AUTOMATIC DELINEATION OF A WATERSHED USING A DEM. CASE STUDY – THE OLTEȚ WATERSHED

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ABSTRACT:

This paper aims to present some solutions for automatic delineation of a watershed. In order to find this study's applicability in the geographical reality, we decided that the river whose watershed will be delineated to be Oltet river. Automatic delineation of the Olteț watershed was carried out comparatively, using two softwares, ArcGIS Desktop 9.3 and Quantum GIS 1.7.0 Wroclaw, and it based on a SRTM digital elevation model of 90 m. After using GIS techniques, there have resulted two maps showing the boundary of the Olteț watershed. By overlapping the resulted maps, obtained with ArcGIS and QGIS, we found some small differences generated by the different way of working of each software involved in this study. We have also calculated a circularity coefficient for the Oltet watershed and the value obtained supports its elongated form and all the implication of it.

1. Introduction

A watershed is a surface that drains waters to a common outlet as concentrated drainage. Other common terms for "watershed", used alternatively in this study are basin, catchment, or contributing area.

The Olteț river, the largest tributary, on the right side (in the lower section) of the Olt river, has its source at 1109 m above sea level in Căpățânii Mountains, Southern Carpathians. As we said above, the Oltet river is a tributary of the Olt River and flows in it near Cioroiu village in the Caracal Plain at an altitude of 70 m above sea level. In it way from the source point to the confluence with the Olt river, the Olteț crosses almost 186 km and its annual average flow measures only 13 m³/s (Ielenicz, 2007).

Involving the Olteț river into the problem of automatic watershed delineation, is a case study, which, once solved, can provide an operating model for a more complex study.

Thus, this paper presents a geographic information systems (GIS) – based on methodology for automatic extraction of the Olteț watershed using a digital

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elevation model. GIS resources used in this study have the necessary algorithms to solve the problem under discussion.

Among the precursors of the idea of automatically delineation of a catchment using GIS resources are SK Jenson, Dean Djokic and Ye Zichuan.

Dean Djokic and Ye Zichuan developed a methodology for automatic extraction of watershed in ArcGIS (1997) and SK Jenson with O.J. Domingue proposed, in 1988, some algorithms for automatic hydrologic data extraction using a digital elevation model (Olivera, 2001). These algorithms can be used to determine flow direction, flow accumulation and watersheds.

The Olteț watershed automatic delineation process, based on a DEM, provide the opportunity to make some analysis related to a series of hydrological processes such as flood occurrence, transmission, their erosive and transportation power etc.

The way of action of the above mentioned hydrological processes can be deduced by analyzing, in instance, the circular or elongated shape of the watershed. In a circular river basin, the main course tributaries flow almost simultaneously towards the geometric center of the basin (Zavoianu, 2006). Also, in a circular river basin, floods are transmitted quickly and have a high capacity of erosion and transportation. By contrast, in the elongated basins, floods are transmitted harder toward the geometric center of the basin and have a reduced erosive capacity.

The shape of the Olteț watershed can be identified with the circularity coefficient (1), used in 2006 by Rădoane et al. (Bilaşco, 2008). This formula requires the length of the watershed boundary, in km (perimeter) and the total area of the basin, in km^2.

$$C = \frac{L_c}{2\sqrt{\pi F}}, \qquad (1)$$

where: C – circularity coefficient,

Lc – watershed length (perimeter - km)

F – total area of the basin (km^2)

Rădoane (2006) believes that the circularity coefficient is dimensionless and when it is close to "1", the river basin has a circular shape.

Later, in this study, after we have identified the watershed boundary, we applied the circularity coefficient formula and we drew some conclusions that match to the value obtained. Till there, we delineated Olteț basin or it watershed boundary using two types of software: a commercial one and an open source software. Each of these presents more or less complex methodology for the identification of the boundary which separates the Olteț basin form the surrounding basins. In the following lines, we are going to present the operating mode of the both software used in our research, i. e. ArcGIS Desktop 9.3 and GRASS plugin of Quantum GIS 1.7.0 Wroclaw.

2. Methods and data

The identification and delineation of the Olteț watershed, without manually processing of a topographic map sheet, can be achieved, according to the introductory part, by using open source and commercial solutions. In this case study, we have used the commercial software ArcGIS Desktop 9.3 and GRASS plugin of the open source software Quantum GIS 1.7.0 Wroclaw.

The input data required by GIS solutions, in order to fulfill our hydrological analysis is a digital elevation model (DEM).

Both sofwares have enabled the processing of 90 m DEM (figure 1) obtained with SRTM project of the National Geospatial- Intelligence Agency (NGA) and National Aeronautics and Space Administration (NASA).

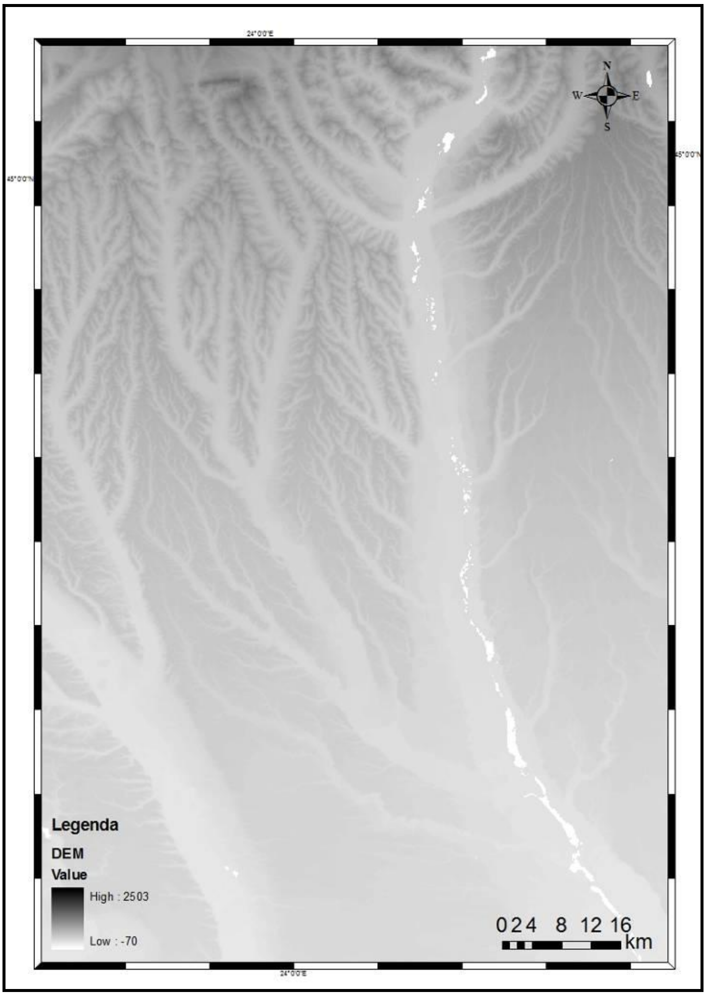

Fig. 1. DEM – processed in Arcgis Desktop 9.3

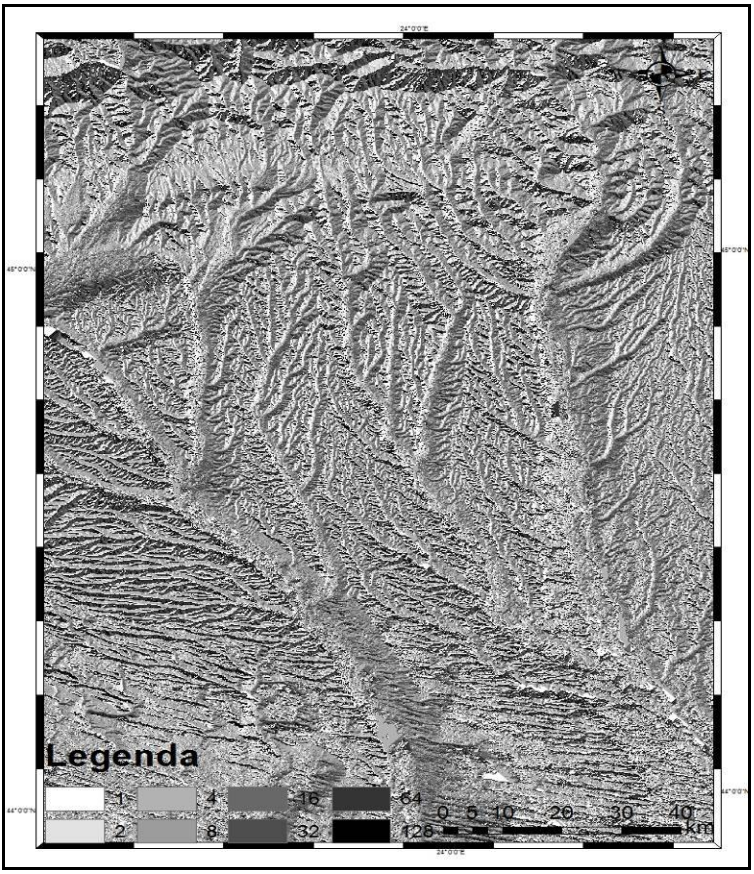

Fig. 2. Flow-direction raster.

The techniques provided by ArcGIS Desktop 9.3, in order to achieve a better hydrological analysis, consist in using Spatial Analyst toolbox and its tools: "Surface" "Hydrology" and "Watershed".

To begin the automatic identification process of a river basin, in ArcGIS, you need to perform some preliminary operations. These operations consists in creating a depressionless DEM, by eliminating the sinks areas, in order to generate, correctly, a flow - direction raster, otherwise the presence of sinks may result in an erroneous flow–direction raster. The flow - direction raster is a grid which stores some code numbers that refers to their downstream cell (Olivera, 2001). This downstream cell is selected so that the descent slope from the cell is the steepest. Therefore, a unique downstream path from each cell can be determined by connecting the cell to its downstream cell, and so forth. This process produces a stream network, with the shape of a spanning tree, that represents the paths of the watershed flow system.

Table 1. Flow - direction matrix.

64	128	1
32	X	2
16	8	4

For example, if the direction of the cell denoted by "x” in the table 1, is to the left (west), its flow direction would be coded with value "32" and would correspond to the steepest direction. (Jenson and Domingue, 1988).

Therefore, from the above lines, you can identify the first steps necessary to automatically extract a river basin using a DEM (in ArcGIS), namely: filling the sinks to get a correct DEM (depressionless) and generate an output raster that indicate flow - direction. (figure 2).

The flow direction raster is used as an input in order to generate the flow accumulation raster (figure 3). The results of Flow Accumulation function can be used to create a stream network by applying a threshold value to select cells with a high accumulated flow. After this step is completed, we must specify the high accumulated flow point or the pour point, i.e. the junction between Olteț and Olt rivers, so that we can bring to almost a final stage, the automatically watershed delineation process. The completion of this process is possible with the help of the „Watershed” function, located into the „Hydrology” toolbox (figure 4).

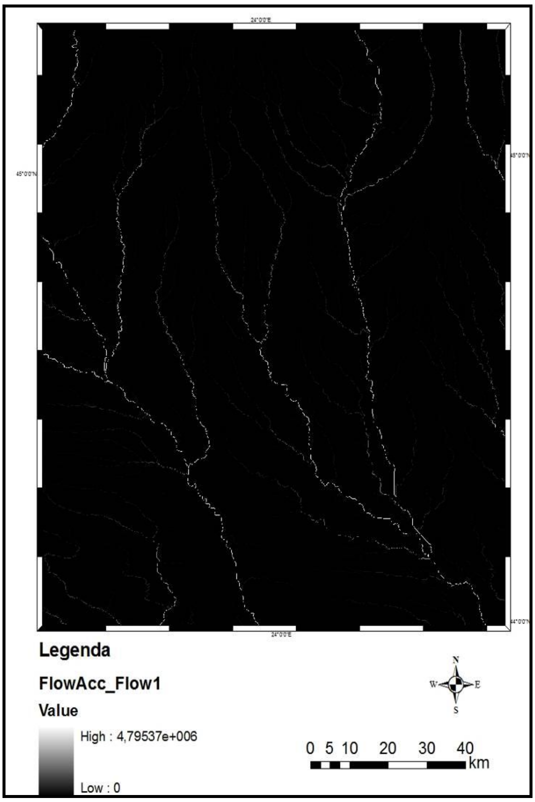

Fig. 3: Flow accumulation - raster

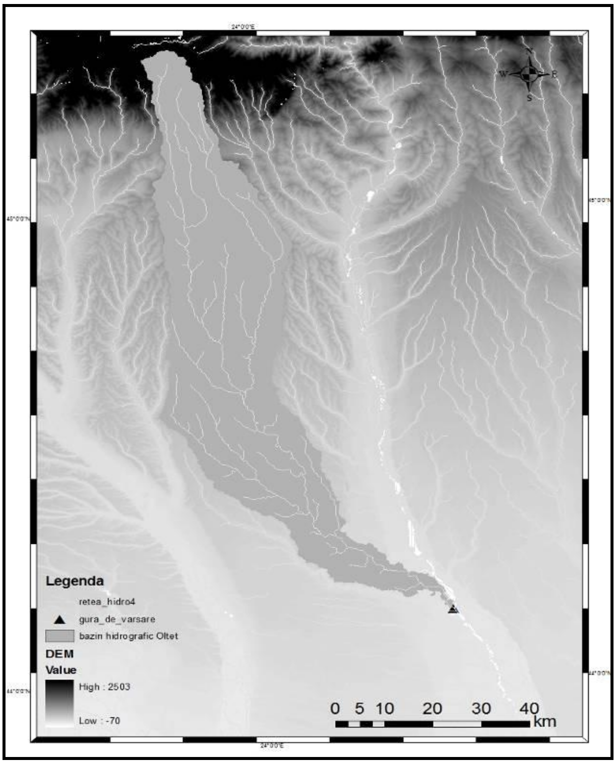

Fig. 4. Olteț watershed – Arcgis Desktop 9.3.

Quantum GIS does not require any pre-processing operations, i.e. eliminating the sinks of a digital elevation model, creating flow direction and flow accumulation rasters, because the algorithm used by this software was designed to minimize the impact of these artificial depressions (sinks) and doesn't need to use more raster data. All that the Quantum GIS user had to do is to import the digital elevation model into Grass environment, which has the necessary tools for identifying river's watershed.

Also, to automatically generate Olteț watershed is no need to establish a pour point, which according to ArcGIS identifies to the maximum flow accumulation point and involves importing a new shapefile into application. All that you have to do is to delineate the region which is under review. This delineation is done using the" Edit Current Grass Region" and the user should seek to draw a bigger area to get a correct result. After delineating the „work region", it is chosen from the Grass list of modules, the function "r.watershed". This function has an algorithm that uses as inputs the digital elevation model on which the entire analysis is based on and a threshold corresponding minimum size of each basin. In this case, the threshold it was 10.000 cells and the river basins smaller than this value were ignored.

3. Results and discussion

After the above mentioned steps were taken to an end, there have resulted two maps showing the spatial configuration of the Olteț watershed.

Figure 4 shows the Olteț basin after processing the digital elevation model in ArcGIS Desktop 9.3, and figure 5 shows the result after we used Quantum GIS 1.7.0 Grass Wroclaw algorithms.

For the map obtained in Quantum GIS 1.7.0 Wroclaw (figure 5), we should do the following comment: excepting the Olteț watershed, which is the main theme of this paper, there were indentified, partially or completely, the neighboring basins larger than 10.000 cells. We might name here the Jiu river, whose basin was almost completely extracted because, in order to get the best results, we established a large work area, which included almost all the Oltenia territory and therefore the space on which Jiu river collects its tributaries. The lower part of the work area severs Jiu - Danube confluence and thus, the mouth of Jiu river is not included in the pool, however the medium and upper courses are well defined.

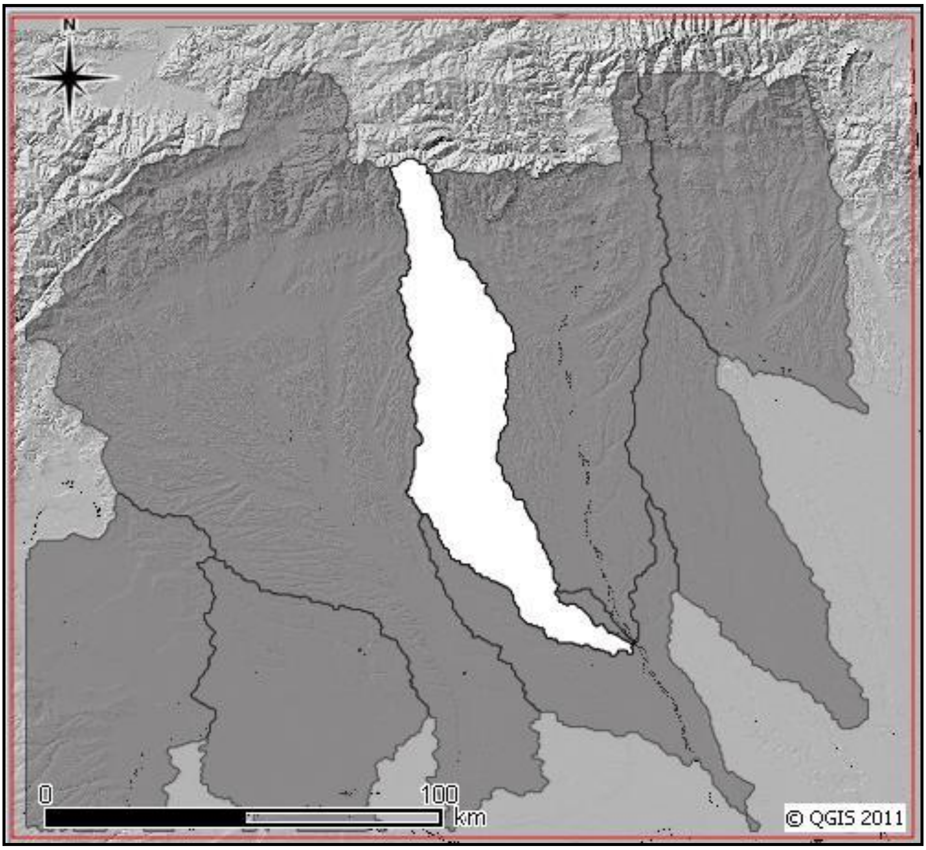

Fig. 5: Olteț watershed (in white) – Quantum Gis 1.7.0.Wroclaw – Grass.

After the automatic delimitation process of the Olteț basin was completed, it was necessary to import in ArcGIS (as shapefiles), the result obtained in Quantum GIS, in order to compare them. This allowed us to underline the differences (figure 6) between the two maps obtained after processing a DEM and to measure the effectiveness of the two softwares.

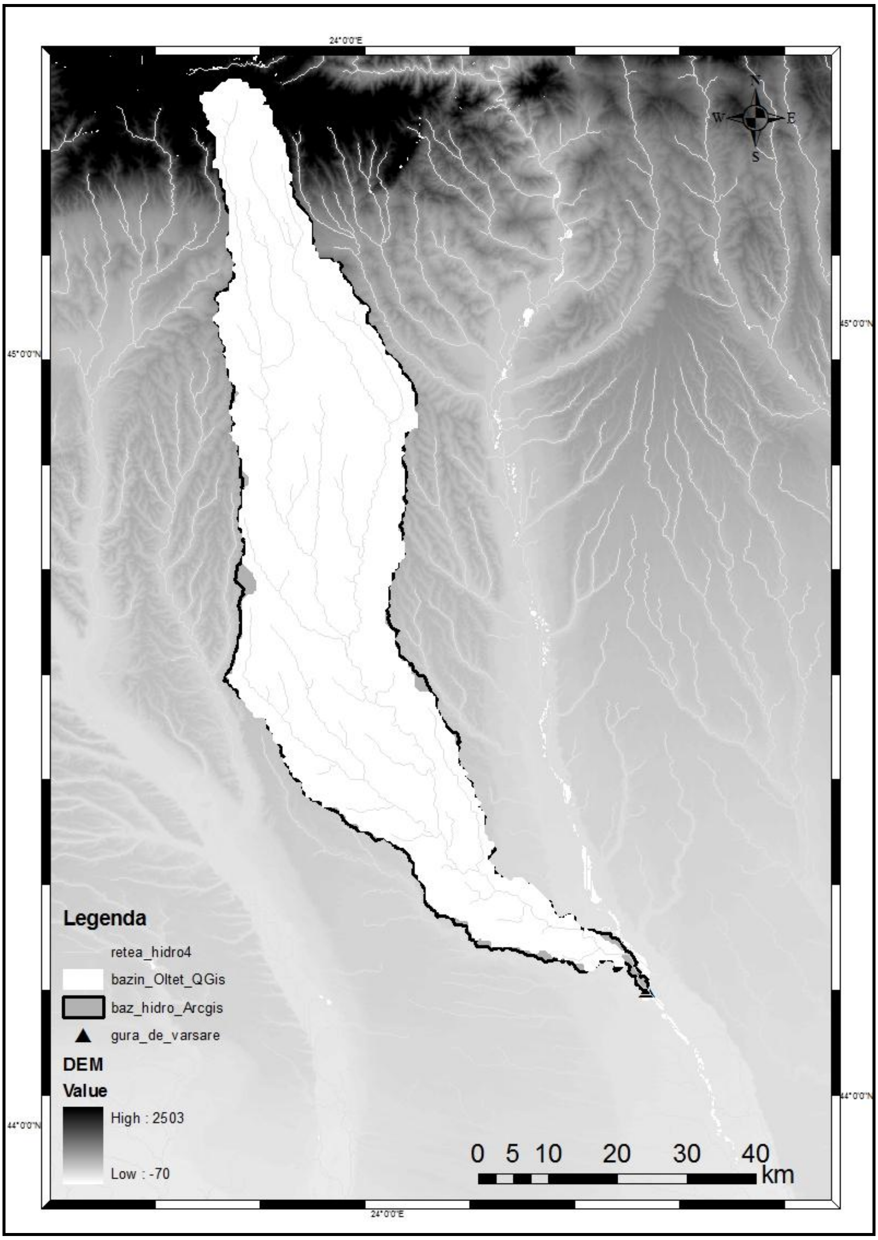

Fig. 6. The Overlapping of the maps obtained in ArcGIS Desktop and Quantum GIS.

At first glance, one can see that there are slight differences (see figure 6) between the maps shown in figures 4 and 5, which are materialized in a larger area for the watershed obtained in Arcgis. Thus, the watershed obtained in ArcGIS Desktop 9.3 has an area of 2485 km^2 and a perimeter of 381 km, while that obtained in Quantum GIS is an area of 2457 km^2 and a perimeter of only 367 km.

Table 2 presents the extreme points, measured in decimal degrees, of the two basins. The greatest difference is recorded in the most eastern point of the basins and characterize and the watershed obtained with ArcGIS Desktop 9.3.

Table 2. The extreme points of the Olteț basin (decimal degrees).

	în Arcgis Desktop 9.3	**în Quantum Gis 1.7.0**
West	23.674922	23.672870
East	24.510020	24.552077
North	45.351735	45.351493
South	44.174349	44.147557

In the introductory part of this study, we motivated the usefulness of the automatic identification process of a catchment, based on a DEM, by saying that once the basin is identified can offer us valuable information about how fast the tributaries waters rich to geometric center of the basin, as well as how great is the river's capacity of erosion and transportation. This information can be found by applying the circularity coefficient formula (1), and if the obtained value will be close to 1, we might conclude that the basin has a nearly circular form. This implies that the floods are reaching quite easily to the geometric center of the basin and we are facing a powerful erosion process.

At one glance, we can determine the real shape of the Olteț Basin (i.e. elongated), but in order to have a mathematical support, we calculated the circularity coefficient. Thus, applying the formula (1) to the model obtained in ArcGIS desktop 9.3, the value of 2.15 was obtained and this reinforces the initial intuition. Therefore, the shape of the Olteț basin is strongly elongated and the consequences arising from this are:

- lower rates of runoff,
- runoff from different points do not reach outlet at same time;
- the erosive capacity is reduced;

4. Conclusions

Following this study we can draw some conclusions:

- Digital elevation models enable the extraction of hydrological information data of great detail and accuracy.

- Commercial and open source software used in this study are ergonomic, reducing the time needed to perform hydrologic data analysis and providing a large amount of information that can be used in complex studies.
- GIS programs enables, when analyzing raster data and not only, some efficient working algorithms.
- ArcGIS Desktop software requires, unlike Quantum GIS plug-in, performing more complex tasks which allows you to identify and remove sinks areas from a digital elevation model or to generate flow direction and accumulation rasters.
- ArcGIS Desktop uses as inputs, in order to deliniate a watershed, the flow direction raster and a point feature class that indicates the maximum flow accumulation. In Grass - Quantum GIS, you only need to edit the current, perhaps empirical, area of interest and determining the appropriate threshold minimum size of a catchment.

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