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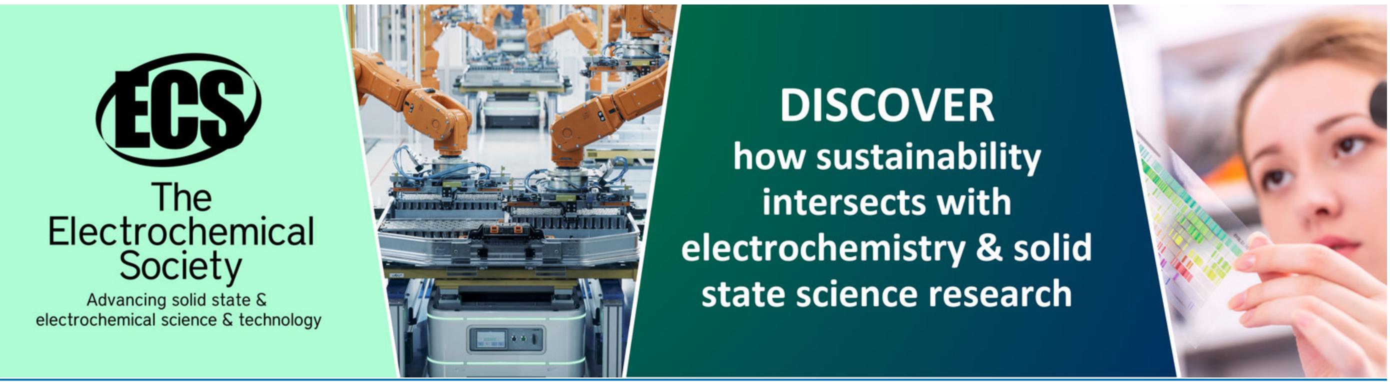

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Development of a GIS Tool for Sustainable Urban Drainage Systems Evaluation

W Barreto[1,2], N Ramos[2], K Castro[2], J Torres[1], R Torres[1], R Picón[1,2]

[1] Dpto. de Geología y Obras Civiles, Facultad de Ingeniería, Universidad Católica de Temuco, Temuco-Chile.

[2] Dpto. de Hidráulica, Decanato de Ing. Civil, Universidad Lisandro Alvarado, Barquisimeto-Venezuela.

E-mail: wbarreto@uct.cl

Abstract. Climate change is forcing the development of new adaptation techniques. Drainage in the cities does not escape to this fact, requiring new techniques that allow the adaptation to the new changing scenarios. Usually, these new techniques for urban drainage systems are based in complex and detailed evaluation methods; therefore, they need to be easy to apply and have a strong physical basis for modelling the rainfall-runoff processes. This paper shows the integration of a geographic information system with a hydrodynamic model. The tool was developed in python language and is able to incorporate all the Low Impact Development techniques (LIDs) contained in the Storm Water Management Model. It was applied to an extreme rainfall event in the city of Cabudare in Venezuela. The drainage system of the city was tested with and without LIDs for comparison and validation of the tool. Results show that the tool is able to model the main drainage features in the city (streets, pipes and channels), showing a good performance. Also, it is a user-friendly tool for urban drainage evaluation.

1. Introduction

Human activities are generating drastic changes on planet Earth, it is well known that excessive consumption of natural and energy resources is leading us to little encouraging scenarios [1]. Some scenarios, predicted by scientists, show a global temperature increase of 4 °C by year 2100 [2]. The consequences of those changes are introducing alterations in extreme weather events, expecting droughts of greater magnitude in dry periods and precipitation events of higher intensity than have occurred until now [3]. On the other hand, population growth generates a pressure for the demand of housing and businesses, which does not always grow in an orderly manner. Combination of greater urbanized area with events of higher intensity, increases the amount of flooded areas and damages in the cities [4] and decreases the water quality and availability.

Also, urban growth increases the demand for services such as drinking water, sanitation and drainage needs to be improved, becoming a challenge for urban planners. Formerly, drainage systems were designed to drain water from cities as quickly as possible[5], but as cities grow they require increasing drainage pipes, increasing the construction costs. In addition to being expensive, these systems are not friendly to the environment since they expose rainwater to contamination because it flows on the streets and in some cases combining with the sewage. In recent decades, new techniques known as "Best Management Practices" (BMPs) have been proposed, mainly aimed at improving water quality and flood control by retaining water in the system and then draining it slowly. This increase in retention time, provides the possibility of a pre-treatment of rain water and reduce the need of higher diameters in drainage pipes systems. These techniques have evolved in what is called “Sustainable Urban Drainage Systems” (SUDS), as they are known in Europe. SUDs include measures to adapt to change in the case of extreme precipitation events or drought, trying to reproduce the natural hydrological cycle as it was before the urbanization process [6]. These techniques are also known as "Low Impact Development" (LIDs) in North America.

The design or rehabilitation of urban drainage systems must include one or several LID techniques that best suit the system or area under study. One of drawback in the application of LIDs techniques is they are complex to model in large urbanized areas. Most of the models were a designed for small areas, houses or parks and not for a complete city or part of it, requiring a high quantity of parameters. For this reason, tools that facilitate the evaluation and selection of LIDs at the project level are required [7]. There are software’s such as the Storm Water Management Model (SWMM) that incorporates, in addition to the hydraulic model of drainage networks, LID measures. However, the introduction of data requires the use of massive information such as: pipe and channel dimensions, drainage areas, land use, soil type, roofs, etc. This information must be entered manually, which slows the process of data manipulation and evaluation of alternatives. On the other hand, geographic information systems (GIS) are capable of handling spatial information in a simple and user-friendly way, so it can potentially facilitate the pre-and post-processing in the SWMM model.

In this work a GIS tool is developed. It can be used for selection, evaluation and design of sustainable urban drainage systems, using LIDs techniques. The tool was tested in a case study for an extreme event in the city of Cabudare-Venezuela.

2. Methodology

In the development of the showed tool, two types of software were used. One capable of modelling the hydraulic and water quality behaviour and the other that acts as a pre and post processor. The pre and post processor software is in charge of manage the large amount of data required in the urban drainage design. It also helps in the selection and evaluation of alternatives. An exhaustive review of the existing hydraulic and GIS software was carried out to choose the most suitable one to build the tool.

2.1. Hydraulic Model for SUDs

There are several hydraulic models that can be used for hydraulic modelling of pipes and channels for urban drainage systems. However, an essential condition is that it should be able to model the characteristics of LID[8]. Among the models that were evaluated and met the best conditions are the following:

2.1.1. MIKE URBAN (MOUSE).

This program developed by the Danish Hydraulic Institute (DHI) is a very stable software for the hydraulic calculation of pipe and channel networks. Its most recent versions (2014) incorporate LID objects and a pre-processor that includes a geographic information system. The main disadvantage is that the software is privately licensed and uses binary input files, so its integration into an external GIS is difficult.

2.1.2. PC-SWMM.

It is one of the available software with a good internal GIS integration and uses the SWMM model as a hydraulic calculation engine, so it has numerical stability and incorporation of LID. This software does not allow the inclusion of additional tools and is patented closed source.

2.1.3 SWMM 5.0.

It is a stable hydraulic calculation model and accepts LID type structures, but the graphical interface is poor, unfriendly and without GIS type interaction. The advantage is the public license and open source, it has ASCII type input files that make it attractive to interact with other software and capable of being contained in a user interface as a hydraulic motor.

You can see in previous descriptions the advantages in the use of publicly licensed software, open source, stability in hydraulic calculation and the incorporation of sustainable drainage or LID measures. The use of SWMM as a hydraulic calculation tool exhibits such characteristics (**Figure 1**).

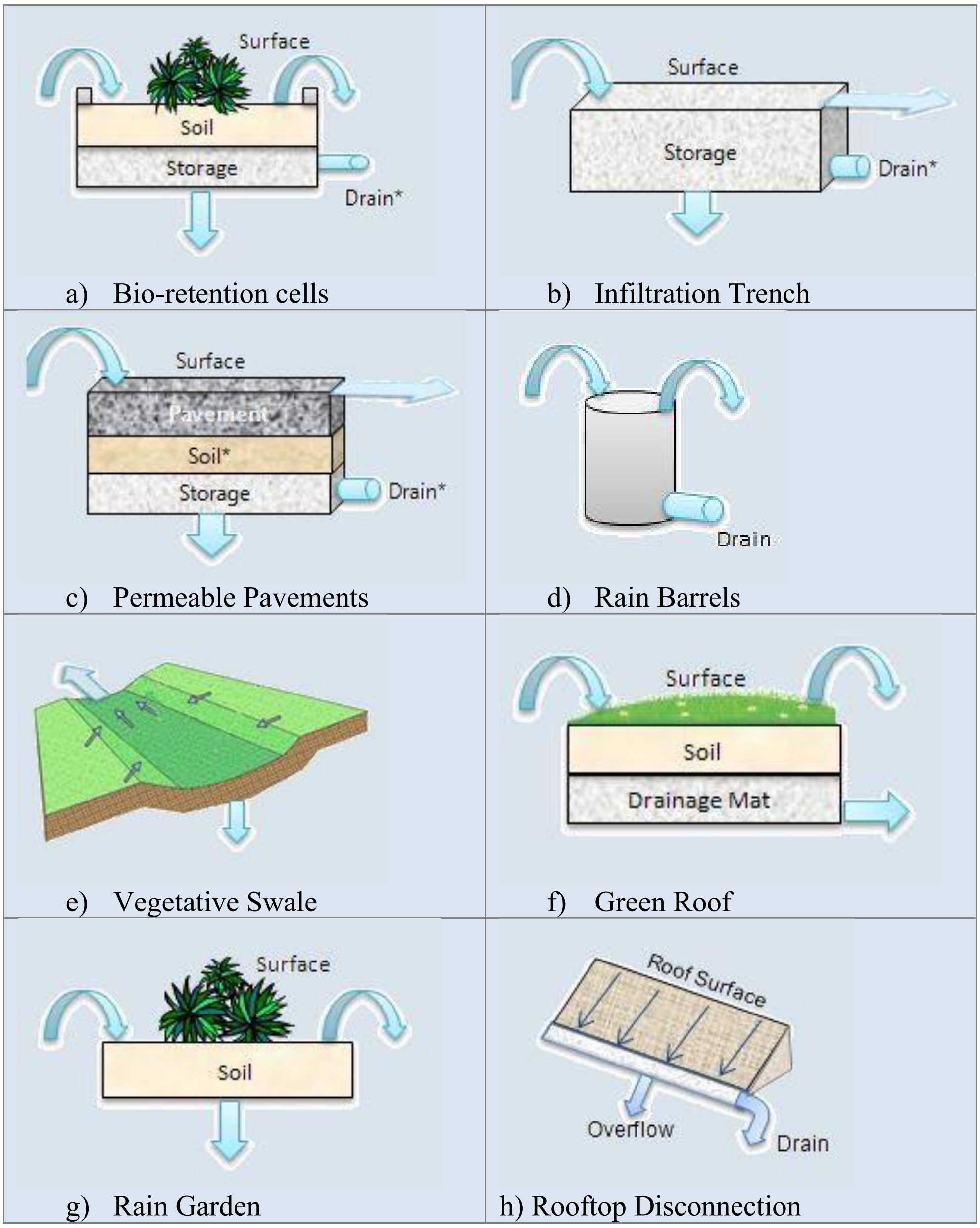

Figure 1. LIDs elements considered in DrainGIS Complement (Source: EPA-SWMM)

2.2. GIS-SWMM integration

The tool to be developed requires an advanced spatial data management, where large areas of urban developments can be managed in sufficient detail to incorporate LID elements. That is why the interface of the tool must be done with a geographic information system. There are several potentially usable geographic information systems. Among them we can mention ARCGIS, MAPWINDOWS, ILWIS, GRASS and QGIS. The characteristics required in the design of the proposed tool are: it must have available spatial vector and raster geo-processing tools, it must allow the programming of user modules and preferably an open license. From the list above, the one that meets all the requirements is the Quantum GIS (QGIS)

QGIS allows the programming of add-ons in PYTHON language, which provides a simple and agile interface to access the potential and tools of the geographic information system. One of the main advantages of PYTHON is its short learning curve. In order to create the drainage tool, the tasks were divided into smaller algorithms or modules:

2.2.1. GIS to SWMM module.
This module is responsible for building and preparing the layers of information required by the SWMM, as well as the parameterization of the LID components. Also, it transforms them into the required input file (inp) used by the SWMM program. The hydraulic elements created in the GIS software should be stored in specific layers, following same sequence as variables used by the SWMM input files.

2.2.2. SWMM to GIS module.
To achieve a complete bidirectional interaction between SWMM and QGIS, an importing function was built. This function can read previously created models in SWMM and representing them into QGIS using thematic layers. The algorithm was coded to reads the SWMM input file and create a valid structure for the designed QGIS tool.

2.2.3. Results and Reports.
It is necessary to visualize the results obtained after the SWMM simulations. It is done in such a way that the user can interpret them in an easier, faster and georeferenced way. The algorithm was written to read the SWMM results file and store the values into QGIS layers. It is able to read both spatial and temporal results.

2.3. DrainGis tool
These algorithms were encoded using PYTHON language. A graphical user interfaces (GUIs) was done and integrated as a QGIS complement called DrainGIS. To install it, the plug-in is provided in a zip file and can be imported from the QGIS plug-in driver (see **Figure 2**).

The *DrainGIS* complement has the elements used in urban drainage systems such as: pipes, canals, drainage areas, sinks, etc., and additional components for urban sustainable drainage systems (SUDS), such as: rain gardens, infiltration ditches, permeable pavements, rain deposits, green roofs, and green swale (**Figure 1**). All these components have been integrated into QGIS through the use of GUIs. **Figure 3** shows an example of a dialog box for the inclusion of LID measures from QGIS using *DrainGIS* complement.

2.4. Study case
In order to validate the DrainGIS complement, the response of an urban catchment was evaluated. It was done through a comparative study in terms of water levels and discharge generated by an extreme precipitation event with and without LIDs.

The area to study is the basin of Tabure stream, in the city of Cabudare, Venezuela. This urbanized area has had a history of flooding and damages, under precipitation events of considerable magnitudes. The total area of the basin is 20.2 km^2 and is divided into 23 sub-catchments, 18 are located in a main urban area and the other 5 in semi-urban areas. The total basin concentration time was calculated using the Kirpich equation, obtaining a value of 126 minutes. This urbanized area has grown exponentially in the last 20 years and few measures for drainage control has been implemented. The increase of impervious area, with almost the same hydraulic infrastructure has raised concern among urban planners. On November 28 of 2016, a 90 mm event was presented in two hours (45 mm / hr), which corresponds to a 50-year return period. his event caused multiple material damages and a human life was lost.

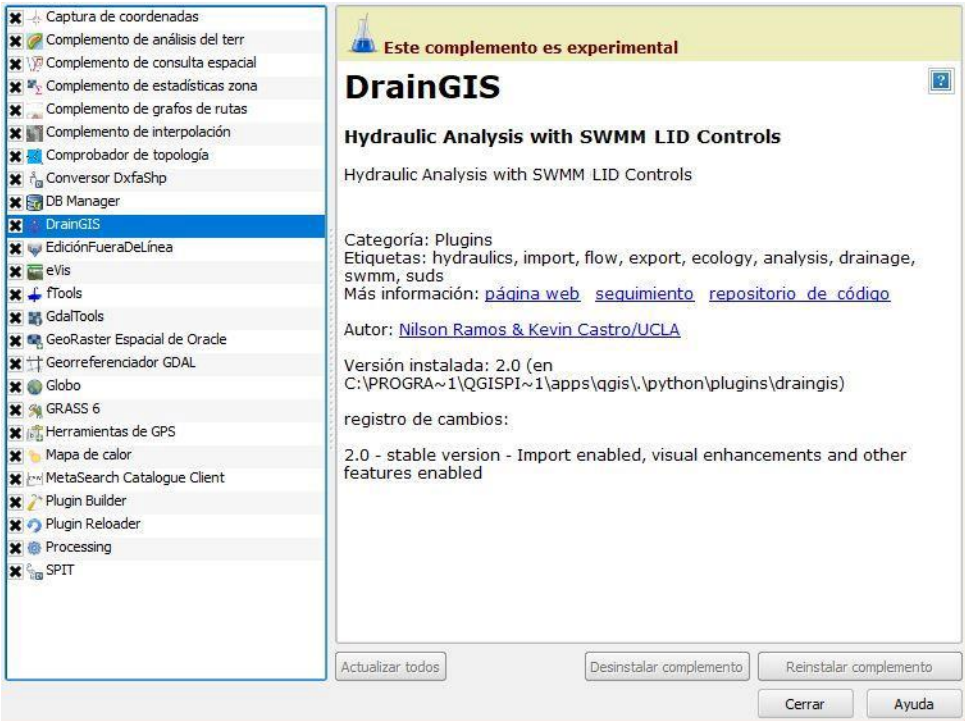

Figure 2. Installation of the DrainGIS Add-in

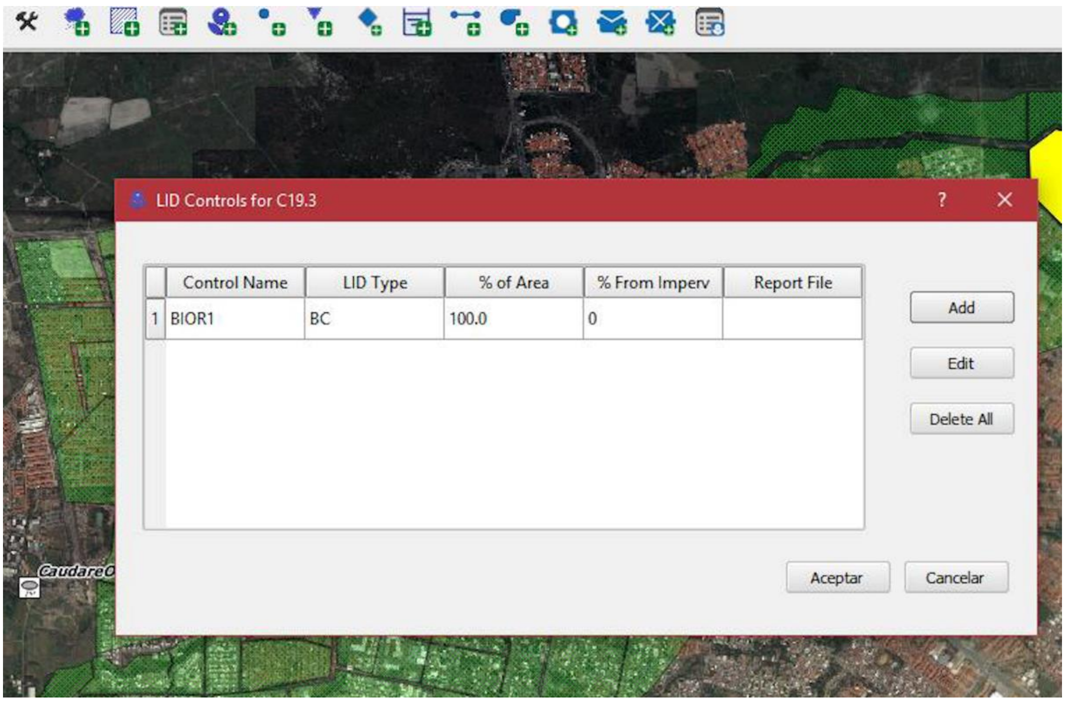

Figure 3. Dialog box for inclusion of LID element

The base terrain model was developed from an image taken using LIDAR and automatically restored in contour lines. A digital elevation model (DEM) of the study case was built. The DEM was imported to QGIS software and channels, pipes system, streets and main natural channels were digitized. Once this information was introduced into QGIS, the layers required by *DrainGIS* complement were constructed through map operations identifying roofs, yards, roads, permeable and impermeable areas (**Figure 4**).

Figure 4. Automated digitization of areas with DrainGIS

Once the areas and components of the drainage system were identified, the drainage parameters of each of them were set. The main inputs were the value of the curve number (CN) over each sub catchments, soil type, land use, Manning's roughness coefficient, pipes and channels dimensions, among others. A calibration of the model was carried out with the event that occurred on November 28, 2016. It was compared that the same places affected in the real event coincided with those of the simulation using DrainGIS. This simulation was taken as the basis for the following comparisons using LIDs elements. Three scenarios were analysed:

2.4.1. Scenario 1 (Current condition).
This scenario corresponds to the baseline comparison scenario, where no LID measures are considered in the urban drainage system.

2.4.2. Scenario 2 (LIDs on a small scale).
In this scenario, the LID measures taken into account were green roofs and rain deposits. Only a half of the potential area for the green roofs is developed and the barrels has small dimensions. The idea is to simulate the first stage of the development of sustainable urbanism. A maximum storage depth of 100 mm and a floor depth of 75 mm is assumed for green roofs. Deposits or rain barrels are considered by unit of 1200 mm of storage, using only one by house.

2.4.3. Scenario 3 (LIDs on an intensive scale).
In this scenario, the implementation of large-scale SUDS was simulated. The parameters of green roofs were changed to an extensive type, the maximum depth is modified to 200mm, the thickness of the soil layer became 100mm and the thickness of the drainage material is 50mm. It was assumed that 80% of the possible develop area is using green roofs. Regarding the use of rain barrels (deposits), these became in a battery of 3 units to increase the total storage capacity by house. On the other hand, permeable pavement controls, bio-retention cell and rain gardens are included under this scenario increasing the number and type of LIDs elements.

For the case study, 6 nodes were selected for comparison of the results for each scenario. Nodes *3.1*, *3.3*, 4.1, 9.1, 13.1 and 18.3 (**Figure 5**).

3. Analysis and Results

In each scenario, several characteristics of the DrainGIS complement were evaluated. First, the ability of the tool to facilitate the construction of hydraulic models compatible with SWMM was evaluated. It is noted that the construction of the drainage model was simpler and friendlier when it was done using the DrainGIS tool. For example, the identification of roofs in urbanized areas (**Figure 4**) facilitated the introduction and use of green roofs as a LID control. It allowed managing several green roofs at the same time, while in SWMM the edition must be done one by one for each sub-basin. This statement can be extended to permeable pavements; it was easier to identify roads and turn them into permeable pavements. The windows (GUI) for entering data were designed similarly to those of the SWMM model, increasing the learning curve for SWMM users.

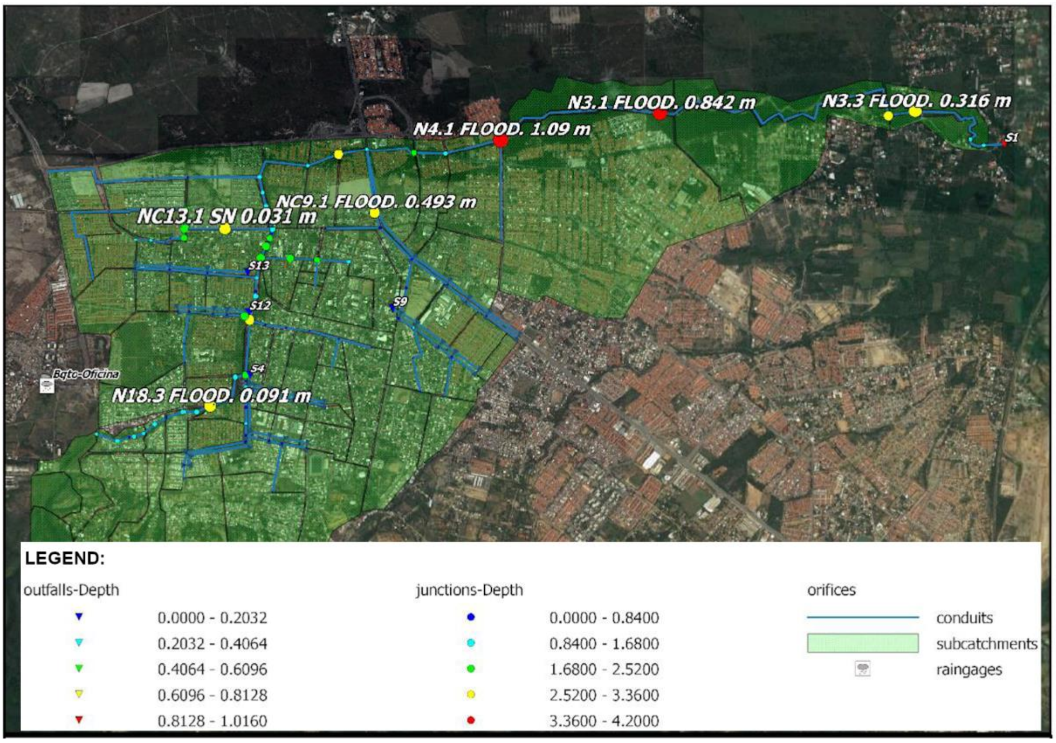

Figure 5. Nodes used for calibration and comparison of results

In the scenario 1, it was possible to reproduce in the simulation the location of the real affected places during the event. The module for reading the results was able to transfer the results obtained in the nodes and channels to the QGIS. They are represented graphically according to the magnitude of the measured variable (flooding, level or discharge). The use of dialog boxes of the DrainGIS complement, allowed adding the LID components to scenarios 2 and 3 and model them using SWMM. The results of the simulation can be observed and compared using the DrainGIS complement and Microsoft Excel. Illustratively, node 4.1 is shown. This node presented the greatest overflow affectation during the event. **Figure 6** shows how the water level decreases as LIDs elements are adopted in the urbanized area, reducing the level in node 4.1 from 4.3m to 3.6m (16.2%) and 2.6m (39.5%) for scenarios 2 and 3 respectively. In **Figure 5** it can be seen that the node 4.1 flooding is 1.09 m while under scenario 3 there is no flooding.

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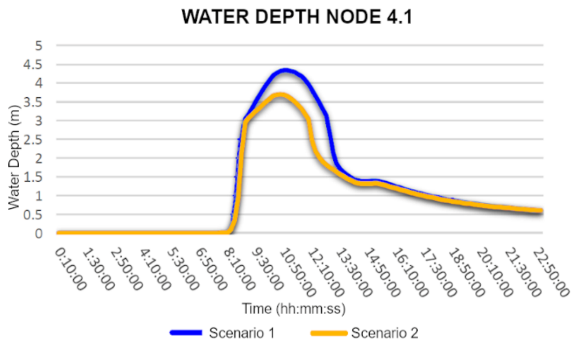

Figure 6. Water level in Node 4.1 for scenario 2

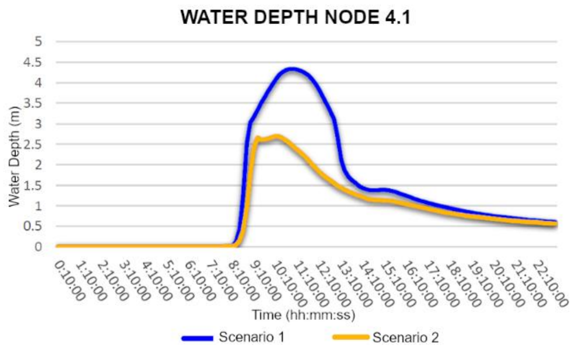

Figure 7. Water levels in Node 4.1 for scenario 3

Figure 8 shows a summary report about the impact of the LIDs adopted in the case study. It can be seen from scenario 3 that green roofs show the greatest impact on the reduction of water levels (30%) in the node, followed by permeable pavements (23%) and rain gardens (22%). This kind of report allows the planning and spatial location of the LIDs elements according to their effectiveness, thus maximizing the investment amount. Reports can be obtained for different variables such as: flow, levels, volume of water generated and flooding; this can be done globally or by nodes. The tool facilitates to the urban planners the design, selection and evaluation of sustainable drainage systems. It is done in an intuitive and friendly fashion without reduction of the hydraulic precision.

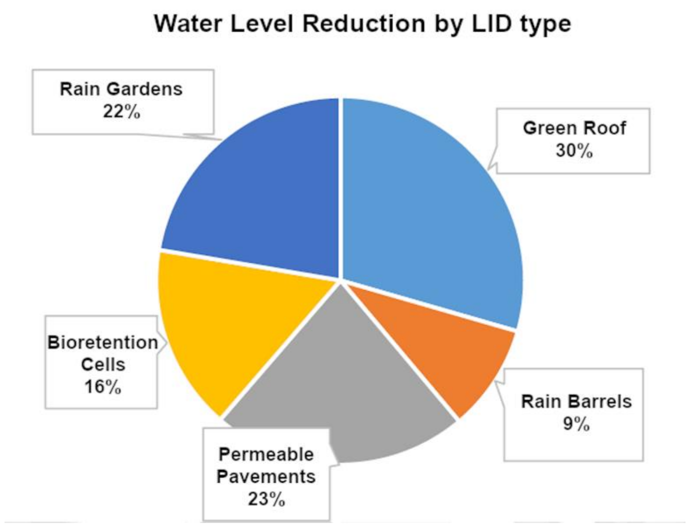

Figure 8. Water level reduction by LID measure implemented in scenario 3

4. Conclusions

A QGIS complement (*DrainGIS*) was developed and validated by integrating the spatial features of the geographical information systems with a hydraulic computation engine such as the "Storm Water Management Model" (SWMM). DrainGIS is able to implement the features of Sustainable Urban Drainage Systems (SUDS) and perform its hydraulic modelling. QGIS and SWMM integration was implemented through the use of PYTHON programming language, which is compatible with the QGIS software.

The tool can be used to design, select and evaluate Low Impact Development (LID) projects in urban drainage systems. *DrainGIS* can be used to improve the adaptability of cities to climate change. The add-in can generate the parameters required by the SWMM and write them to an input file compatible with SWMM and vice versa, allowing two-way communication between them.

It is possible to read the SWMM result files and generate space-time reports in the QGIS software. These reports facilitate the analysis of the results, detailing water levels, flow rates, flooded areas, volume of water retained or released in the nodes, pipes and channels.

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