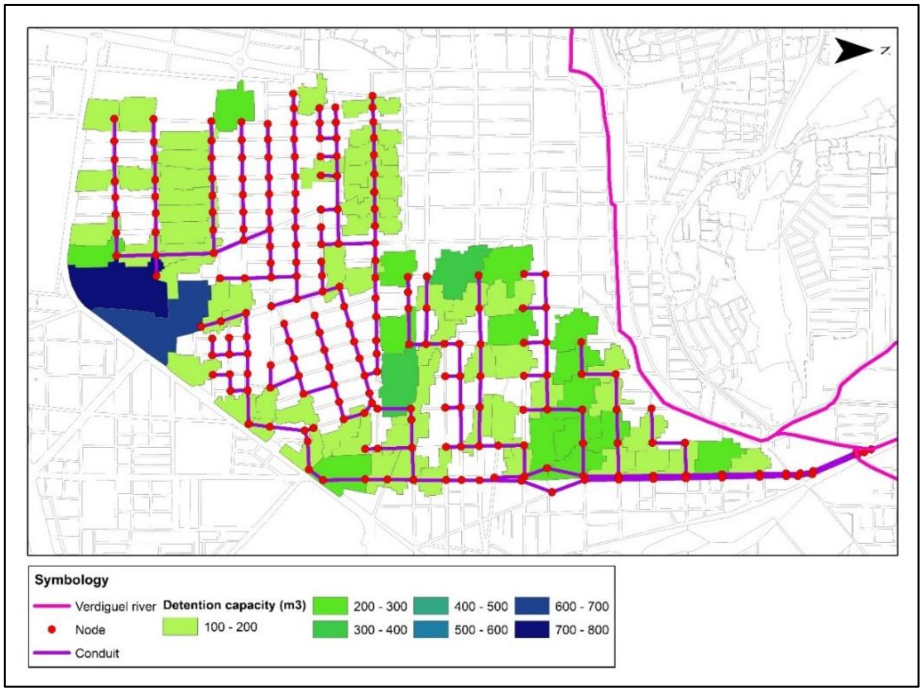

Figure 18. Location and storage capacity associated with the different detention systems incorporated in the study area

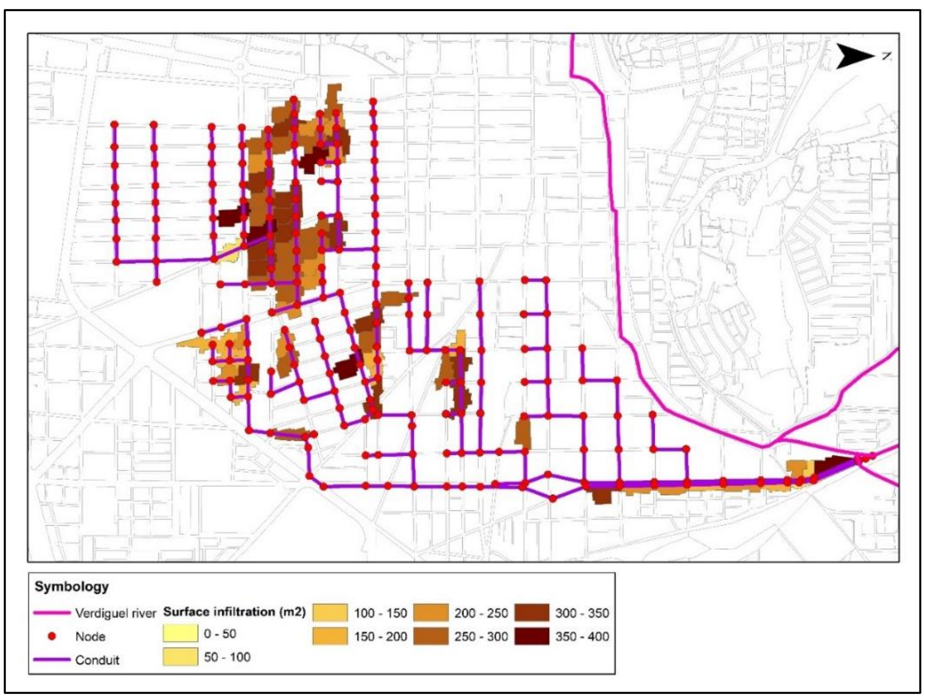

Figure 19. Location and infiltration area associated with the different infiltration systems incorporated in the study area

The systems described for the case study are created using the files available in the *SUDS* folder. Figures 20, 21, and 22 present the steps for creating the retention, detention, and infiltration systems, respectively.

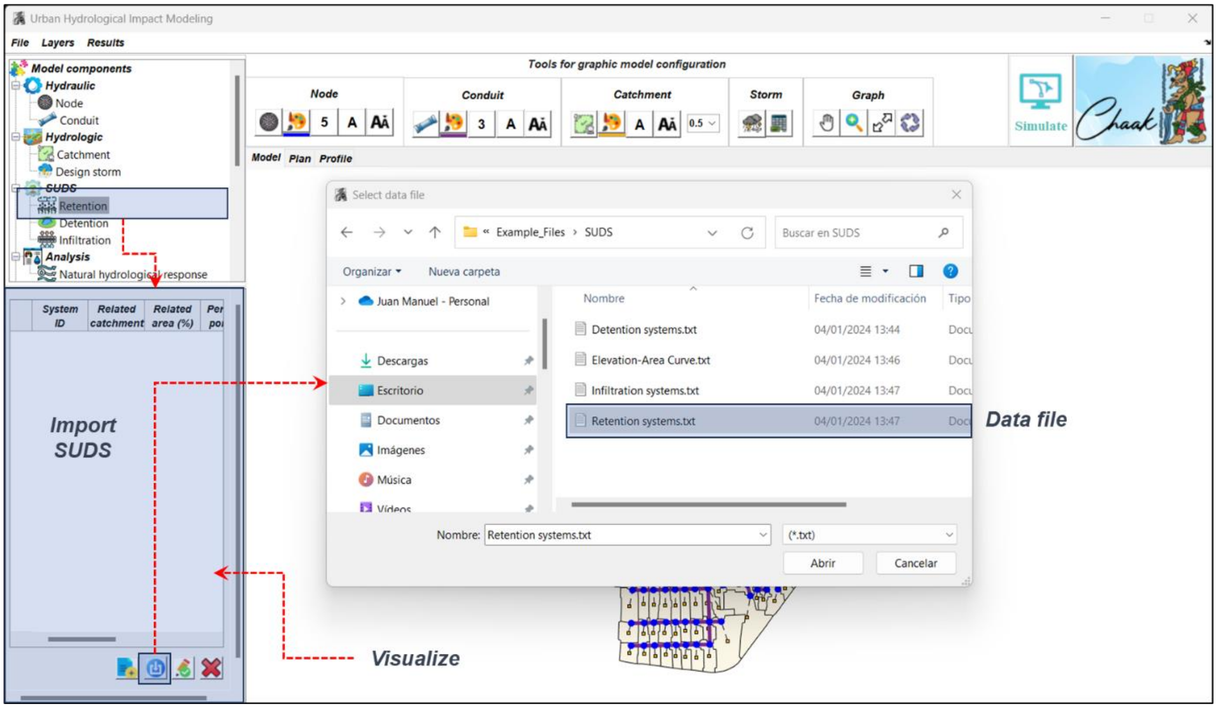

Figure 20. Importing retention systems in Chaak: UHI

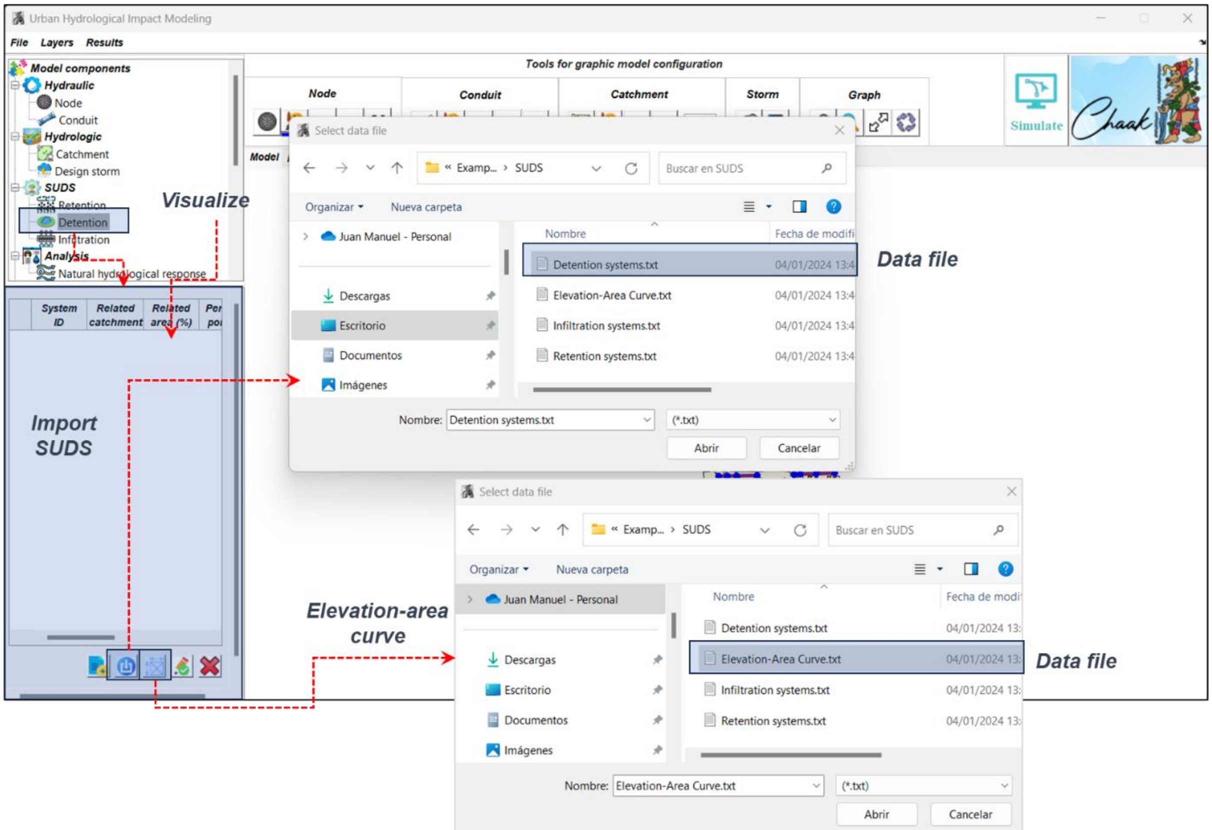

Figure 21. Importing detention systems in Chaak: UHI

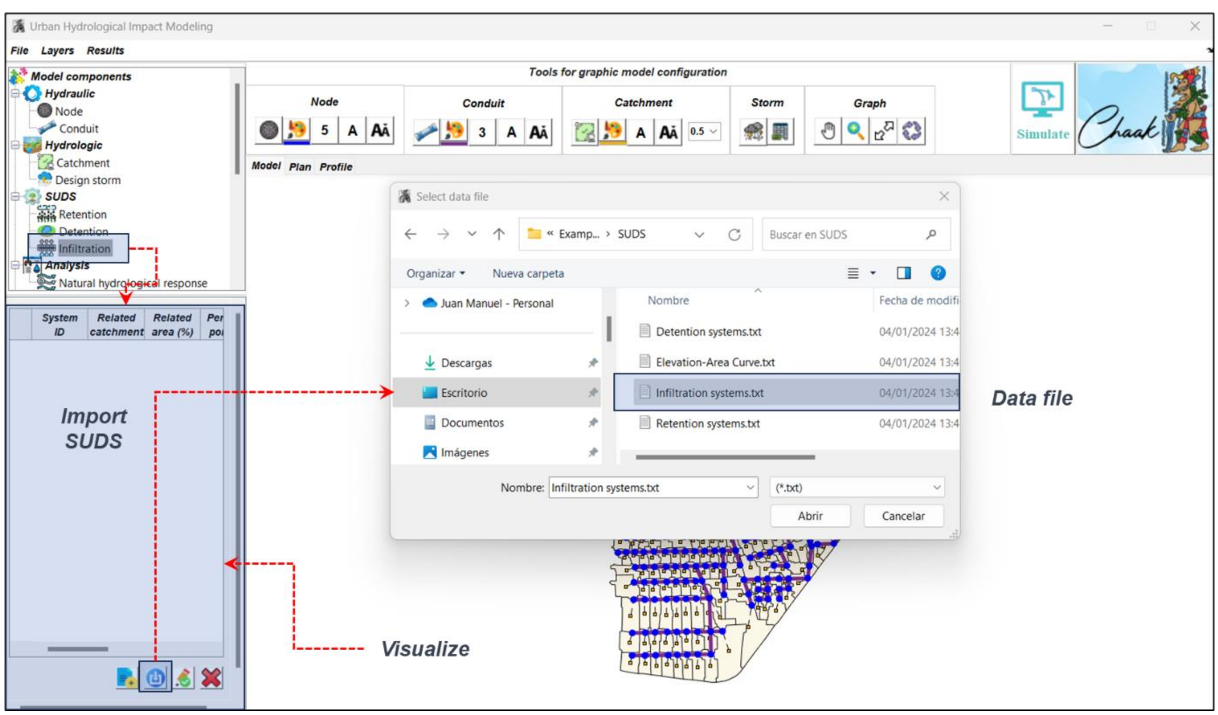

Figure 22. Importing infiltration systems in Chaak: UHI

Simulation options

Once the drainage network model is built, it is necessary to configure the general options and simulation time parameters. Figure 23 shows the general options to configure related to the hydraulic transit method to consider and the different hydrological responses to estimate.

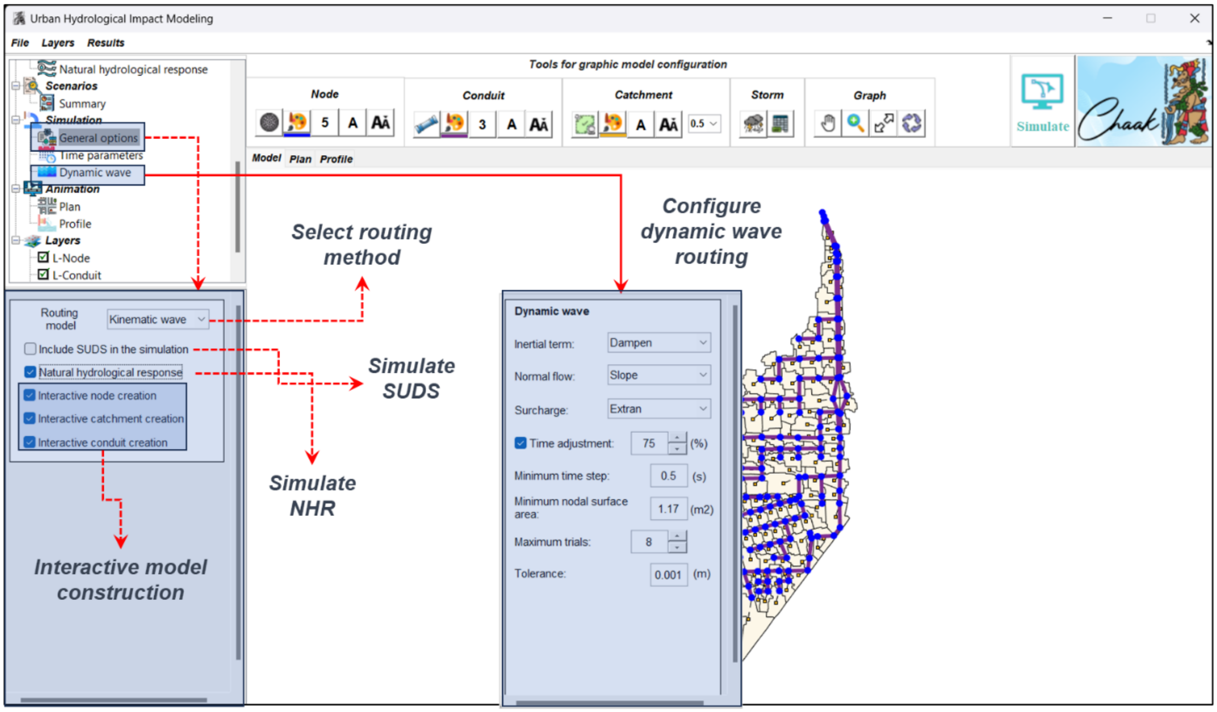

Figure 23. Configuration of simulation general options in Chaak: UHI

On the other hand, Figure 24 shows the configuration of the required time parameters. In each analysis case, it is necessary to define the start and end dates of the simulation, as well as the time steps required in the solution schemes. An important aspect to consider is that the simulation period between the start and end dates must encompass the temporality of the simulated precipitation event.

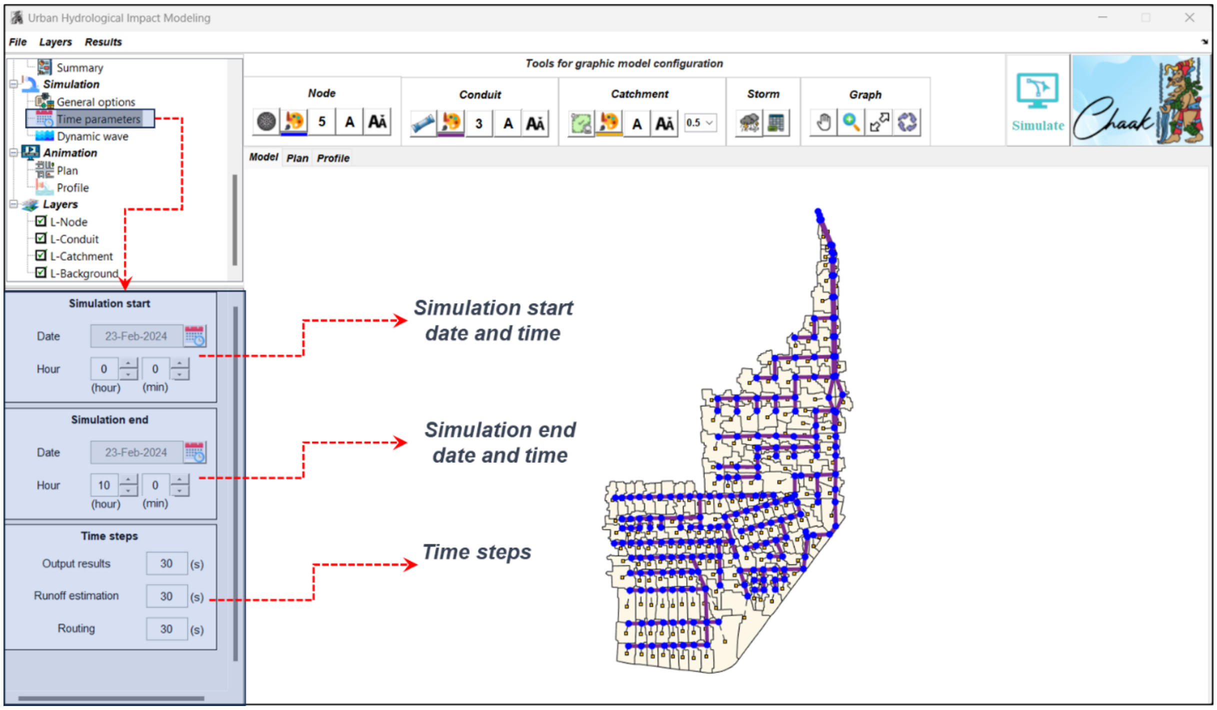

Figure 24. Simulation time configuration in Chaak: UHI

Estimation of UHI and operation of SUDS

One of the main objectives of the developed tool is to analyze the UHI. Its estimation is obtained through a direct comparison between the NHR and UHR obtained during the simulation process. The analysis process consists of evaluating two baseline scenarios, the first of which estimates the UHI, and a second one where the operation of the SUDS is simulated and changes in the UHI are analyzed.

In Figure 25, the steps required for simulating the first scenario are shown, while in Figure 26, the process required to configure the simulation of the SUDS is depicted. In both cases, it is assumed that the model has been successfully created and the simulation options have been configured.

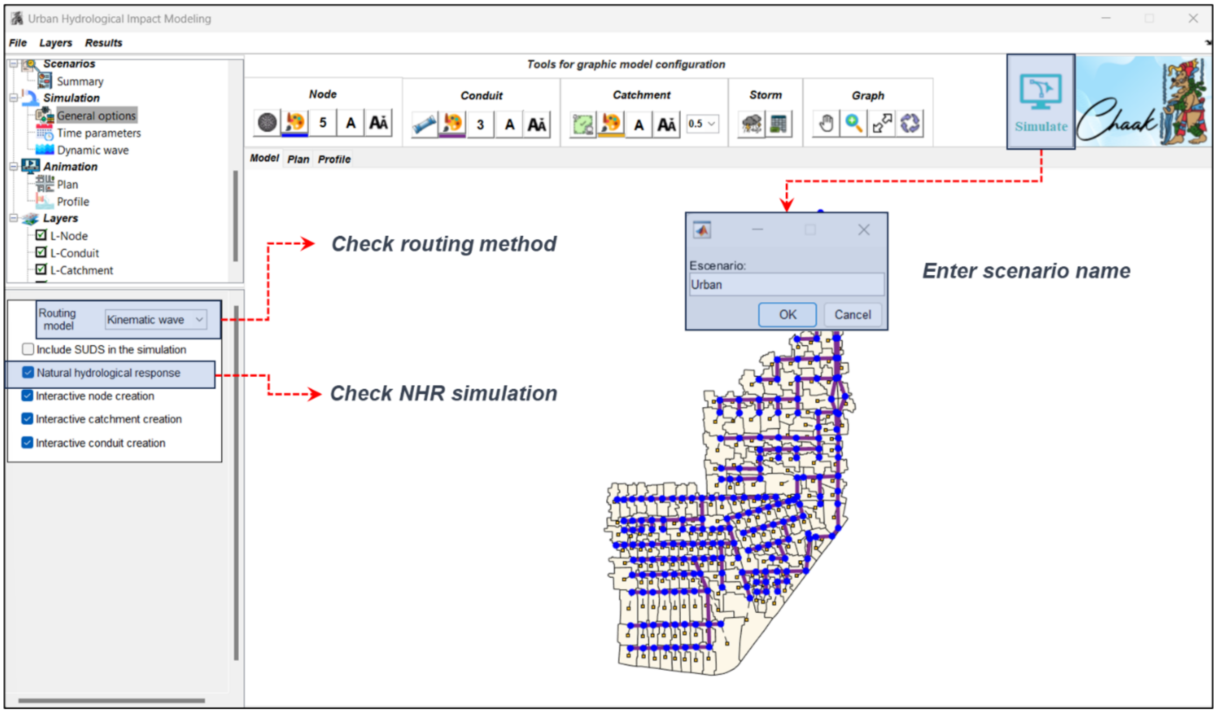

Figure 25. Setting up the baseline scenario for UHI estimation in Chaak: UHI

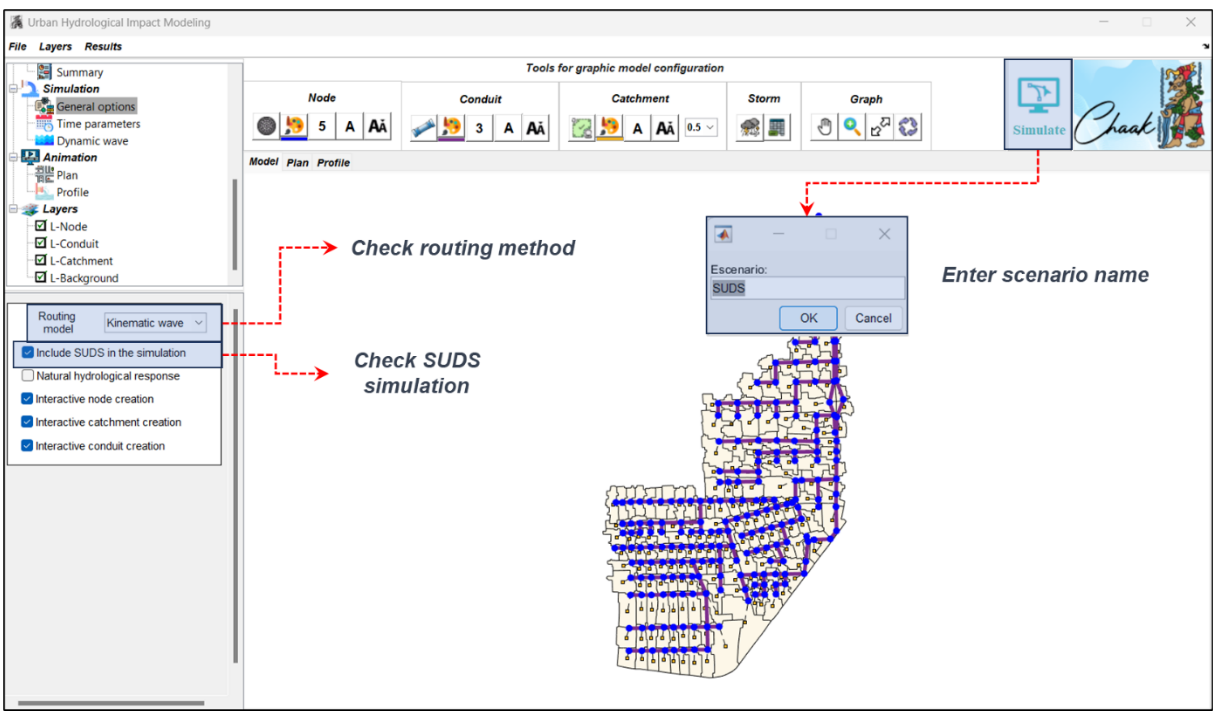

Figure 26. Setting up the baseline scenario to simulate the operation of SUDS in Chaak: UHI

Result visualization

Once the two baseline scenarios have been simulated, the conditions are set to visualize the obtained results. To observe the impact, it is necessary to go to the *Results* tab and select the *Urban Hydrological Impact* option, which will display a window designed to allow the comparison of the hydrological responses (Figure 27).

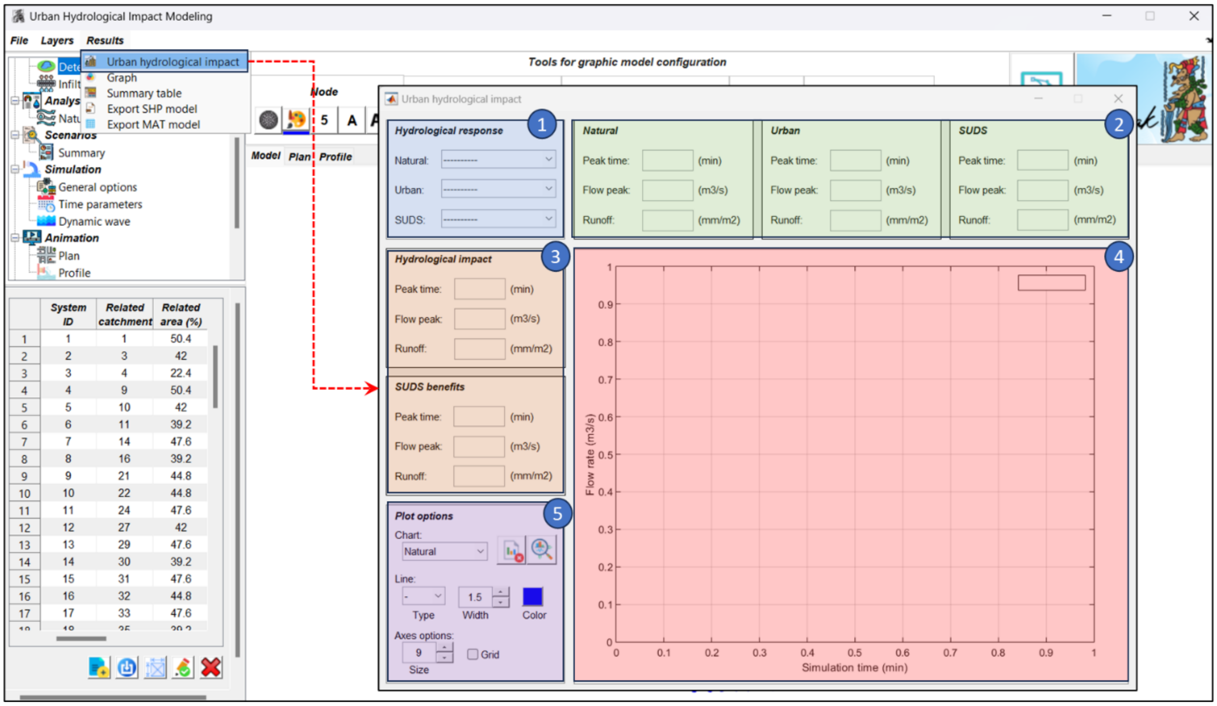

Figure 27. Graphical window for analyzing hydrological responses. 1) Select response; 2) Summary of responses; 3) UHI and SUDS benefits; 4) Plot area; 5) Plot options

The window consists of five specific areas for comparing the different simulated hydrological responses. Area 1 allows selecting the simulated hydrological responses to be compared (natural, urban, and SUDS conditions). Area 2 displays relevant information for each selected hydrological response (peak time, peak flow, and surface runoff). Area 3 presents a summary of the estimated UHI where characteristic values (increase in peak time, peak flow, and surface runoff) are obtained by comparing UHR to NHR. On the other hand, the benefits of incorporating SUDS are shown in terms of UHI (reduction in peak time, peak flow, and surface runoff) and are obtained by comparing UHR to SUDS response. Finally, area 4 shows the respective graph of the analyzed hydrological responses, which can be modified using the tools available in area 5.

For the developed case study, the UHI and the benefits of incorporating SUDS are obtained by selecting the hydrological responses as shown in Figure 28. It illustrates the hydrological benefits of implementing SUDS in the analysis area while keeping each of the simulated conditions in mind.

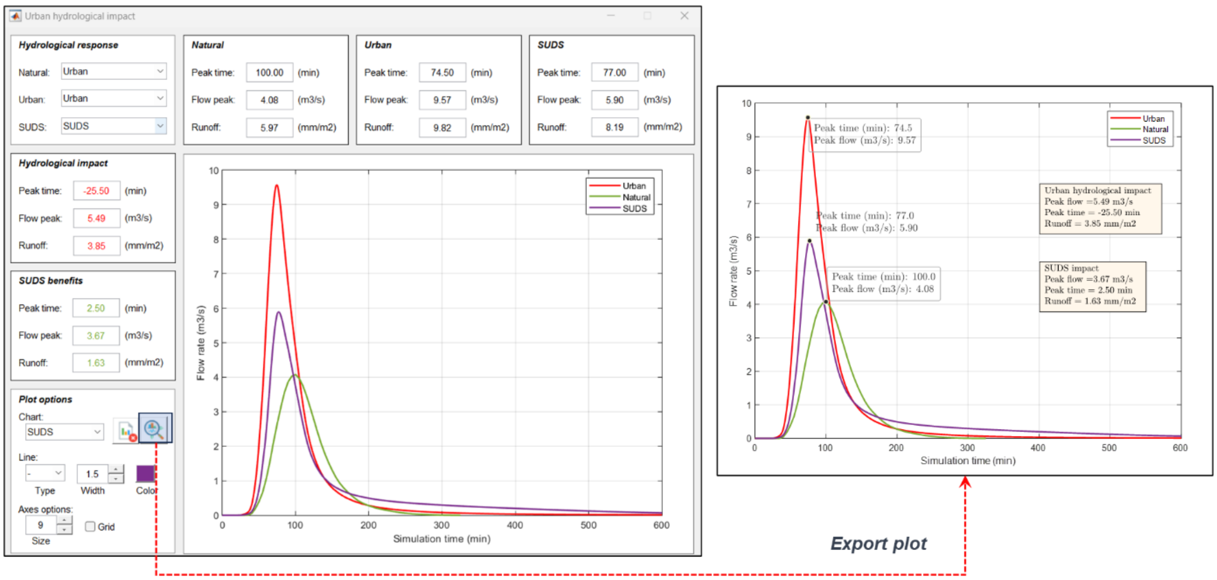

Figure 28. Visualization and analysis of urban hydrological impact in Chaak: UHI

Additionally, Chaak incorporates a range of tools for visualizing specific results. Being a simulation model for drainage networks, it allows the analysis of the temporal evolution of specific variables in each element of the network, highlighting result animations, color scale management, and the exportation of graphics or videos.

Figure 29 presents a summary of the results through a plan view grouped according to the element type. For Cionduit-type elements, it is possible to visualize their hydraulic capacity, flow depth, velocity, and functional state. In the case of Node-type elements, the variables are flooding and functional state. Finally, for Catchment-type elements, the variable to be analyzed corresponds to surface runoff.

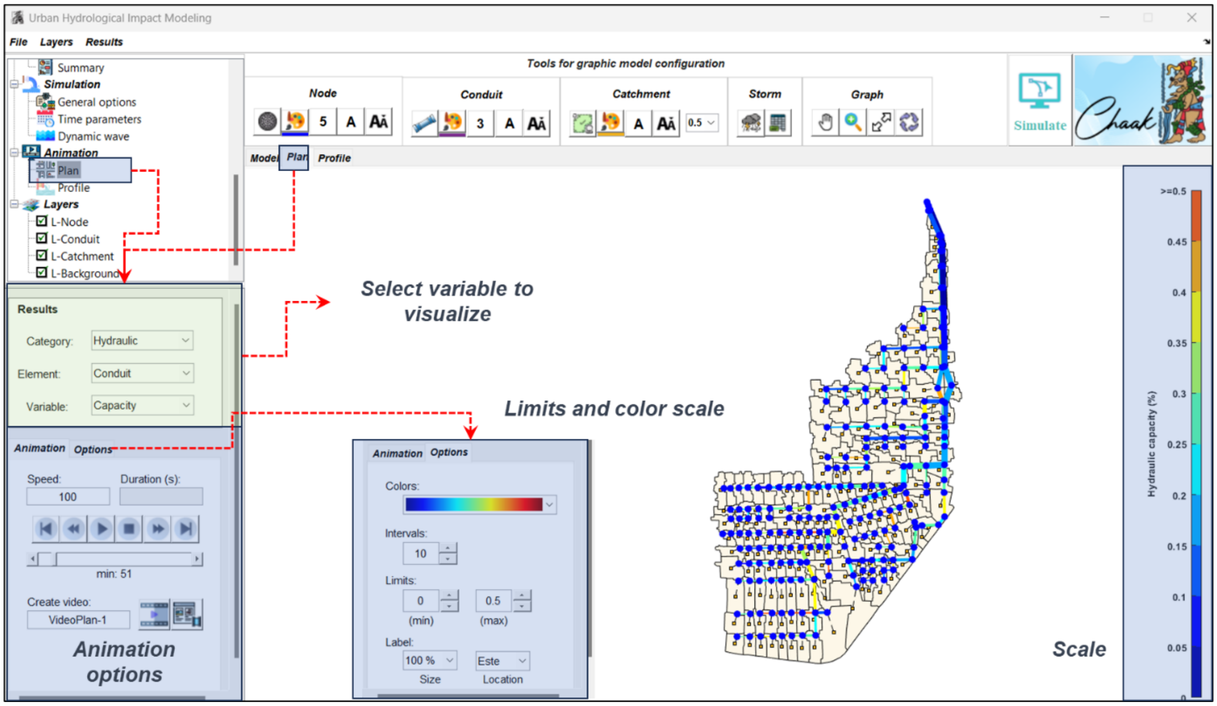

Figure 29. Plan view of results in Chaak: UHI

On the other hand, in Figure 30, a profile view is presented, where it is possible to analyze the variation in flow depth. To do this, it is necessary to select the starting and ending conduits, allowing control over the animation playback, colors, and graph information.

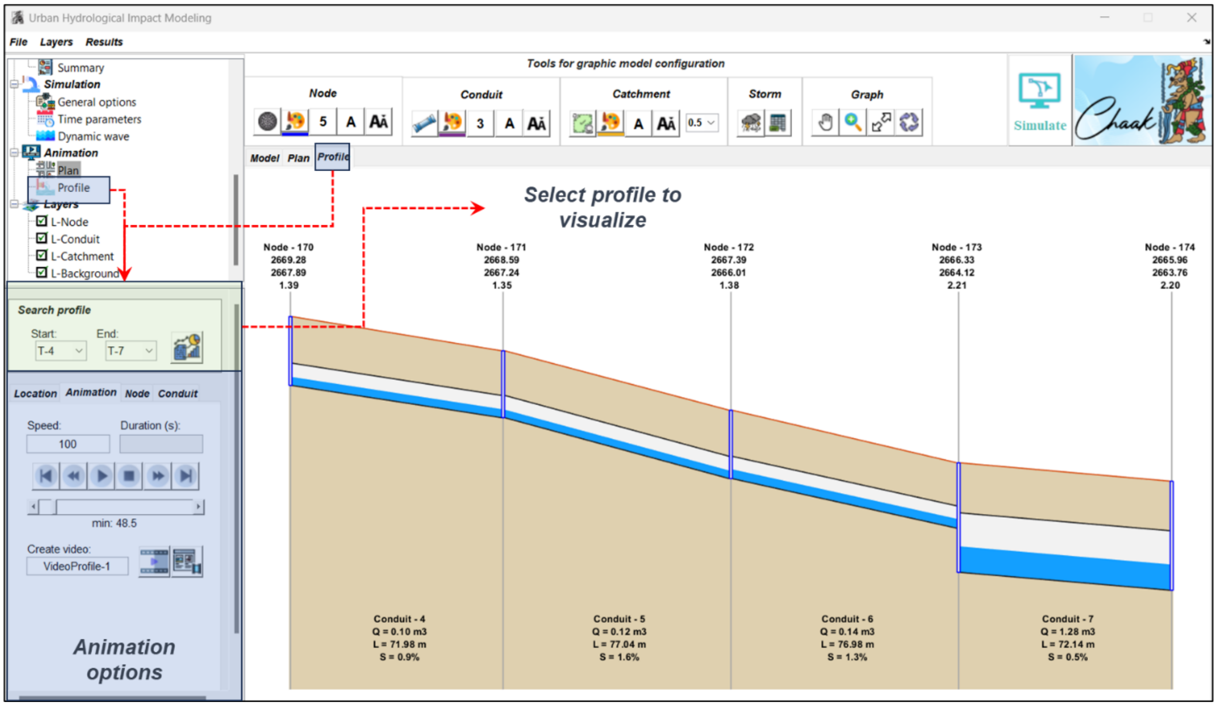

Figure 30. Profile view of results in Chaak: UHI

Furthermore, the Chaak tool offers an option for generating specific graphs, the structure of which is presented in Figure 31. The displayed window consists of four specific areas for comparing the temporal evolution of specific variables. Area 1 allows selecting different variables to analyze according to the associated element type (Node, Conduit, Catchment, SUD-retention, SUD-detention, and SUD-infiltration). The variables corresponding to the Node-type element are the amount of drained runoff, total flow, and flooding. Regarding Conduit-type elements, the considered variables are depth, inflow, and outflow. The variables associated with Catchment-type elements are runoff, precipitation, and infiltration. Finally, for each type of SUDS, it is possible to analyze direct runoff, inflow, outflow, and flow evolution in the system.

Area 3 displays the graphs of the analyzed variables, while area 2 contains graphic options to modify graph characteristics (color, line type, and thickness). Finally, area 4 shows the location in the global system of the element associated with the analyzed variable. Figure 32 illustrates an example of generating graphs corresponding to a retention system.

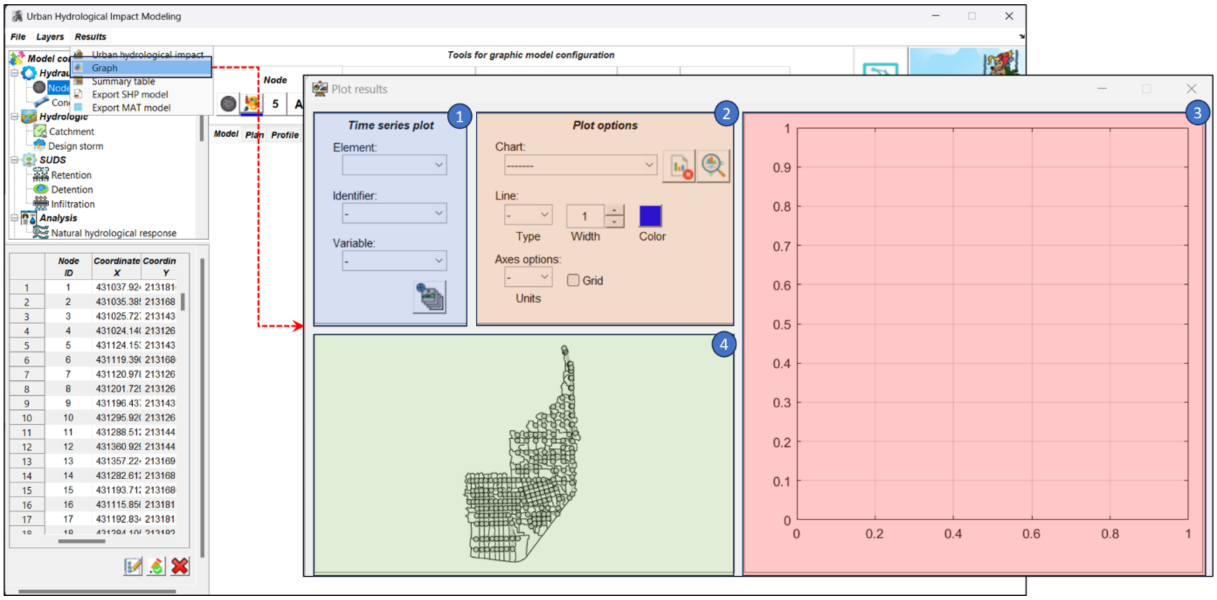

Figure 31. Graphic window aimed at generating specific graphs in Chaak: UHI

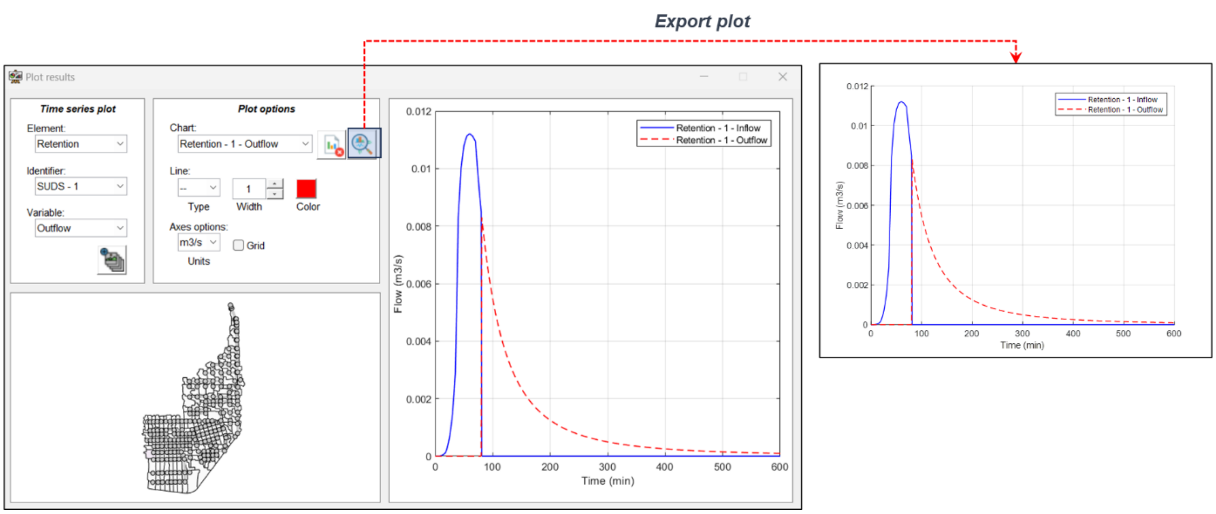

Figure 32. Specific graph of the operation of a retention system in Chaak: UHI

Finally, it is possible to visualize and export a table with the values of the main variables associated with the elements of the system. This generated information is saved in a TXT file so that it can be analyzed or processed as desired. Figure 33 shows the structure and characteristics of the window designed for managing the information.

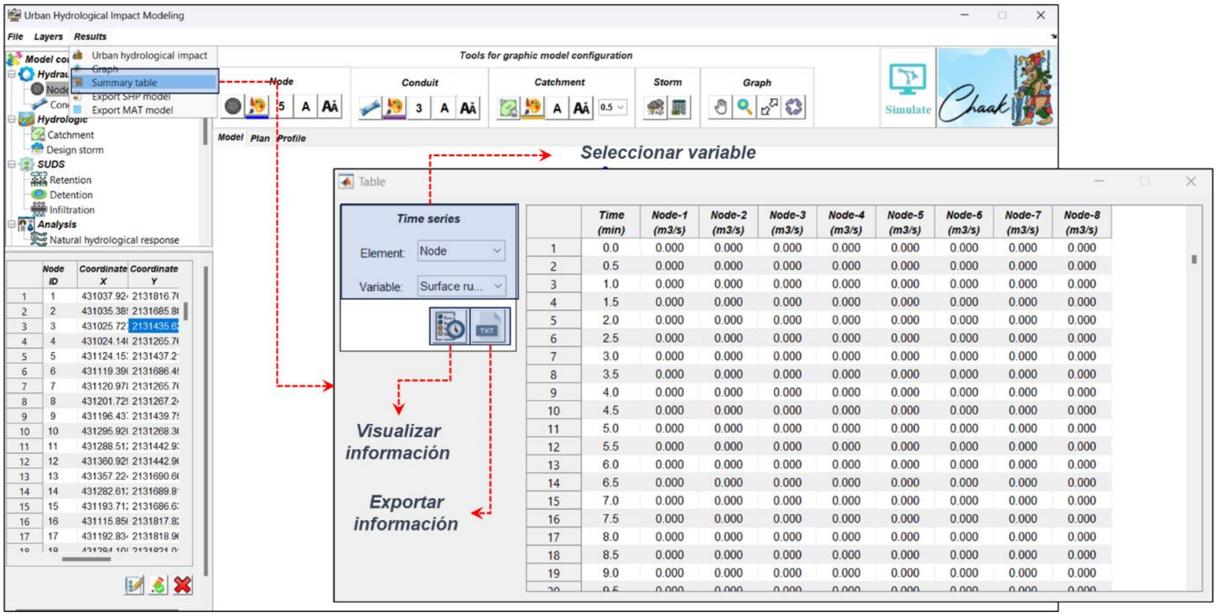

Figure 33. Graphical window for visualization and exportation of simulation results in Chaak: UHI

Furthermore, the drainage network analyzed in each project can be exported to MAT or SHP format through the *Results* tab, enabling these files to be loaded into another project. To close the program, conventional Windows buttons are used. In case you wish to modify or view an already created file, the following steps should be taken: Start the program conventionally, select the *Open* option from the *File* menu, a window will appear where the main folder of the previously created project will be searched, and the file with the project name and MAT extension should be selected. This will display the information that was previously worked on.

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