ArcDrain Simulation: How Nature based solutions can reduce flooding

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Highlights

- This tool can locate most prone subwatersheds to flooding with an automated method.
- We modified in a simulation with Nature based solutions in problem areas.
- We estimate runoff can be reduced up to 50% in flood prone areas in the city of Santander.

Introduction

Urban expansion and climate change have caused urban floods to increase in frequency and this increases economic and human losses during the last years (CRED, 2021). Having tools and methods to improve the identification and prediction of flood-prone areas is a very important task that is increasingly being taken into account for future urban planning.

One of the tools for the evaluation and mitigation of these events most commonly used is the Geographic Information Systems (GIS) (Ahiablame and Shakya, 2016). Currently there are few GIS tools independent from other computational models that perform an estimate of surface runoff by themselves. Some of the existing ones have the problem that they are very simplified versions of models that do not take into account some factors of the impermeability of the surface (Jamali, 2018). Otherwise, there are other GIS tools that are coupled to complex hydrographic methods with a high degree of parameterization that are not suitable for calculating runoff quickly (Rezazadeh Helmi, 2019).

Considering the advantages and disadvantages of the features of GIS-based tools developed in the past for the determination of runoff, we have developed ArcDrain and the ArcGIS plug-in by automating the Rational Method. ArcDrain has been developed with the intention of being a tool that provides an independent and simple but accurate means of calculating maximum urban runoff. These aspects were tested using the city of Santander (northern Spain) as a case study.

Methodology

Setup and data required

The data required to use the ArcDrain tool are four that are summarized in Table 1. The data used as input data in the tool have been selected on the basis that they are elsewhere. Thus, the DEM with a resolution of 25m, the hydrogeological map or the land use data are available through the Copernicus (Copernicus Land Monitoring Service, 2021). Also, for this same continent there are precipitation data provided by the European Climate Assessment & Dataset (Klein Tank et al., 2002).

Table 1. Summary of datasets required to run ArcDrain.

Data	Type	Preparation
Digital Elevation Model	Grid	Clip to the limits of the study area
Land cover map	Polygon	Classification according to a 3-digit code
Hydrogeological map	Polygon	Classification based on runoff potential
Daily precipitation	Point	Calculation of extremes and interpolation

All these input data should be treated minimally so they have a similar consistency in the limits of the study area. In addition, each the databases will subsequently have its own treatment. Once processed, all the input data is stored in a geodatabase linked to the tool to facilitate its use in the following modules.

Catchment delineation

The first step in this module is to delineate the area into a series of sub-basins based on surface water flow paths. This is done by automating the application of a series of ArcGIS tools from a Digital Elevation Model (DEM). Next, the number of cells upstream of each cell in the study grid was calculated using the "Flow accumulation" tool. The layer derived from this task and the flow direction map is used to create a stream network made up of cells with at least 0.5% upstream cells flowing into them.

Data combination

This module includes a series of pre-processing tasks of the variables in determining the maximum runoff. On the one hand, discrete data such as land cover and soil types are combined with the catchment layer. On the other hand, a multiband raster layer is produced combining continuous data of precipitation, slope, and stream network with the sub-basins. This procedure allows you to prepare all the necessary data to apply the Rational Method in the last module of the ArcDrain plug-in.

Peak runoff calculation

The runoff is designed from the Rational Method, a standard in Spain when calculating the runoff flow of a basin. This method is applied to each of the previously defined sub-basins. The general equation (Equation 1) for the runoff calculation has different factors are involved. The main factor that is modified to study the use of Nature Based Solution is the runoff coefficient, which is the element where we can act by changing the surface of the terrain.

Equation 1. $Q_T(m^3/s) = \frac{I(T,t_c)\cdot C\cdot A\cdot K_t}{3.6}$ I (T, tc) : Precipitation intensity; C : Runoff coefficient; A : Area; Kt : Coefficient of temporal distribution of precipitation.

Modification of the runoff coefficient

Once the prone flooding zones have been selected, a modification of the land use codes is made, simulating an improvement in permeability conditions show in table 2. These modifications are a simulation of how runoff could be reduced in the original land uses if natured based solutions were used such as permeable pavement design on sidewalks, porous asphalt on roads or the use of green roofs in buildings.

Table 2. Summary of datasets required to run ArcDrain.

Original Land Use	Modified Land use
Fast Transit	Discontinuous very low density urban fabric (S.L.: <10%)
Other Roads	Discontinuous very low density urban fabric (S.L.: <10%)
Continous Urban Fabric	Discontinuous very low density urban fabric (S.L.: <10%)
Discontinous Urban Fabric (all classes)	Green Urban Areas
Industrial, commercial, public, military and private units	Discontinuous very low density urban fabric (S.L.: <10%)

Results and discussion

The tool divided the city into 786 sub-basins in which it carried out calculations to determine the flow of each one of them and to calculate the accumulated flow. Two critical flood zones have been located and one of them has been selected to verify the effect of Natured Based solutions on accumulated runoff. For this, a simulation was carried out using the modifications explained in the previous section for the selected area (Figure 1).

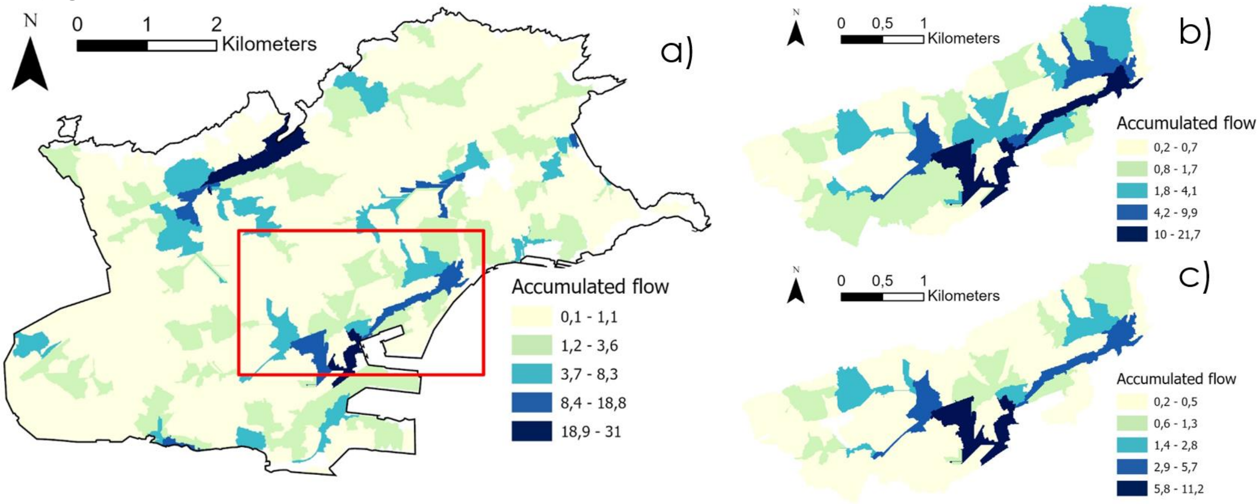

Figure 1. Output with accumulated runoff values (m3/s). a) General view of the city of Santander, red square indicates the selected area. b) Detail of the accumulated runoff study area without installation of Natured-based solutions. c) Detail of the studied area with the simulation of the installation of solutions based on nature.

This selected area ends in two independent sub-basins where we have accumulated runoff values of 20.3 and 21.7 m^3/s respectively. The modification of the surface that affects its accumulated runoff causes these values to decrease considerably in the simulation, specifically by 62.5% and 48.3%. In other words, the accumulated runoff in that area was reduced in total by 55.2%. These estimates can be of great help for urban planning in the city.

Conclusions and future work

These simulations show that Natured-based solutions can be a great solution to flood problems in cities by improving the permeability of urban areas. This can encourage urban plan designers and policy makers to implement these measures to improve the quality of life for citizens. In future approaches to this problem, the ArcDrain tool could be improved to be more precise in modifying the terrain. In addition, AI techniques could give you enough independence to be able to select within critical areas the best solutions within Natured-based solutions.

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