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Soil-Landscape-Erosion. Gully erosion in the Alt Penedès – Anoia (Catalonia).

A spatial information technology approach: Spatial databases, Geographical Information Systems and Remote Sensing

Memoria presentada por:

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5.3. Automatic delineation of drainage networks and elementary catchments from Digital Elevation Models.

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Automatic delineation of drainage networks and elementary catchments from Digital Elevation Models

Abstract

This paper explains a method to automatically obtain drainage networks and the elementary catchments of the drainage network elements from Digital Elevation Models (DEMs), in front the traditional manner (extraction of hydrographic information from aerial photo-interpretation or from topographic maps). At a given resolution, a DEM is used to derive the drainage network and the elementary catchments by applying flow direction, flow accumulation and watershed functions. Three main aspects are addressed in this paper: (1) the establishment of a threshold area value (A_t) to derive the best fit drainage network of an area from a given DE; (2) to generate a GIS data structure with the outlets of the elementary catchments to depict the boundaries of the elementary catchments; and (3) to develop a program that uses the capabilities of the GIS program Arcinfo (a raster-vector GIS), to obtain a drainage network within a given drainage basin and derive the elementary catchments according to the proposed methodology. Automating the obtention of the spatial representation of drainage networks and elementary catchments is important since these entities are terrain objects nested in a hierarchical aggregation structure. This structure connects different aggregation levels of hydrographic information. It can also be useful for automatic generalisation (Martínez-Casasnovas 1994).

Keywords: Drainage network, Catchment delineation, Threshold area values, DEMs, GIS.

5.3.1. Introduction

Maps and digital spatial databases have the purpose to portray and identify features of the Earth's surface as faithfully as possible within the limitations imposed by scale.

The representation of hydrographic information is important, not only important because of the fact to depict the most reliable representation in a map but because of the use of this information in terrain analysis, resource and environmental management, hydrological studies, etc. For example, the drainage network provides a skeleton for all the features shown on a topographic map (Böhme 1988), it indicates the major landform structure of an area and, sometimes, a better-known phenomena than other features (Mulders 1987, Robinson *et al.* 1978). Hydrographic information is also one of the first subjects to be considered when generalising detail information for inclusion on smaller scale maps (Böhme 1988, Richardson 1993).

Usually, hydrographic information is represented by means of a set of line and/or areas features and a list of attributes, which describe the relevant characteristics of the depicted information. Different entities are often recognised. The area upon which water falls, and the network through which it travels to an outlet is referred to as a drainage system. A catchment or drainage basin is an area from which water, sediments and dissolved materials flow to a common outlet as concentrated runoff (Dunne and Leopold 1978). The boundary between two catchments is referred to as a drainage divide or catchment boundary. A elementary catchment is that upstream area flowing to an outlet as overland flow, without including channel flow from upstream catchments. The drainage network consists of a set of channels or drainage network elements by which water flows in a concentrated manner. These drainage network elements are usually represented by lines. A difference is established between stream and drainage networks. A stream network includes permanent and perennial well-defined channels whilst a drainage network also includes the main runoff lines. The elements of a drainage network can be ordered (classified) according to the number of tributaries. Two common ordering methods are the proposed by Strahler (Strahler 1957) and the proposed by Shreve (Shreve 1966). All these concepts are represented in Figure 5.3.1.

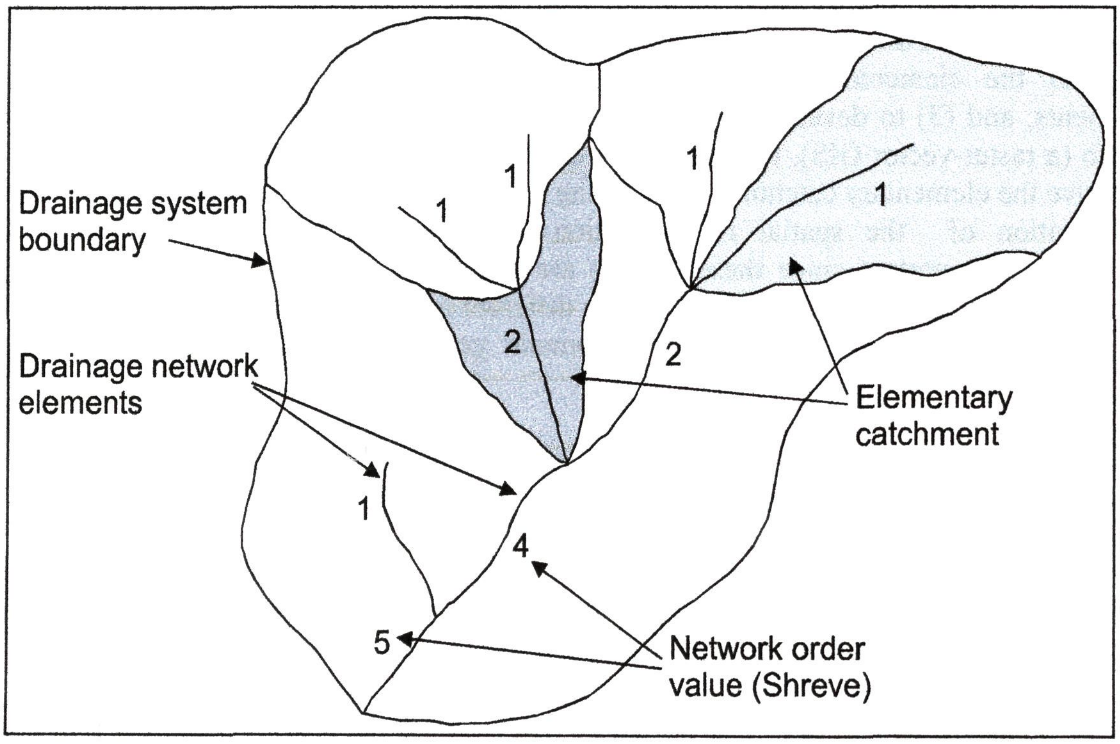

Figure 5.3.1. Representation of hydrographic terrain characteristics.

A catchment is considered to be a basic spatial object to refer terrain information to because of several principal reasons Chorley 1969):

1) It is a limited, convenient and usually clearly defined and unambiguous topographic unit, available in a nested hierarchy of scales on the basis of stream ordering (Figure 5.3.2).
2) It provides the basis to link different aggregation levels of terrain information, particularly at regional level (Shrahler 1956, Ichoku *et al.* 1996, Martínez-Casasnovas 1994, Molenaar and Martínez-Casasnovas 1996).
3) It reflects the upstream geologic and hydrologic character of a watershed.
4) It is a physical process-response system that is open to a cascade of inputs and outputs and viable as spatial basis for landform analysis.

5) It also constitutes the basic area unit, within which morphometric characteristics can be collected, organised and analysed, particularly those of dominant fluvial erosive origin.

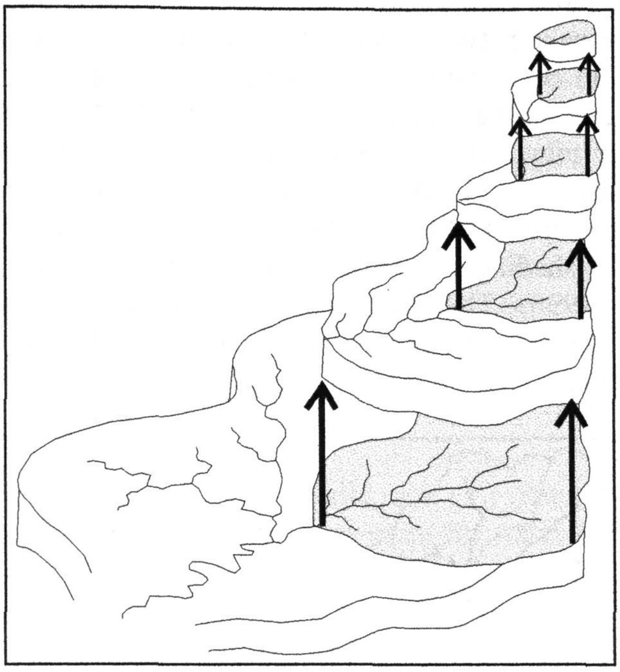

Figure 5.3.2. Nested hierarchy of drainage basins (after Marsh 1991).

For these reasons, Martínez-Casasnovas (1994) proposed a discretization method of catchments that allows automatic generalisation through a hierarchical aggregation structure implemented in a GIS environment. The method takes into consideration the drainage network elements that can be interpreted from aerial photographs. From these elements, the elementary catchments are depicted (Figure 5.3.3). The hierarchical aggregation structure was used to determine the erosion severity class of each elementary catchment, on the basis of morphometric characteristics of the drainage elements and the catchment characteristics, at different resolution levels.

Until recently, delineation of drainage networks and catchments has been made from relief information (contour lines) in topographical maps or from aerial photo-interpretation (Dunne and Leopold 1978, van Zuidam 1986, Böhme 1988, Mulders 1987, Klinghammer and Loránd 1991). Since the advent of GIS, this usual cartographical representation of topography has been gradually substituted by digital representations in the form of digital elevation models (DEMs) (Gandolfi and Bischetti 1997). This also has stimulated the development of automatic procedures to extract topographic as well as hydrological information, such as slope, curvature, drainage network, catchment delineation, flow direction, flow accumulation, etc. In this respect, regular grid or raster DEMs have been usually used for extraction of this type of information (O'Callaghan and Mark 1984, Jenson and Domingue 1988, Moore *et al.* 1991, Tarboton *et al.* 1991, Felicísimo 1994).

Although technological advances allow to automatically delineate drainage networks or catchments, still several problems are found, as when this information is derived from topographic maps or aerial photographs. One of the main problems is to determine which elements make-up the most reliable drainage network at a given scale for a specific purpose. From these drainage network elements, catchments are built. Ideally, all drainage network elements should be considered. However, at a given scale, only the drainage network elements bigger than the spatial resolution of the DEM can be depicted. Also the criteria of the observer may have a significant influence in determining the drainage network elements (Chorley *et al.* 1984, Meijerink 1988). Other authors have accomplished the detection of drainage networks from digital satellite images, based on the knowledge of the spatial behaviour of shading with respect to streams and other topo-morphological features (Ichoku *et al.* 1996). This technique could produce the basic stream network structure from which elementary catchments are derived, but at present GIS functions have shown more efficient and reliable for this purpose.

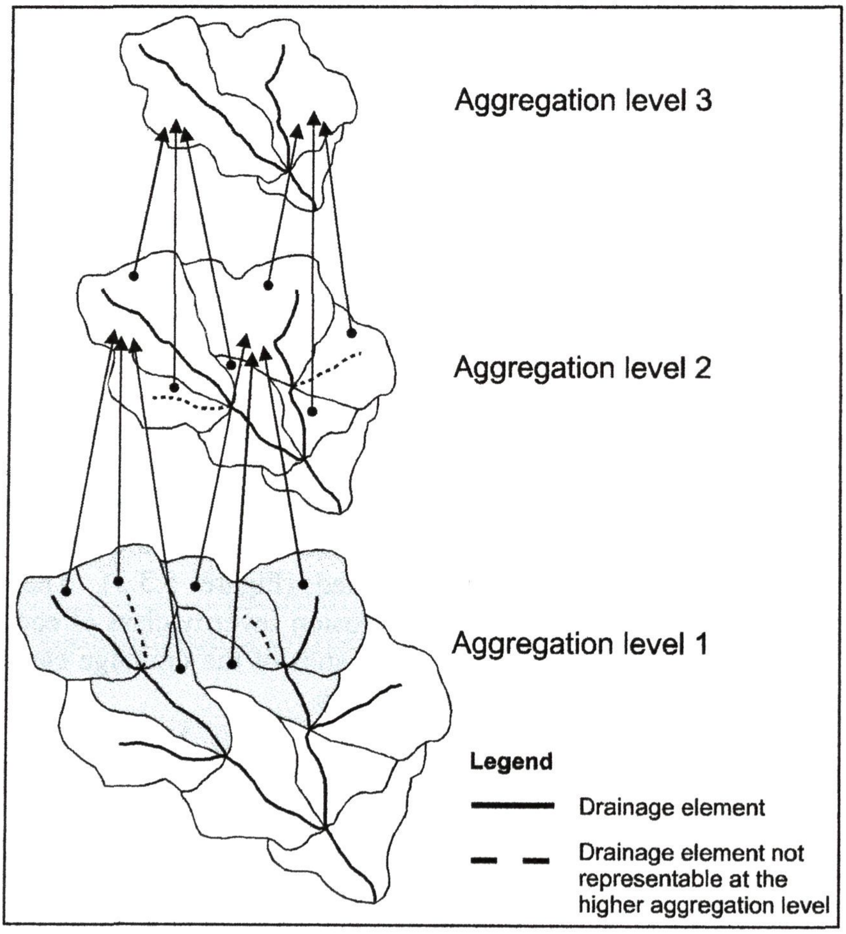

Figure 5.3.3. Drainage elements, elementary catchments and aggregation hierarchy (after Martínez-Casasnovas 1994).

Three approaches have been formulated for the automatic recognition of drainage network elements (Tarboton *et al.* 1991, Da Ros and Borga 1997). Of these approaches, the most commonly used procedure is the based on the O'Callaghan's and Mark's algorithm

(O'Callaghan and Mark 1984). This consists in the assignment of a drainage direction to each cell in the DEM and the following derivation of the drainage network. For the present research, these functions were available in the raster GIS environment of Arcinfo's Grid module. The three main functions used for this purpose are flow direction, flow accumulation and determining a watershed from a given source.

First, the flow direction function determines the direction of flow from each cell in the raster data structure (Grid) using a DEM as an input. Hereafter, the flow direction is determined by finding the direction of the steepest descent from each cell taking into account its eight neighbouring cells. Cells with undefined flow (sinks) must be filled first in order to have a so-called sinkless DEM. The flow direction grid is used to compute the flow accumulation of each cell. The value stored in the cell represents the accumulated number of cells flowing into the cell. The resulting grid outlines the drainage network. A threshold value must be applied for its final delineation: all cells with a flow accumulation value above the threshold will belong to the drainage network and cells with a value below the threshold will not.

This threshold value is referred to as a threshold area (A_t) (Rieger 1993), that represents the minimum support area required to drain to a point for water to flow in a concentrated manner and for a channel to form. Different drainage networks are obtained depending on this threshold area. A high threshold area value will create a drainage network with the main streams. A low threshold area value will also create drainage network elements where flow tends to accumulate but possibly where incision caused by concentrated runoff is not detected (i.e. in-filled valley bottoms). According to the objectives of the user's application, different threshold area values can be applied to obtain the best fit drainage network. In this respect, several authors have pointed out that a variable threshold area should be considered for areas with different relief characteristics (Da Ros and Borda 1997, Gandolfi and Bischetti 1997), and have suggested the use of a slope-dependent threshold area. However, no experimental evidence of a relationship between slope and threshold area has been found.

In this respect, the first part of the present paper is addressed to find a slope or other topographical-variable dependent function to establish the flow accumulation threshold area (A_t) to derive the best fit drainage network for a given area from a DEM. Drainage networks of sample catchments, obtained from aerial photo-interpretation, are use as reference data to set-up the threshold area.

Once the best fit drainage network is drawn, catchments can be automatically delineated from a DEM using the flow direction grid and a source grid from where the upstream cells are detected. These upstream cells distinguish the area of the catchment. A problem arises in the identification of the outlets of elementary catchments from the drainage network data structure. This structure only recognises the nodes or junctions of the stream elements as possible outlets to compute the elementary catchments (Figure 5.3.4). Regarding this problem, the second part of the paper concerns the generation of a GIS data structure with the outlets of the elementary catchments to depict their boundaries (drainage divides).

Finally, a program to automate the delineation of the drainage network of a given catchment and to derive the elementary catchments from a DEM, according to the proposed methodology, is developed using the capabilities of ArcInfo (a raster-vector based GIS).

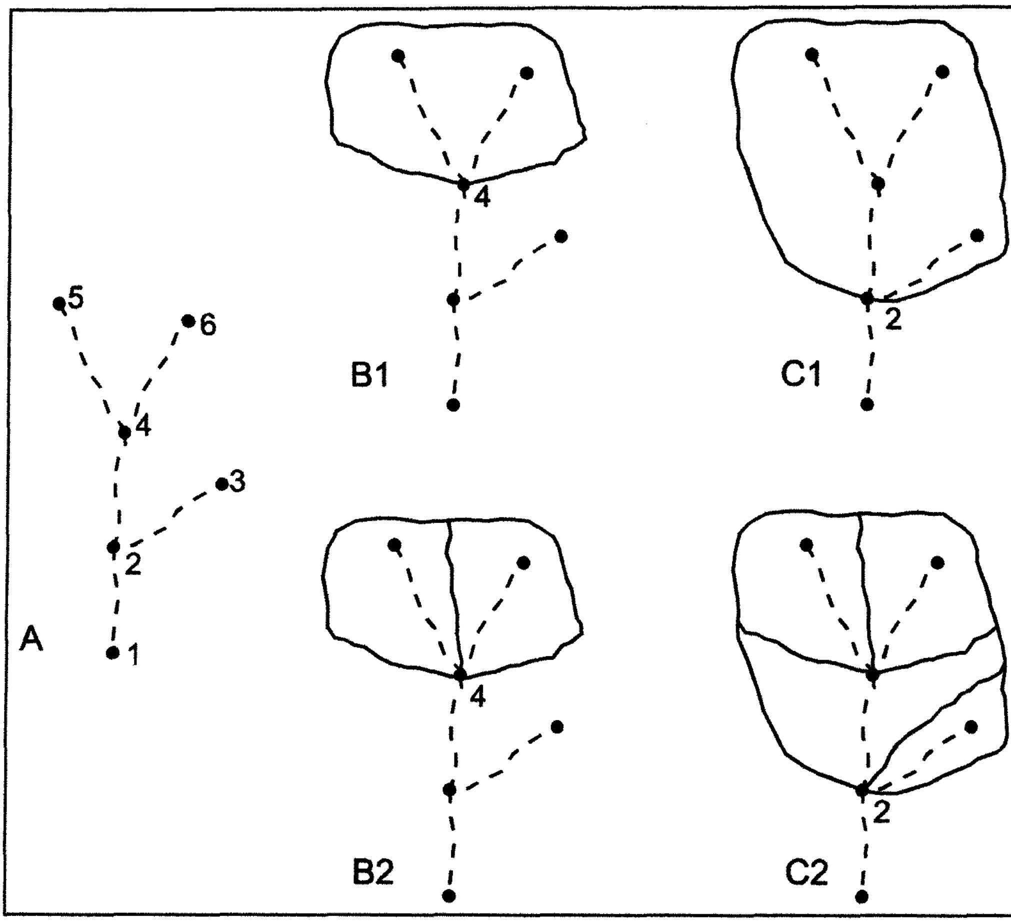

Figure 5.3.4. (A) Representation of a drainage network in a vector data structure (the nodes or junctions are labeled). (B1) and (C1) Catchments if nodes 4 and 2 are respectively used as source points of watersheds. (In a raster data structure the same catchment's boundaries are derived if the nodes are considered as source cells). (B2) and (C2) Elementary catchments that should be obtained according to Martínez-Casasnovas (1994).

The resulting methodological approach and the program were applied to two test areas in the Alt Penedès - Anoia region (NE Spain), using a DEM with a 45 m resolution.

5.3.2. Methodology

5.3.2.1. Delineation of the best fit drainage network from a DEM

As introduced above, the delineation of the drainage network of an area from a DEM requires the establishment of a threshold area. In the present research, several comparisons between a drainage network obtained from aerial photo-interpretation and drainage networks obtained by using different threshold area values were made, in order to set the threshold area.

Two test areas, located in the Alt Penedès – Anoia (Catalonia, NE Spain) (Figure 5.3.5), were considered to apply the proposed methodology. These areas were selected because of their different landscape and drainage pattern as consequence of the different lithologic characteristics and geomorphologic forming processes.

The area to the north of the Anoia river (Fig 5), called Piera-Masquefa area, is located in a high dissected valley-glacis landscape unit. Terrain is typically undulating to hilly, with slope degrees between 10-20%. The area is highly affected by gully erosion: 23% of the area has been affected by deep gullies and ravines. The drainage network shows a clear dendritic pattern. The area to the south of the Anoia river, called Pla del Penedès area, is located in a low dissected valley-glacis landscape unit, where wide alluvial surfaces and gentle slopes are the main relief units. The slope degrees are between 3-15%. The drainage pattern is mainly parallel. Gully erosion is less intense than in the Piera-Masquefa area: 10% of the area has been affected by gullies and trenches excavated into the recent alluvial sediments.

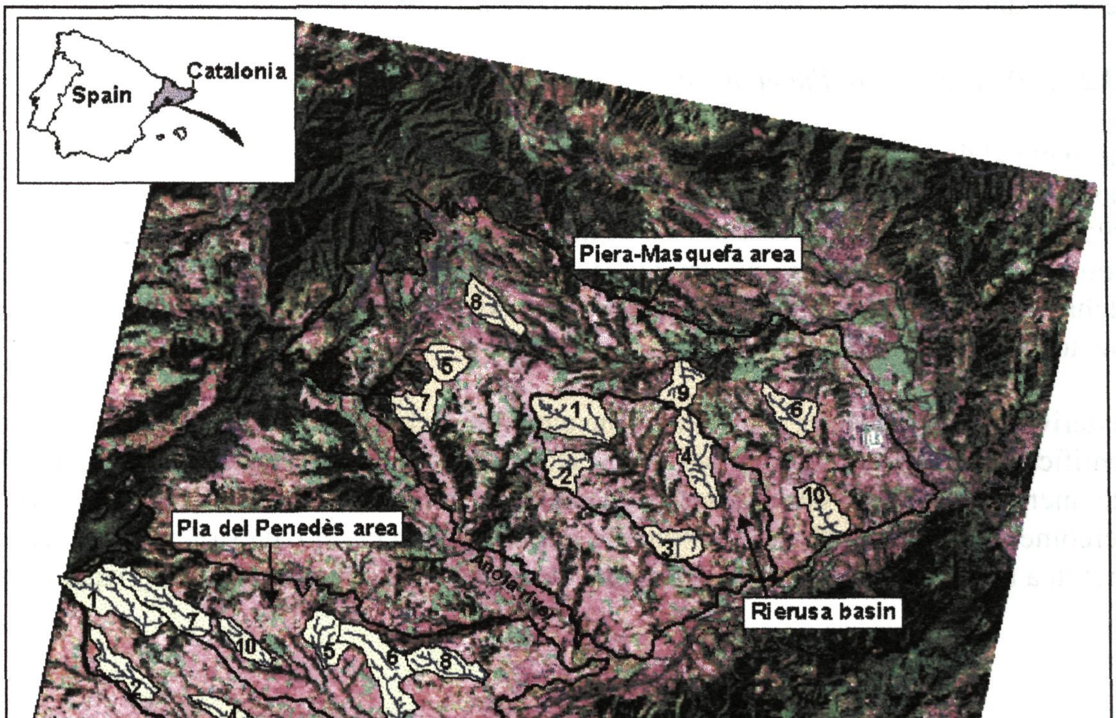

Figure 5.3.5. Location of the test areas and sample catchments that were considered to establish the threshold area (At) to derive the best fit drainage network.

Since the areas show different drainage network characteristics, a threshold area to delineate the best fit drainage network for each of them was considered. To obtain these values, 10 sample catchments of each test area were selected (Figure 5.3.5). For those sample catchments, the drainage network obtained by aerial photo-interpretation and the drainage networks obtained by using different threshold area values were compared. The considered threshold area values were between 10 cells (20250 m^2) and 100 cells (202500 m^2). Aerial photographs (stereoscopic pairs) with an approximate scale 1:30.000 were used to obtain the reference drainage networks. Also a DEM of 45 m resolution, produced by the Cartographic Institute of Catalonia, was used as source data to automatically obtain the drainage networks and the catchments. The decision on the threshold area producing the most faithfully drainage network for each sample catchment was taken on the basis of visual comparison.

Once the threshold area for each sample catchment was established, a least-squares regression between the threshold area values and different topographical variables (slope, relief amplitude and relative relief), extracted from the DEM was computed. The idea behind this operation was to obtain different equations to estimate the best fit threshold area for each test area, with the only input of easy derived topographical variables.

5.3.2.2. Delineation of the elementary catchments of the drainage network elements

The methodology used takes into account the catchment data structure as proposed by Martínez-Casasnovas (Martínez-Casasnovas 1994, Martínez-Casasnovas and Molenaar 1995). This means that the catchments of the drainage network elements, whether they be permanent or perennial, are interpreted from the aerial photographs at a given scale. The catchment of each drainage network element is considered as the area draining overland-flow to any point of the element.

To derive these elementary catchments, the outlet of each element has to be identified. The identification of these outlet points in a vector data structure is not easy since individual catchment areas cannot be obtained from each junction of the network (Figure 5.3.6). To overcome this problem, these junctions are converted into raster data structure and used as input in a neighbour operation to determine the outlet cells of each elementary catchment.

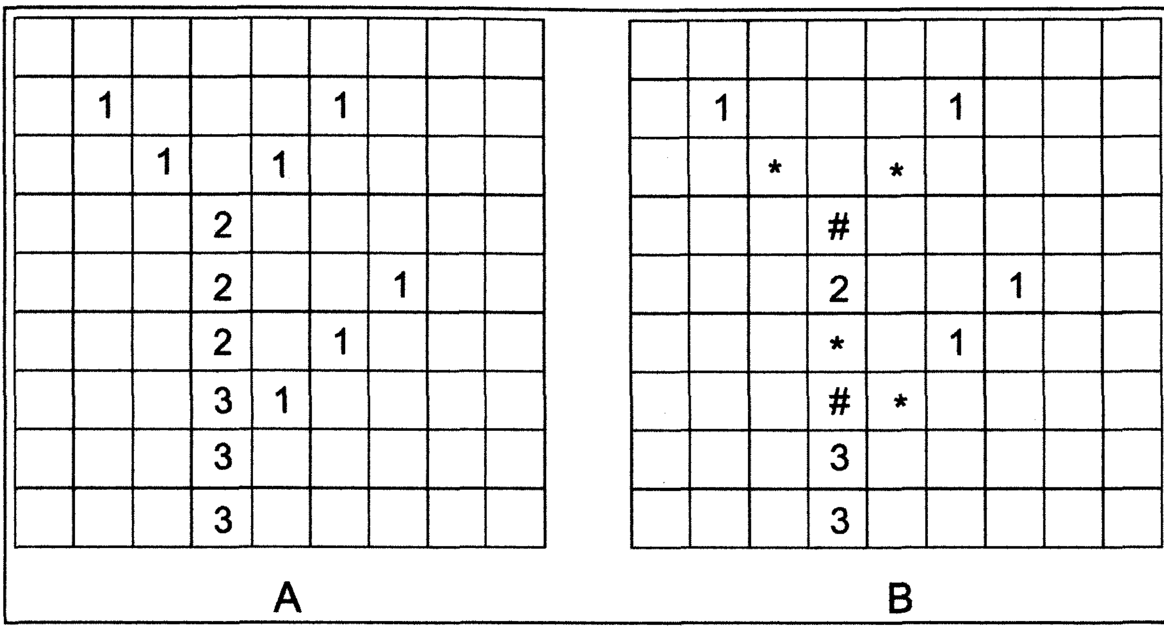

Figure 5.3.6. (A) Raster data structure of the drainage network of Figure 5.3.4. (The cell values represent the Shreve stream order). (B) Representation of the drainage network element junctions (#) and the cells that are considered as outlets to compute each elementary catchment (*).

The correct outlet sources must be depicted before the elementary catchments are computed. A method to do so has been developed, using the capabilities of the Grid module of Arcinfo. It is based on the identification of the upstream outlet cells that are adjacent to the junction cells of the drainage network (Figure 5.3.6). These cells are also the outlet cells of the elementary catchments. These cells must fulfil the following criteria (Figure 5.3.7): 1) The processing cell is a cell of the drainage network, 2) The neighbouring cell is of a higher Shreve order, 3) The same neighbouring cell is a junction cell of the drainage network. These criteria are easily programmed in a cell by cell search using a 3x3 grid filter within a DOCELL operation or ArcInfo's Grid module. The neighbourhood cells used in this routine are shown in the notation given in Figure 5.3.8.

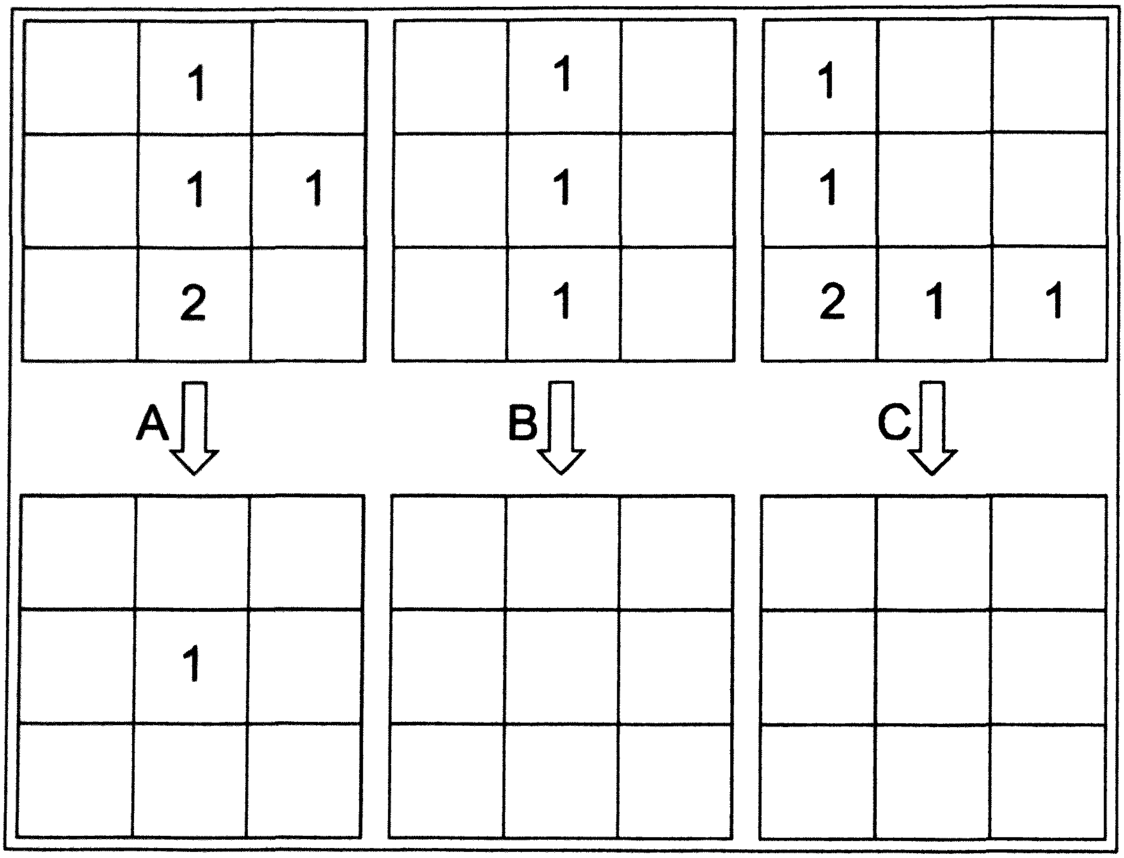

Figure 5.3.7. Examples of criteria that the processing cell (central cell in the 3 x 3 window) must fulfil to be labeled as outlet cell: (A) The processing cell fulfil the required criteria; (B) The processing cell is a cell of the drainage network but no neighboring cell is of a higher Shreve order; (C) The processing cell is not a cell of the drainage network.

The DOCELL process needs two input grids. A drainage network grid ordered according to Shreve and a grid representing the junctions of the drainage network. The output grid is made using the previously described criteria.

Very important in this approach, is the necessity to give each outlet cell its own unique value. This value is used to identify each elementary catchment at the end of the routine. A scalar is used in the DOCELL loop to realise this result. The value one is added each time to the scalar when a criteria is true. The scalar value is thereafter saved in the selected cell. Finally, the elementary catchments are computed by means of the WATERSHED function. This function uses the flow direction grid and the grid with the uniquely defined outlets.

(-1,-1)	(0,-1)	(1,-1)
(-1,0)	(0,0)	(1,0)
(-1,1)	(0,1)	(1,1)

Figure 5.3.8. Arcinfo-Grid neighbourhood notation: cell position within a 3 x 3 window.

5.3.2.3. Program to delineate the drainage network and the elementary catchments from a DEM

A program that applies the proposed methodology, to automatically delineate the drainage network and the elementary catchments of an area from a DEM, was written in Arc Macro Language (AML). This program operates in the Arc, Arcedit and Grid environments of ArcInfo. The structure of the program is represented in the data flow diagram of Figure 5.3.9.

The program has the following four main blocks:

1. Pre-calculation Block
2. Obtaining the drainage network
3. Interactive editing of the drainage network
4. Determining the outlets and computing the elementary catchments

The pre-calculation block requires a sinkless DEM. The sinkless DEM can have any grid cell resolution. All further derived grids will receive the resolution as the input DEM. The required flow direction and flow accumulation grids are computed in this block. The flow accumulation grid can be adapted to fulfil different lithological characteristics, since the drainage pattern of an area is related to the erodibility of the materials (Chorley *et al.* 1984).

A preliminary threshold area value is another input. This can be established according to a user criterion or according to a threshold area function. The program gives the option to enter a user defined flow accumulation value or a value coming from a function concerning the topographical variables of interest for an area (i.e. mean slope).

The next program block is to obtain the preliminary drainage network using the selected threshold area value by a simple reclassification of the flow accumulation grid. Thereafter, the Shreve ordering function is applied to the computed drainage network. These order values are used in the DOCELL process (Table 5.3.1).

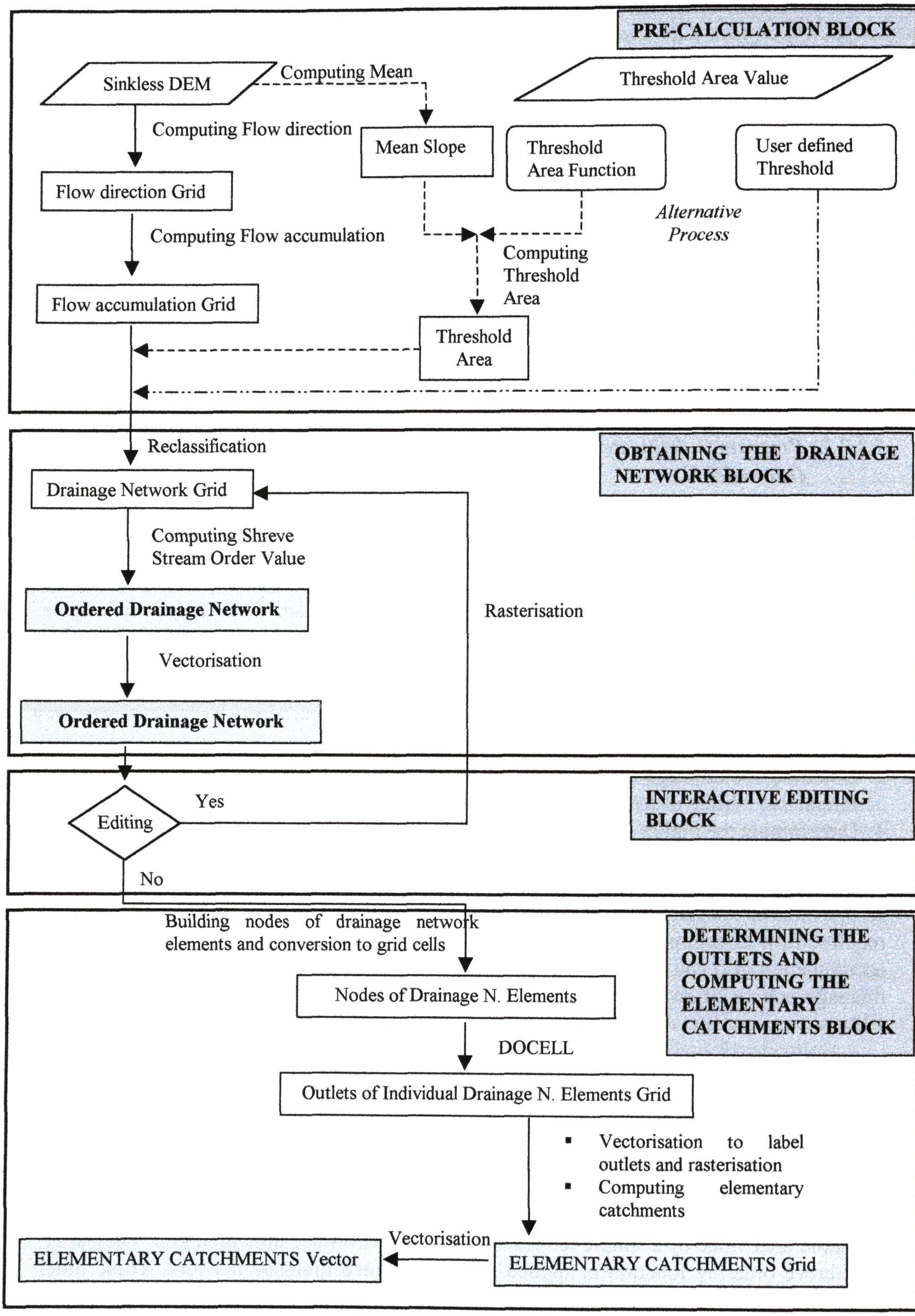

Figure 5.3.9. Flow diagram of the program to obtain the drainage networks and the elementary catchments.

Table 5.3.1. DOCELL process to find the outlets of the elementary catchments as implemented in Arc Macro Language.

```
/* DOCELL PROCESS
/* outgrid = grid with subcatchment outlets
&if [exists %outgrid% -grid] &then
   kill %outgrid%

/* Grids used in the following DOCELL loop
/* %.indem%strord = streamnet grid with Shreve order (input)
/* %.indem%grdpoint = streamnet grid with function points (input)
/* %outgrid% = grid with subcatchment outlets (output); each cell has a unique value.

/* remove scalar  count and give it the starting value 1.
removescalar count
count = scalar(0)
DOCELL
&type "DOCELL ACTIVE: 8 NEIGHBOURS"
   IF (%.indem%strord(0,0) > 0 & %.indem%grdpoint(-1,-1) > 0 & ~
      %.indem%strord(-1,-1) > %.indem%strord(0,0)) {
         count += 1
         %outgrid% = count
   }
   IF (%.indem%strord(0,0) > 0 & %.indem%grdpoint(0,-1) > 0 & ~
      %.indem%strord(0,-1) > %.indem%strord(0,0)) {
         count += 1
         %outgrid% = count
   }
...
{Repeated for the rest of neighbour positions}
...
END

/* COMPUTE ELEMENTARY CATCHMENTS
kill %.indem%watshed
%.indem%watshed = watershed(%.indem%flowdir, %outgrid% )
```

During the experiments, it was always necessary to edit the computed drainage network. This necessity arises, among other reasons, due to errors in height that are always found in a DEM. However, the better the threshold value is chosen, the less time need to be spent on editing the drainage network.

Typical errors that are found in the computed drainage network are:

- non-connected arcs to the drainage network
- parallel drainage lines in meandering zones
- very short drainage lines that are of no significance
- missing drainage network elements when comparing the computed drainage network with a photo-interpretation check.

To edit these errors, an optional vector editing menu was implemented. The editing of the network is not compulsory. The user can decide to whether to use this facility or not.

Once the drainage network passes the editing phase, the final computation to derive the elementary catchments is executed. In this part, both the junction points of the drainage network and the drainage network itself are rasterized to create the necessary input.

Three datasets emerge from this program:

1. A grid dataset with the elementary catchments (uniquely identified) of a drainage basin.
2. A polygon coverage dataset of the same elementary catchments.
3. A line coverage containing the drainage network elements with the Shreve order attribute.

Once developed, the program was applied to compute the best fit drainage network and the elementary cathments in one representative catchment of each test area (Figure 5.3.5). The Rierusa drainage basin, with an extension of 24.3 km^2, was selected as representative of the Piera-Masquefa area, and the Romaní-Bribons basin, with an extension of 29.6 km^2, as representative of the Pla del Penedès. The threshold area value for each basin was computed from the respective topographical-variable dependent functions, as proposed in paragraph 2.1.

5.3.3. Results

5.3.3.1. Establishing the threshold area value to derive the best fit drainage network pattern

Very different drainage network representations are produced by using different threshold area values. As an example, the Figure 5.3.10 shows this situation after applying different threshold area values to the flow accumulation grid of the Rierusa basin, in the Piera-Masquefa test area. This figure also shows the drainage network as derived by means of aerial photo-interpretation.

The application of the proposed methodology, to obtain the best fit drainage network for areas with different relief types, produced the results that are summarised in Table 5.3.2. This table shows the threshold area values that produced the most faithfully representation of the drainage networks of each or the 20 sample catchments located in the two test areas. The values of mean slope degree, relief amplitude and relative relief for each sample catchment are also indicated.

These data was used as input in a linear regression analysis to find out any relationship between the threshold area and the considered topographical variables. Table 5.3.3 summarised the obtained results.

Although some researchers affirm that no experimental evidence of a relationship between slope and threshold area exists (Da Ros and Borga 1997, Gandolfi and Bischetti 1997), in our study we found a negative correlation between the mean slope of a catchment and the threshold area value that gives the best fit drainage network. This is confirmed for the two test areas that were considered in the present research.

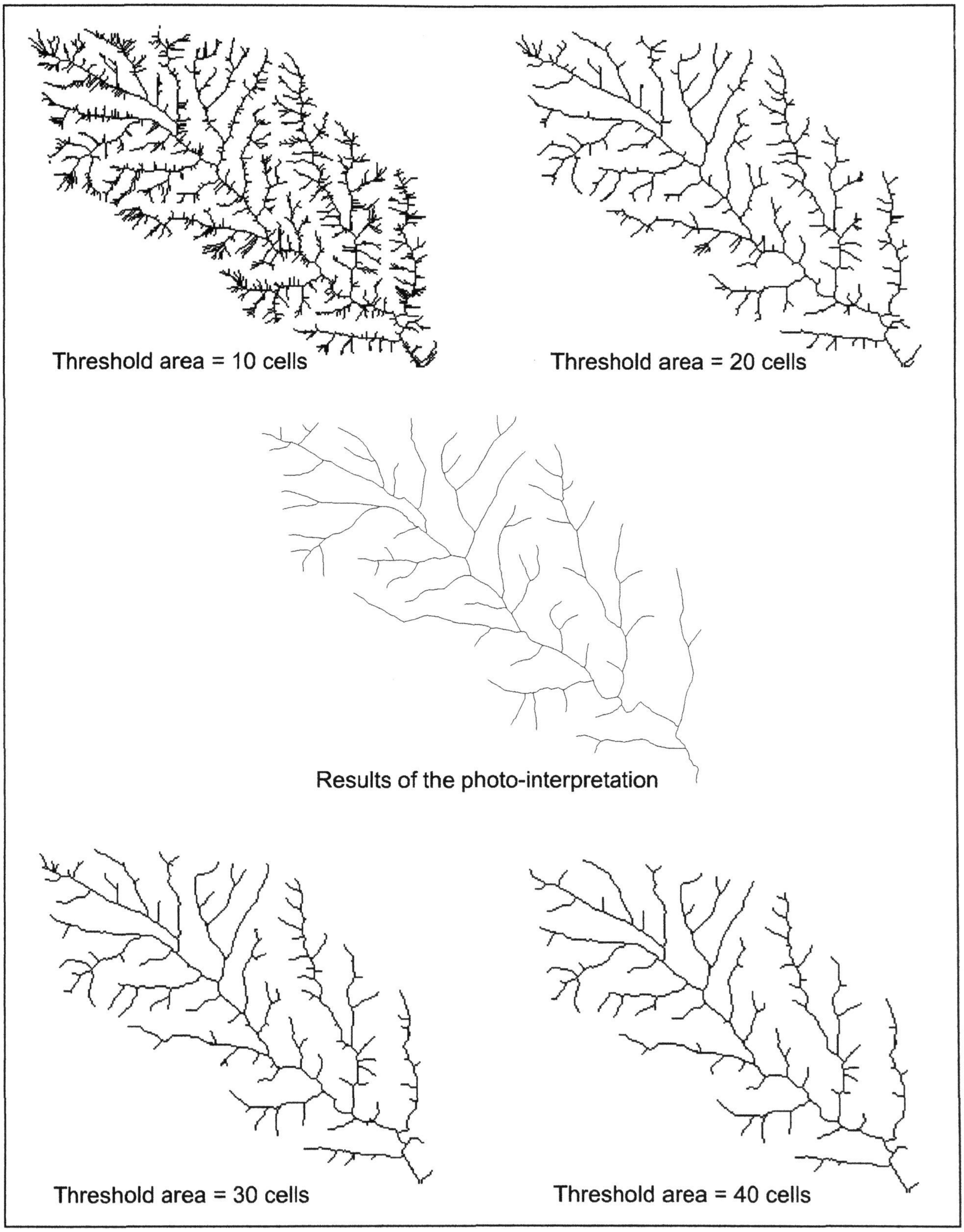

Figure 5.3.10. Resulting drainage networks (Rierusa basin) after the application of different threshold area values and comparison with drainage network as result of the photo-interpretation.

Table 5.3.2. Topographical variables and threshold area for the sample cathments in the two test areas located in the Alt Penedès – Anoia region (Catalonia, NE Spain).

Test Area	Sample catchment	Area (m^2)	Mean slope (%)	Relief amplitude (m)	Relative relief ($m\ ha^{-1}$)	Threshold area (number of cells)
North:	1	2610625	16.5	151	0.58	40
	2	1240000	15.6	123	0.99	40
Piera –	3	1303125	15.4	116	0.89	35
Masquefa	4	2275000	19.4	172	0.76	35
	5	1105625	14.8	118	1.07	40
	6	1402500	17.7	125	0.89	40
	7	1494375	14.1	133	0.89	45
	8	1359375	10.7	108	0.79	65
	9	1235000	21.4	137	1.11	35
	10	1551250	18.8	125	0.81	35
South:	1	2756250	19.1	235	0.85	45
	2	1550625	13.7	157	1.01	30
Pla del	3	1545625	9.0	116	0.75	75
Penedès	4	1589375	6.2	94	0.59	95
	5	1467500	14.8	125	0.85	35
	6	2815625	15.0	177	0.63	50
	7	2258750	16.4	278	1.23	35
	8	1641875	8.3	134	0.82	60
	9	1190000	8.2	82	0.69	65
	10	968750	10.8	140	1.45	55

Table 5.3.3. Results of the linear regression analysis between the threshold area values and topographical variables for the sample catchments.

Test area	Independent variables	Linear regression equation A_t = Threshold area (number of cells)	Coefficients
North:	Mean slope (%)	[1] $A_t = 80.69 - 2.41\ S$	$r^2 = 0.657$ F = 15.3 **; df = 8
Piera – Masquefa	Relief amplitude (m)	[2] $A_t = 69.51 - 0.22\ RA$	$r^2 = 0.204$ F = 2.0; df = 8
	Relative relief ($m\ ha^{-1}$)	[3] $A_t = 50.75 - 11.11\ RR$	$r^2 = 0.036$ F = 0.3; df = 8
	Mean slope (%) Relief amplitude (m)	[4] $A_t = 79.49 - 2.47\ S + 0.01\ RA$	$r^2 = 0.658$ F = 6.7 *; df = 7
South:	Mean slope (%)	[5] $A_t = 101.17 - 3.84\ S$	$r^2 = 0.648$ F = 14.8**;df = 8
Pla del Penedès	Relief amplitude (m)	[6] $A_t = 85.50 - 0.20\ RA$	$r^2 = 0.377$ F = 0.3; df = 8
	Relative relief ($m\ ha^{-1}$)	[7] $A_t = 40.49 + 0.57\ RR$	$r^2 = 0.003$ F = 2.6; df = 8
	Mean slope (%) Relief amplitude (m)	[8] $A_t = 100.7 - 4.43\ S + 0.05\ RA$	$r^2 = 0.656$ F = 6.7*

** Significant relationship ($P<0.01$); * Significant relationship ($P<0.05$)

Other topographical variables, as the relief amplitude and the relative relief, presented a very low r^2 (coefficient of determination) and were rejected as predictors of the threshold area. The multiple linear regression, with mean slope and relief amplitude as independent variables, did not improve the correlation between the threshold area and the mean slope. Even, the significance level of rejecting the null hypothesis, concerning the existence of a relationship between the dependent and the independent variables, was lower in the case of the multiple linear regression for the two test areas, (see F values).

In the present study, the equations 1 and 5 (Table 5.3.3) were selected to obtain the best fit drainage network of the Piera-Masquefa and Pla del Penedès test areas respectively. These equations were implemented in the developed program to compute the drainage network and the correspondent elementary catchments.

More data would be necessary to find a better correlation between the mean slope of a drainage basin and a threshold area to compute the drainage network. In a large area, with different relief types, it is few probable the same threshold area produces the best fit drainage network for the different relief type areas. Therefor, the proposed method should be applied to landscape units where a repetition of the a similar relief pattern is observed.

5.3.3.2. Automatic obtention of the drainage networks and elementary catchments

The implemented program (paragraph 2.3) was applied to compute the drainage network and the elementary catchments of two representative drainage basins located in the considered test areas (Figure 5.3.5). The threshold area for each drainage basin was derived by means of the mean slope functions. The threshold area for the Rierusa basin, with an average slope of 17.6%, was computed from equation 1 (Table 5.3.3), yielding a value of 37.2 cells (rounded to 38 cells). The threshold area for the Romaní-Bribons basin, with an average slope of 10.9%, was computed from equation 5 (Table 5.3.3), yielding a value of 62.7 cells (rounded to 63 cells). The drainage network coverages derived from those values were edited. In this case it was found that the dangle arcs less than 225 m (5 cells) could be removed before computing the elementary catchments. Figure 5.3.11 shows the elementary catchments computed from the DEMs for the Rierusa and Romani-Bribons basins, in test area in the Alt Penedès - Anoia (NE Spain).

5.3.4. Conclusions

The present paper discussed a method that tries to reproduce, in an automated way (using DEM data and GIS capabilities), the traditional manner of delineating drainage networks and catchments.

When using DEM data, a drainage network representation of a given area can be achieved by a simple reclassification of a flow accumulation grid. Then, in comparison with the whole process of aerial photo-interpretation plus hand digitizing of the drainage network of the same area, the first is very much faster. However, is the that process (reclassification of a flow accumulation grid) more reliable than the manual oriented method ?

The present research showed that very different drainage network representations can be produced by using different threshold area values. Comparisons between those representations and the aerial photo-interpretation results were needed to establish, for each test area, the most reliable threshold area, according to the purposes of the user. This training stage to establish the threshold area function slows down the automatic process, but it is needed to obtain the most faithfully drainage network representation of an area. However, once the threshold area function is computed it can be applied to larger areas in order to obtain the drainage network and to automatically compute the elementary cathcments of the drainage network elements.

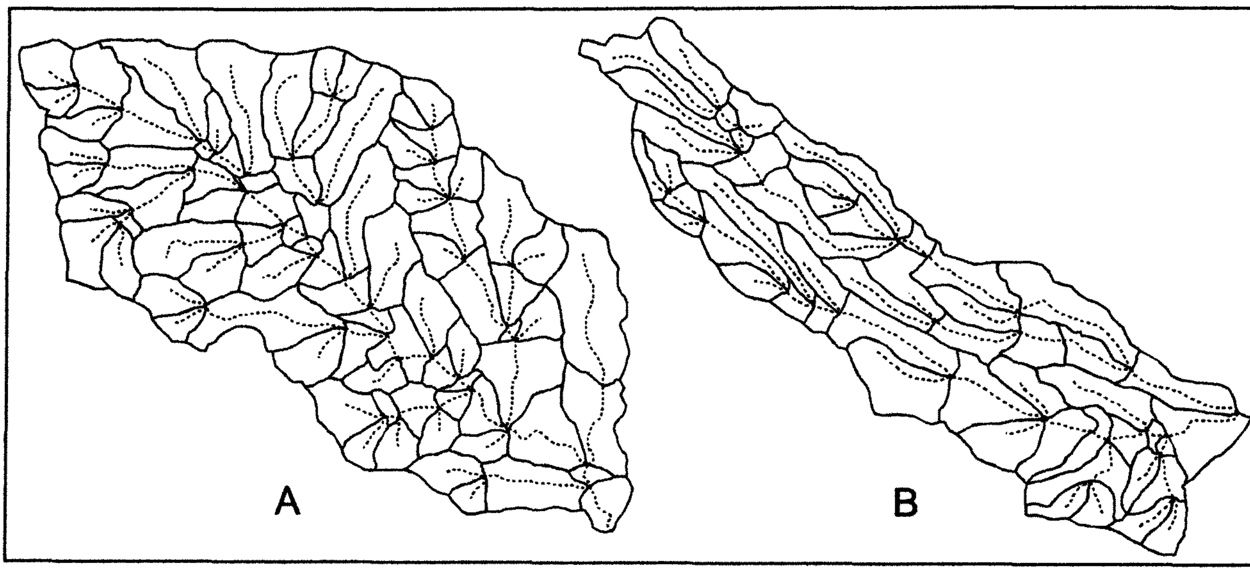

Figure 5.3.11. Elementary catchments of the Rierusa (A) and Romani-Bribons (B) drainage basins according to the proposed methodology. (The drainage network has been superimposed).

Regarding the automation of the process, two main methodological aspects were addressed. A start is made in finding a function to determine the threshold area needed to derive the best fit drainage network pattern from a given DEM. Different drainage networks for different sample catchments within the test areas, derived from varying the threshold value, were compared with the drainage networks coming from aerial photo-interpretation. A relationship between the average slope of the sample catchments and the best fit threshold area value was confirmed. Different relationships (linear regression equations) were computed for the two different test areas, that show distinct relief characteristics. It reveals the convenience of using different threshold area values in landscape units with different relief types, in order to compute the most faithfully drainage network of each area. Other morphometric characteristics as relief amplitude or relative relief (relief amplitude/area of the catchment) were looked at but they did not improve the correlation, even in a multiple regression analysis.

The second aspect addressed is a method to derive a spatial dataset of individual elementary catchments from drainage network elements. This method overcomes the problem of using drainage element nodes or junctions as source points in the watershed function. This method was easily implemented in the grid environment of Arcinfo using a cell-by-cell operation.

The final aspect addressed is the implementation of the proposed methodology in a program, which serves as a base to derive drainage networks and elementary catchments from a DEM. The program allows the user to determine the threshold area value, either setting a value according to the user criteria or by means of a threshold value function. Also, it allows the user to edit the preliminary drainage network before computing the elementary catchments. In the present study, the threshold area function was specific for each test area, using a 45 m resolution DEM. Therefor, the result of the threshold area function is not directly applicable to any area or to DEMs with a different resolution without further studies. This is one of the main topics for future research that were identified: the variability of this correlation with DEMs of different resolution levels. Another main topic is the study of the correlation between other terrain characteristics and the flow accumulation threshold value, in order to dispose of better threshold area functions to derive the best fit drainage networks.

The automatic delineation of elementary catchments is a big step forward in several types of studies and projects related to watershed management, hydrology, erosion, etc.; especially at semi-detailed or reconnaissance level. At a higher study detailed level, other management units like hillslopes or plots become more relevant. The elementary catchments derived are nested in the aggregation hierarchy structure, as proposed by Martínez-Casasnovas (1994), that allows the automatic generalization of this terrain information.

5.3.5. References

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