UNIVERSITAT DE LLEIDA
Escola Tècnica Superior d'Enginyeria Agrària
Departament de Medi Ambient i Ciències del Sòl

Suelo-Paisaje-Erosión. Erosión por cárcavas y barrancos en el Alt Penedès – Anoia (Cataluña).

Un enfoque de estudio mediante tecnologías de la información espacial: Bases de Datos, Sistemas de Información Geográfica y Teledetección.

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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Para optar al grado de Doctor

Director: Prof. Dr. Jaume Porta i Casanellas

El director de la tesis,

El doctorando,

Lleida, septiembre de 1998

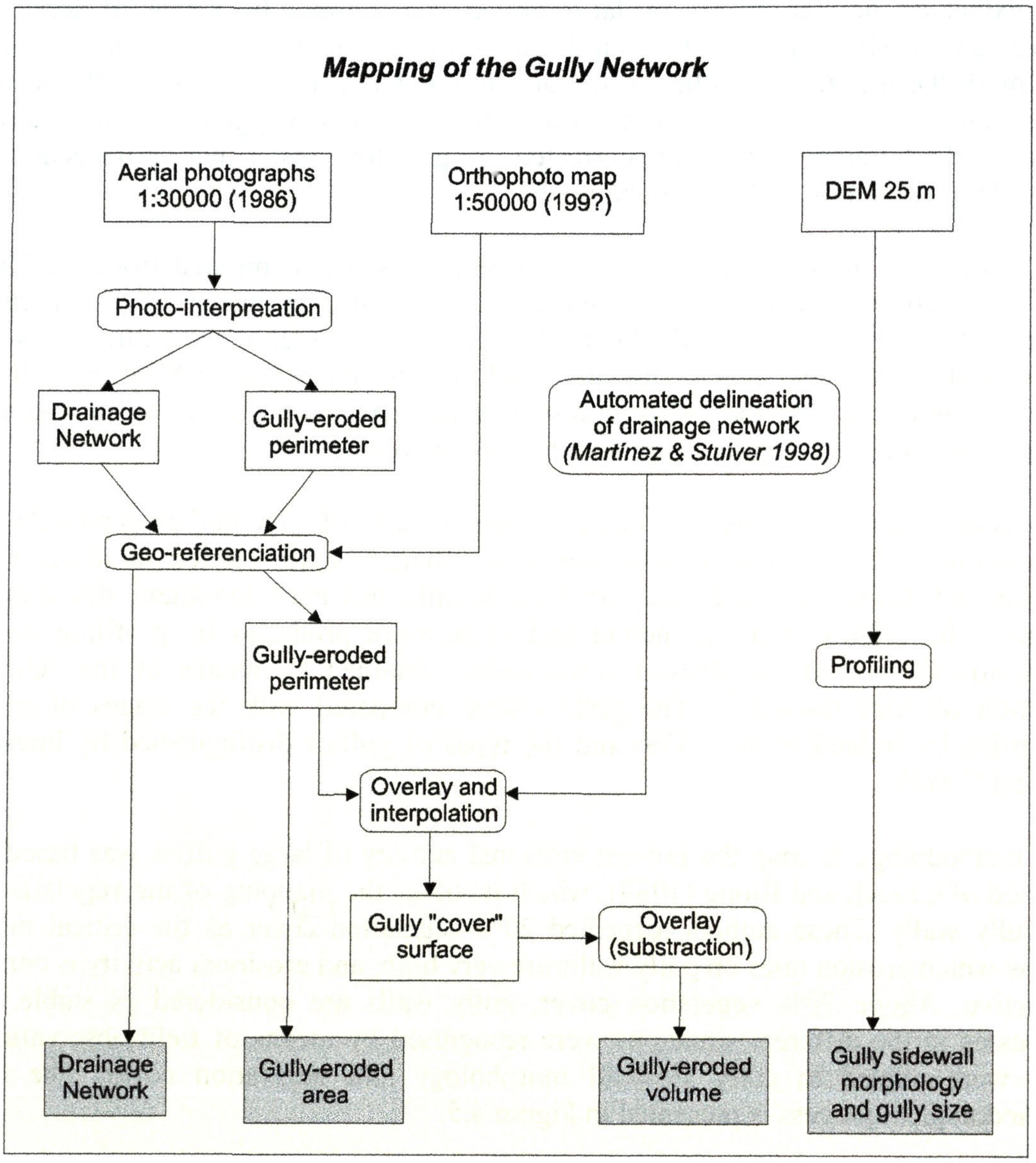

Figure 4.4. Methodological process applied to the characterisation of gully erosion at regional scale: drainage network, gully-eroded area and volume and sidewall morphology.

Provided the big size of large gullies (between 75-375 m width and up to 60 m depth), a Landsat TM subscene (March 1993) was used to map the vegetation cover on gully sidewalls. The pixel was shightly decreased from 30 m resolution up to 25 m, in order to match the resolution of the DEM. The classification of the image was made by means of a hybrid unsupervised-supervised process, using bands 4, 5, 7, NDVI and principal component analysis bands 1, 2 and 3 as a colour composition, following the approach of land cover/use mapping unit definition and generalisation from remotely sensed data proposed by Martínez-Casasnovas (see secction 5.2). Approximately 1% of the study area was sampled to assess the accuracy of the classification, that yielded an overall accuracy of 80.6%. The main informational classes for the classification of the image are summarised in Table 4.2.

Table 4.2. Main informational classes for land cover/use mapping in the Alt Penedès – Anoia.

Land cover/use class	Description
Bare gully sidewalls and badlands	Gully sidewalls and badlands without vegetation cover
Semivegetated gully sidewalls and badlands	Gully sidewalls and badlands, less than 30% vegetation cover (shrubland): *Brachipodium rhamosum, Ulex parviflorus, Genista sp., Juniperus oxicedrus, Rosmarinus officinalis, Thymus vulgaris, Quercus coccifera, Pinus halepensis*
Grassland & shrubland	Grassland & shrubland, 30-60% vegetation cover, typically southern oriented areas: *Brachypodium rhamosum, Ulex parviflorus, Genista sp., Rosmarinus officinalis, Thymus vulgaris, Spartium junceum, Lepidium graminifolium,Quercus coccifera*
Shrubland	Shrubland, 50-75% vegetation cover, typically north and eastern oriented areas: *Brachipodium phoenicooides, Vicia sp., Spartium junceum, Diplotaxis erucoides, Shorgum halepense, Genista sp., Rosmarinus officinalis, Quercus coccifera, Quercus ilex*
Forested shrubland	Forested shrubland, 65-80% vegetation cover, typically north and northwestern oriented areas: *Brachipodium phoenicoides, Coriaria myrthifolia, Vicia sp., Spartium junceum, Genista sp., Pistacia lentiscus, Rosmarinus officinalis, Quercus ilex, Pinus halepensis, Pinus pinea*
Forested areas	Forested areas, 65-80% vegetation cover, typically northern oriented areas: *Pinus halepensis, Pinus pinea, Quercus ilex, Quercus coccifera*
Vineyards	Old traditional or modern vineyard plantations, without vegetation cover at the date of the image
Winter cereals	Well-developed winter cereals: wheat or barley
Bare soil parcels	Bare soil parcels and recent level parcels
Residential or industrial built-up areas	Residential (urban and recreational) or industrial built-up areas

The initial erosional activity classes, as proposed by Crouch and Blong (1989), were adapted to the results of the land cover mapping method. The following classes were finally considered: Active – Semi-active (<40% vegetation cover), Semi-active (40-60% vegetation cover) and Semi-active – Stable (>60% vegetation cover).

The landscape unit map at 1:50.000 scale (Figure 4.2), was used to relate gully erosion and geomorphologic and lithologic terrain characteristics. Five main landscape units were identified (see chapter 2). The principal geomorphologic and lithologic characteristics are summarised in Table 4.1.

4.2.2. Gully change analysis and estimation of erosion rates at sub-catchment scale

A study based on a multi-temporal analysis of remotely sensed data (aerial photographs from 1957 and 1986 at 1:30.000 scale and orthophotos from 1993 at 1:25.000 scale) and digital elevation models was applied to:

a) map and to analyse the changes on small and medium-size gullies within the considered period,
b) map an to analyse the changes on the vegetation cover on the walls of large gullies,
c) map the retreat of the walls of large gullies an to compute the retreat rate,
d) compute the rate of material losses by gully erosion in the considered period.

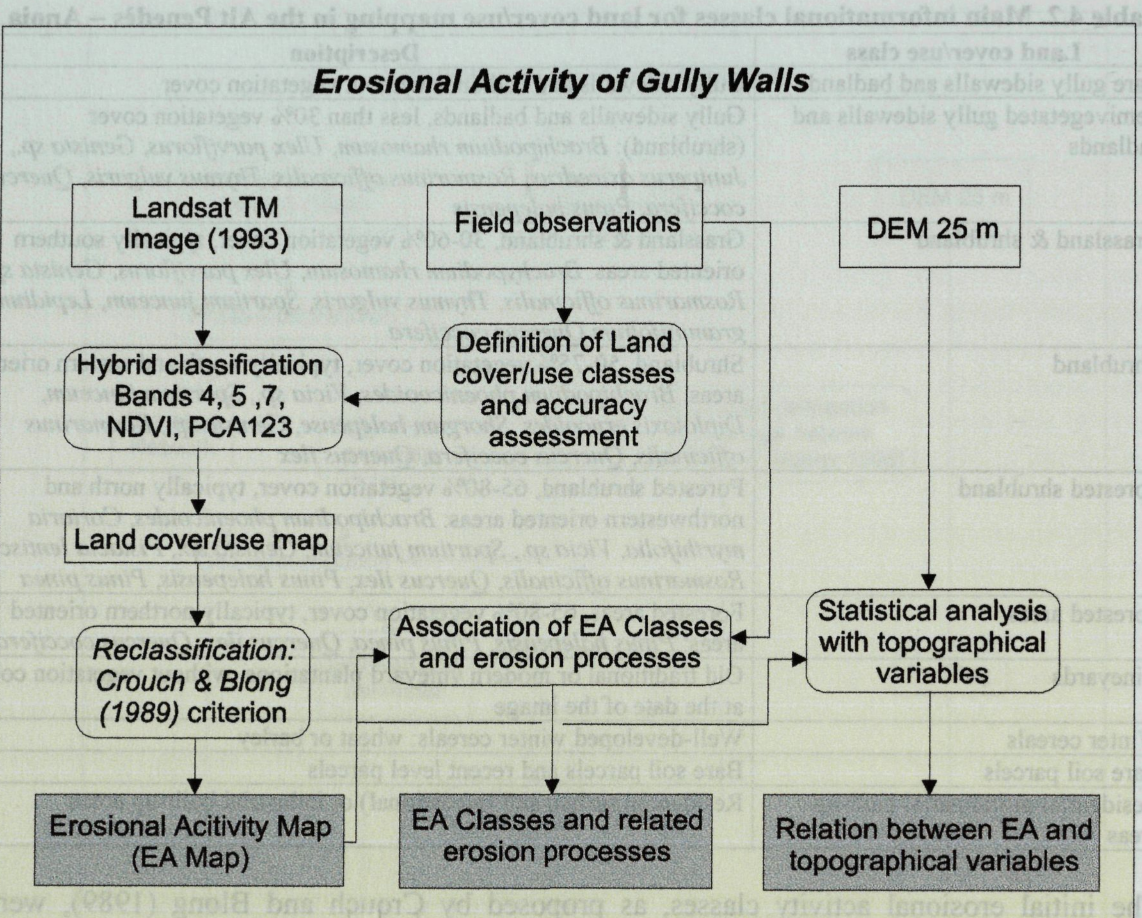

Figure 4.5. Methodological process for mapping the present erosional activity of walls of large gullies.

The materials that are referred in the last paragraph, that are affected by gulling, are compound by soils and, in a large extent, by Tertiary deposits of calcilutites. An average value of 1735 kg m^{-3}, computed from measures made for the present research and by Usón (1998), was considered as bulk density value of the calcilutites, in order to estimate the weight of the eroded materials.

The methodological process is presented in Figure 4.6. According to the mapping scale (1:25.000) gullies 2-10 m depth and <25 m width were considered medium-size gullies, and gullies <2 m depth and 2-3 m width as small or incipient gullies. The volume of the eroded materials during this period was estimated by subtraction elevation data from 1957 and 1993. The DEM of 1957 situation was generated by spatial interpolation using 20 m spaced contour lines. The contours were drawn by means of photogrammetric restitution of the 1957 aerial photographs. The resolution given to the DEM was 25 m, the same as the 1993 DEM produced by the Servicio Geográfico del Ejército. The computation of the average rate of gully erosion and the study of changes was only applied to the Rierusa catchment, a sample area of 24.7 km^2, at a resolution equivalent to a 1:25.000 scale.

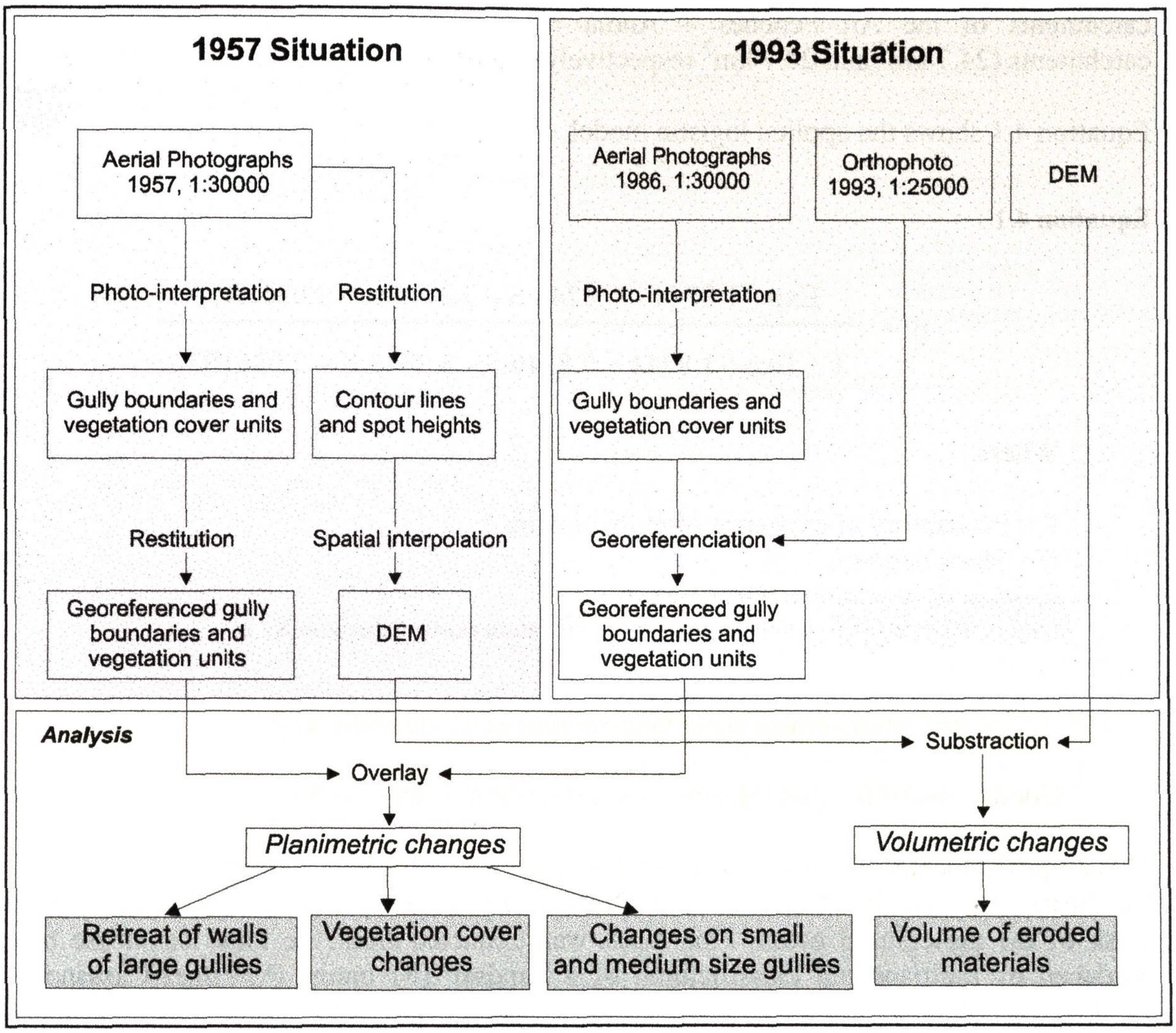

Figure 4.6. Methodological process for the analysis of changes on gullies and for the calculation of erosion rates at sub-catchment scale.

4.2.3. Assessment of the gully erosion risk

Two situations were considered with respect the mapping of gully erosion risk in the Alt Penedès - Anoia. One was the prediction of existing incipient or small gullies at parcel level, and the another was the risk of development of existing gullies.

4.2.3.1. Prediction of existing gully erosion at parcel level

The model developed by Meyer and Martínez-Casasnovas (1998, see secction 5.4) was applied to the entire study area to predict the probability of existence of gully erosion at parcel level. This approach is preferred in front of the estimation of growing of existing gullies, since farmers continuously remove them after rainfalls and the amount of retreat of gullies can hardly be measured (Thomas *et al.* 1986, Meyer and Martínez-Casasnovas 1998).

The model was calculated and applied using reference data from two sample sub-catchments of the Alt Penedès – Anoia region: the Rierusa and Romaní-Bribóns catchments (24.7 km^2 and 28.7 km^2 respectively).

Equation 4.1 shows the applied logistic model.

Equation 4.1

$$p = \frac{\text{Exp}\,(-1.8744 + 0.8246\,S - 3.2843\,X - 2.0361R)}{1 + \text{Exp}\,(-1.8744 + 0.8246\,S - 3.2843\,X - 2.0361R)}$$

Where,

P = Probability of existence of gully erosion
S = Slope degree
X = Rectilinear planar form curvature
X= 1 when a rectilinear planar form curvature exists. Otherwise X= 0.

R = Convex planar form curvature
R= 1 when a convex planar form curvature exists. Otherwise X= 0.

Goodness-of-Fit value (Hosmer and Lemeshow 1989) = 0.8424

This empiric-stochastical model was implemented in the Image Calculator function of the GIS Idrisi 2.0, using the 25 m resolution DEM. The probability map was intersected with a mask of the agricultural areas. This mask was extracted from the Land cover/use map produced by multispectral classification of a Landsat TM image (Martínez-Casasnovas 1998, see secction 5.2). The land cover/use classes included in the mask were: vineyards, winter cereals, bare soil parcels and grassland and shrubland. Forested areas and forested shrubland were masked out. Also, a mask including the areas with gully-prone materials was applied. The information on gully-prone materials was extracted from the soil information system of the Alt Penedès – Anoia (see chapter 3). The following lithologies were included in the mask: fine detritic deposits, calcilutites, unconsolidated sandstones and unconsolidated conglomerates. Those masks were applied to map the probability of gully development out of forested areas and areas where the lithology of the deposits is not prone for gully erosion.

Figure 4.7 summarises the methodological process applied to map the probability of existence of fully erosion at parcel level in the entire study area. The detailed process to compute and to validate the logistic model can be found in Meyer and Martínez-Casasnovas (1998).

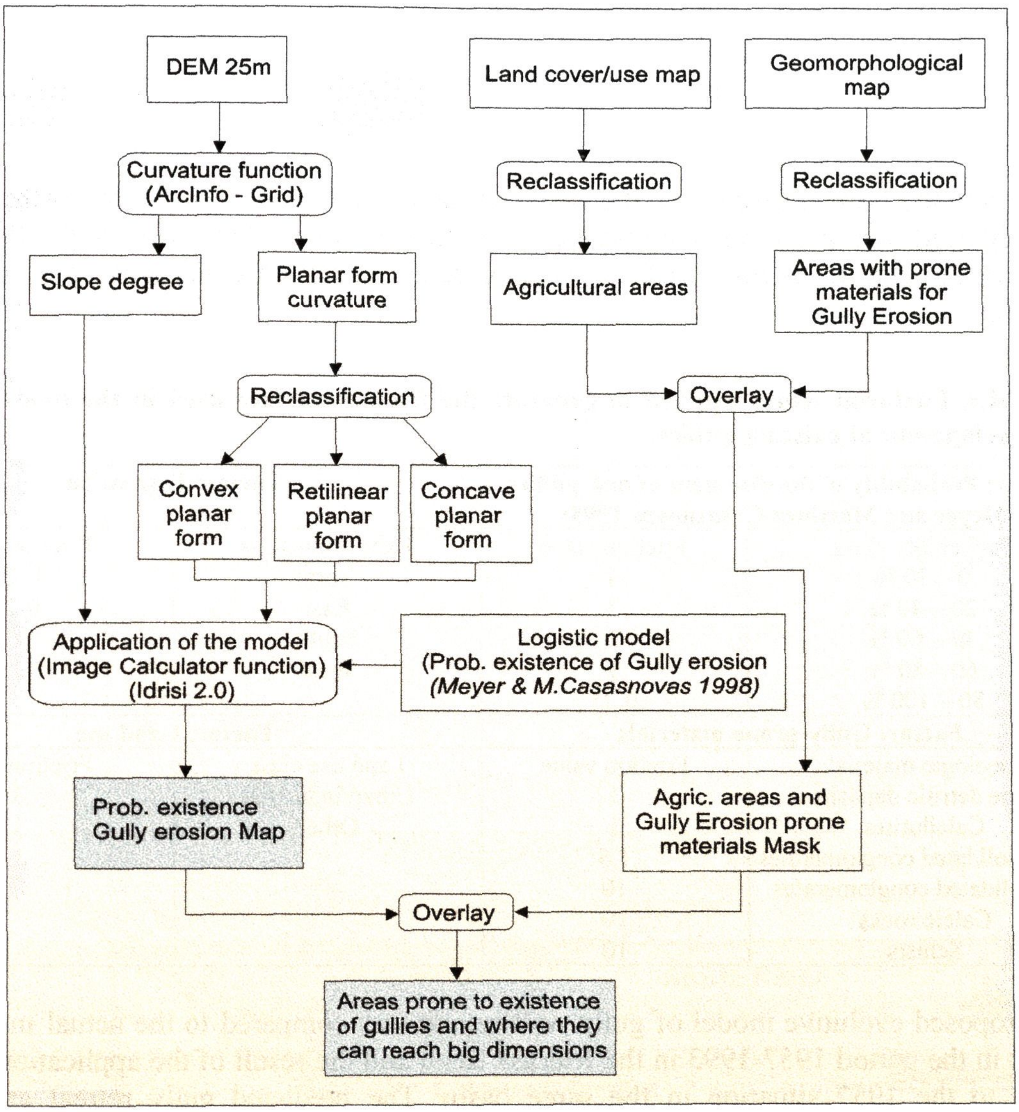

Figure 4.7. Methodological process applied to map the probable areas where small gullies exist and can reach bigger dimensions in the Alt Penedès – Anoia.

4.2.3.2. Risk of development of existing gullies

The risk of development of existing gullies was assessed by means of an evolutive knowledge based model. This model integrates the knowledge acquired during field work as well as the results of the data analysis: multi-temporal analysis of aerial photographs, terrain factors responsible for the concentration of runoff in the border of gullied areas, and distribution of gully-prone materials (derived from the soil database of the Alt Penedès – Anoia).

All those factors were integrated in a friction surface by means of a per-cell sum of the factorial scores of Table 4.3. A cost-distance function was applied from the perimeter of the gullied areas of the 1993 situation, using the calculated friction surface. The cost-distance function generates a distance/proximity surface (also referred to as a cost surface) where distance is measured as the least effort in moving over a friction surface. The unit of measurement is a "grid cell equivalent". A grid cell equivalent of 1 indicates the cost of moving through a grid cell when the friction equals 1. A cost of 5 grid cell equivalent might arise from a movement through 5 cells with a friction of 1, or 1 cell with a friction of 5.

Applied to the present case study, the areas that will be affected in the future by the retreat of gully heads and gully walls are predicted on the basis of the facility/difficulty they find to move through the friction surface that represents the terrain conditions prone to gully growth.

Table 4.3. Factorial scores applied to generate the friction surface used in the modelling of the development of existing gullies.

Factor: Probability of development of new gullies (Meyer and Martínez-Casasnovas 1998)		**Factor: Exposition**	
Probability class	Friction value	Exposition class	Friction value
0 – 20 %	4	North	0.25
20 – 40 %	3	East	0.25
40 – 60 %	2	South	1
60 – 80 %	1	West	1
80 – 100 %	0.25		
Factor: Gully-prone materials		**Factor: Land use**	
Geologic material	Friction value	Land use class	Friction value
Fine detritic deposits	1	Urban/industrial	3
Calcilutites	1	Other	1
Unconsolidated conglomerates	1.5		
Consolidated conglomerates	10		
Calcic rocks	10		
Schists	10		

The proposed evolutive model of gully wall retreat was compared to the actual measured retreat in the period 1957-1993 in the Rierusa basin and the result of the application of the model to the 1957 situation in the same basin. The predicted gully retreat area was obtained by the reclassification of the cost-distance function. The cells considered as eroded in the 1957-1993 period were those that had a low cost value and sum the same number of cells that conform the actual gully retreat areas.

4.3. Results and discussion

4.3.1. The regional perspective of gully erosion in the Alt Penedès – Anoia region

4.3.1.1. Drainage network and gully erosion

The drainage network system of the Alt Penedès - Anoia presents different characteristics in the main landscape units (Figure 4.8). The drainage system is NW–SE oriented, following the dip direction of the Tertiary deposits that fill the Penedès Depression. The drainage pattern is mainly dendritic, except for the Low dissected valley-glacis unit and the SW part of the Piedemont-glacis unit. Here, the presence of residual deposits has produced a parallel pattern with characteristic infilled valleys. The absence of residual deposits and the presence of unconsolidated calcilutites or sandstones in the High dissected valley-glacis unit and the NW part of the Piedemont-glacis unit has produced a dendritic pattern, with a characteristic dense and deep gully network. The estimated gully-eroded volume, in the recent geologic history, reach the impressive value of 466.4 hm^3, and 809.2 Tg (809.2 10^6 Mg) of eroded materials.

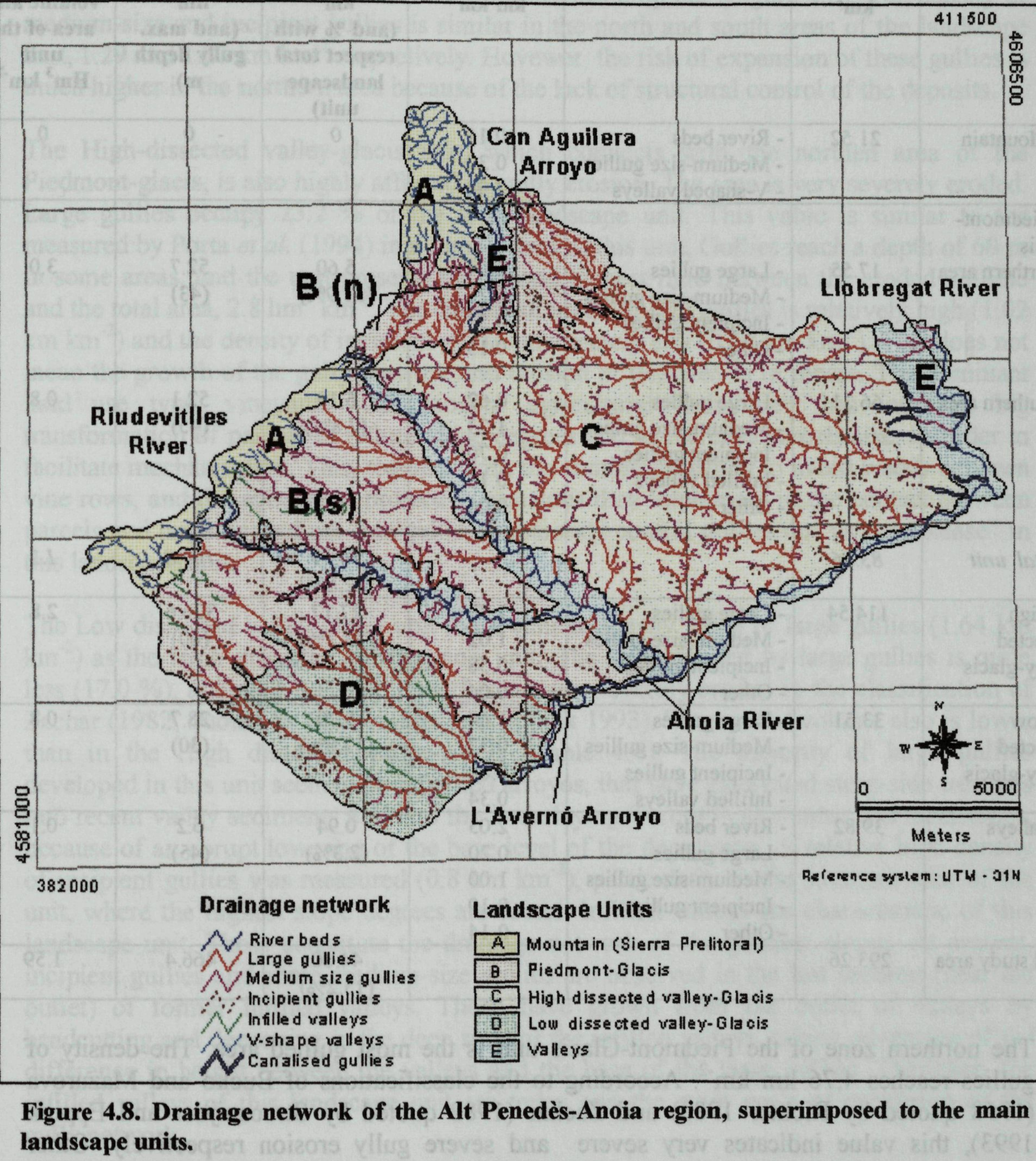

Figure 4.8. Drainage network of the Alt Penedès-Anoia region, superimposed to the main landscape units.

Although the different landscape units present similar drainage density values, with exception of the Valley landscape unit (Table 4.1), differences on the density per type of drainage element and on the gully-eroded area and volume were observed (Table 4.4).

Table 4.4. Drainage density, gully-eroded area and volume in the main landscape units of the Alt Penedès-Anoia region.

Landscape unit	Area of the unit km^2	Type of drainage network element	Drainage density $km\ km^{-2}$	Gully-eroded area km^2 (and % with respect total landscape unit)	Gully-eroded volume hm^3 (and max. gully depth m)	Relation eroded volume and area of the unit $Hm^3\ km^{-2}$
A. Mountain	21.52	- River beds - Medium-size gullies - V-shaped valleys	0.11 0.30 2.94	0	0	0
B. Piedmont-Glacis - Northern area	17.55	- Large gullies - Medium-size gullies - Incipient gullies - Other	2.94 1.29 0.53 0.15	5.60 (31.9%)	52.7 (43)	3.0
- Southern area	66.31	- Large gullies - Medium-size gullies - Incipient gullies - Infilled valleys - Other	0.62 1.23 0.70 0.13 0.06	5.19 (7.8%)	52.1 (45)	0.8
- *Total unit*	*83.86*			*10.79* *(12.8%)*	*104.8*	*1.2*
C. High dissected valley-glacis	114.54	- Large gullies - Medium-size gullies - Incipient gullies - Other	1.77 1.02 0.58 0.04	27.17 (23.2%)	326.6 (60)	2.8
D. Low dissected valley-glacis	33.51	- Large gullies - Medium-size gullies - Incipient gullies - Infilled valleys	1.64 0.37 0.80 0.34	5.70 (17.0%)	28.7 (30)	0.8
E. Valleys	39.82	- River beds - Large gullies - Medium-size gullies - Incipient gullies - Other	2.03 0.20 1.00 0.19 0.14	0.94 (2.3%)	6.2 (45)	0.1
Total study area	293.26			44.60 (15.2%)	466.4	1.59

The northern zone of the Piedmont-Glacis unit is the most gullied area. The density of gullies reaches 4.76 km km^{-2}. According to the classifications of Bucko and Mazurova (1958 quoted by Richter 1980) and Zachar (1982 quoted by Stroosnijder and Eppink 1993), this value indicates very severe and severe gully erosion respectively. Other authors also consider this density as high (Meijerink 1988, Hernández 1991). The area affected by large gullies is 31.9 % of the total sub-landscape unit. According to the classification of Zachar (1982, quoted by Stroosnijder and Eppink 1993), this value confirms the very severe gully erosion. The total eroded volume is 52.7 hm^3 and the ratio eroded volume/landscape unit area of 3 hm^3 km^{-2}. Different values of density and eroded area are observed in the sourthern zone of the Piedmont-glacis unit, 2.55 km km^{-2} and 7.8 % respectively (severe gully erosion according to Zachar 1982, quoted by Stroosnijder and

Eppink 1993), with a similar eroded volume but low eroded volume in relation to the total area (0.8 hm^3 km^{-2}). The difference lies in the limited development of large gullies due to the control performed by the consolidated conglomerates that fill this part of the Tertiary depression. Some large gullies have grown in the lower parts of the slopes that connect with the valleys of the main rivers where calcilutites crop out (Figure 4.8). The density of medium-size and incipient gullies is similar in the north and south areas of the landscape unit, 1.29 and 1.23 km km^{-2} respectively. Hovewer, the risk of expansion of these gullies is much higher in the northern area because of the lack of structural control of the deposits.

The High-dissected valley-glacis unit, which connects with the northen area of the Piedmont-glacis, is also highly affected by gully erosion. The area is very severely eroded. Large gullies occupy 23.2 % of the total landscape unit. This value is similar to the measured by Porta *et al.* (1994) in a sample area of this unit. Gullies reach a depth of 60 m in some areas, and the unit presents the second highest ratio between the eroded volume and the total area, 2.8 hm^3 km^{-2}. The density of medium-size gullies is relatively high (1.02 km km^{-2}) and the density of incipient gullies moderately low (0.58 km km^{-2}). This does not mean the growth of the gully network and erosion in this area is in recess. The dominant land use type, vineyards with modern agricultural techniques, has involved big transformation of parcels to reduce slope degrees and to increase parcels size, in order to facilitate mechanisation. This, together with the continuous tilling to avoid weeds between vine rows, and the ephemeral protective measures they implement in the contact between parcels and large or medium-size gullies, apparently control gullies do "as they please" in this landscape unit.

The Low dissected valley-glacis unit has a similar density value of large gullies (1.64 km km^{-2}) as the High dissected valley-glacis unit. The area affected by large gullies is quite less (17.0 %), although it is also classified as very severely eroded in the classification of Zachar (1982, quoted by Stroosnijder and Eppink 1993). The eroded volume also is lower than in the High dissected valley-glacis (Table 4.4). The majority of large gullies developed in this unit seem to be inherited arroyos, that have excavated steep side trenches into recent valley sediments and into the underlaying Tertiary calcilutites and sandstones, because of an abrupt lowering of the base level of the depression. A relative high density of incipient gullies was measured (0.8 km km^{-2}), particularly in the southern area of the unit, where the highest slope degrees are found. Infilled valleys are characteristic of this landscape unit. These constitute the drainage network of the gentlest slopes. At present, incipient gullies and some medium-size gullies are observed in the last sections (near the outlet) of former infilled valleys. Those have grown from the outlet of valleys by headcutting and deepening in the deep soils of the infilled valleys, taking adventage of the difference in height between the valleys and the base of the large gullies. Therefore, the infilled valleys of this landscape unit are today one the main ways of expansion of the gully network.

The valleys of the main rivers also show an incipient problem of gully erosion. Some large gullies cut the terraces of the Riudevitlles and Anoia rivers and medium-size gullies are frequent in this unit. The growth of gullies in the terraces is mainly related to the drainage of slopes in adjacent landscape units. The low density of incipient gullies confirms this fact. Deepening of gullies in the terraces is favoured by the relative height of these landforms with respect to the river beds.

All those values of drainage density and gully-eroded area and volume should be considered as indicative of the past erosion rather than present erosion (Morgan 1979). On the other hand, other authors, as Strömquist *et al.* (1986 quoted by Giordono and Marchisio 1991), Bergsma (1982), Zachar (1982 quoted by Stroosnijder and Eppink 1993), consider those parameters as reliable erosion ones. In this research, those parameters should be understood as indicative of past erosion but they are also indicative of present activity of the ongoing gulling process, since there are field evidences (later studied) that confirm it.

4.3.1.2. Analysis of gully morphology

Some authors have emphasise the importance of the gully morphology as one of the first steps in evaluating gully processes and as a link between past, present and future gully erosion (Ireland *et al.* 1939, Heede 1970, Imeson and Kwaad 1980, Bergsma 1982, Crouch and Blong 1989).

Differences on planar form of large gullies and on cross-sectional shapes were found in the different landscape units in the Alt Penedès – Anoia. Those differences are mainly related to the lithological properties of the materials the gully network cuts. Table 4.5 summarises the dominant planar form of gullies and the degree of crenelation of the gully perimeter in the different landscape units. Figure 4.10 and Figure 4.11 show the results of the cross-sectional shapes of the large gullies indicated in Figure 4.9.

Table 4.5. Dominant planar form and degree of crenelation of the gully perimeter in the landscape units.

Landscape Unit	Planar form	Crenelation
Piedmont-glacis (North)	Bulbous and dendritic	High
Piedmont-glacis (South)	Dendritic, few branched Linear in some areas	Low
High dissected valley-glacis	Dendritic Bulbous in some confluence areas	High
Low dissected valley-glacis	Linear, very few branched	Low – medium
Valley	Linear or dendritic	Low – medium

The planar surface of the gully-eroded area, 44.6 km^2, and the cross-sectional dimensions of the mapped large gullies, between 13 – 56 m depth and 75 – 450 m width, can be a first indication of the magnitude of the studied phenomena.

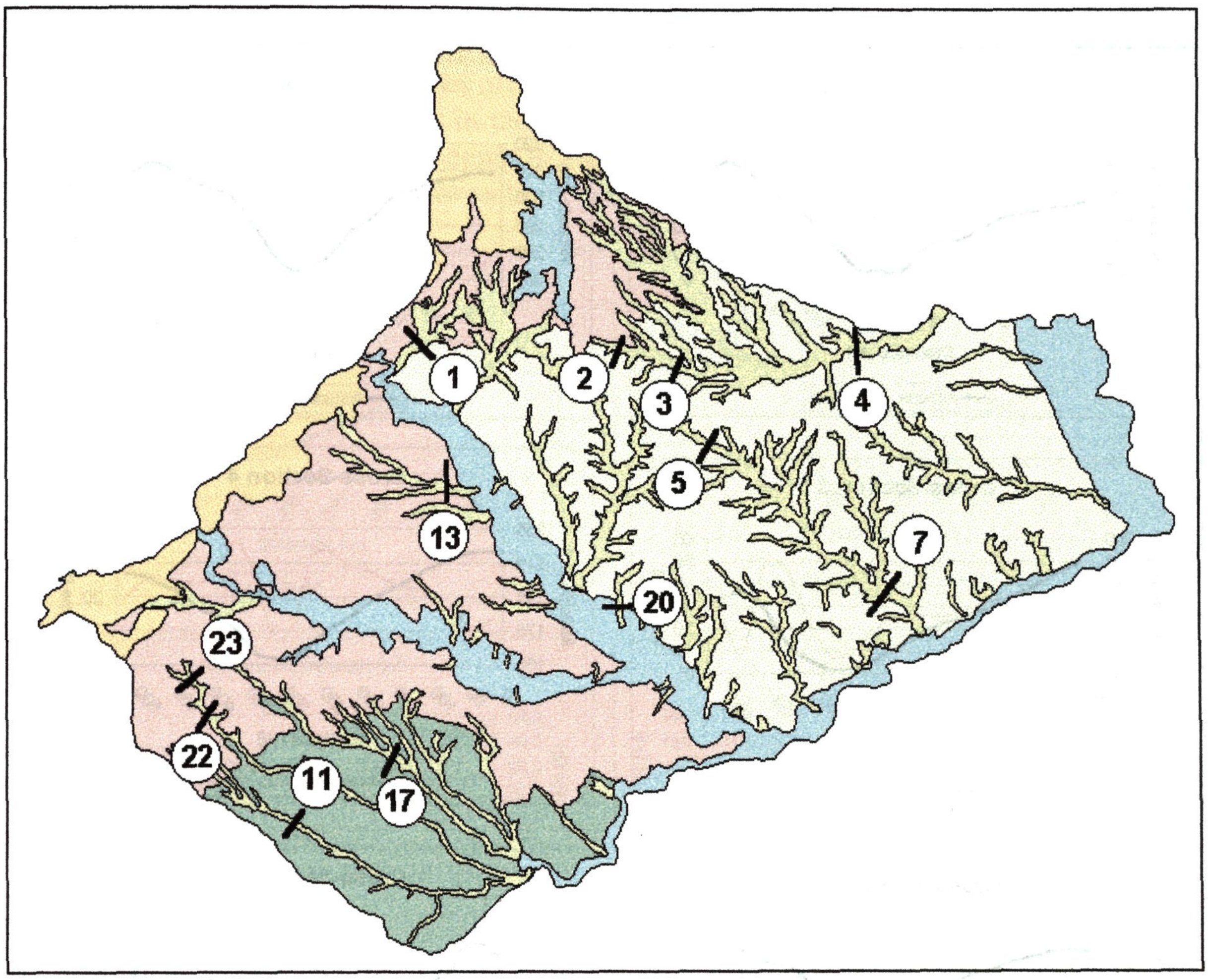

Figure 4.9. Location of the cross-sectional shapes referred in Figure 4.10 and Figure 4.11.

The gullies of the northern area of the Piedmont-glacis unit and the High dissected valley-glacis unit present morphologies and degrees of crenelation associated to a high erosional activity. They are the deepest of the study area, with average values of 11-13 m and maximum of 40-60 m. The retreat of gully walls is not controlled by consolidated materials, and gullies have a high degree of lateral expansion in relation to head retreat or linear advance. The high degree of crenelation is due to the frequent failure of gully walls and the retreat of gullies towards the drainage ways of parcels. The materials that fall off from the walls are usually removed by flowing water after high intensity rainstorms. In other cases, they are deposited in the gully bottom and may lead to some degree of stabilisation of the sidewalls. The cross-sectional shapes of the gullies is typically V to U-shaped or U-shaped. The last forms are usually found in the sections near the outlets of main branches (Figure 4.10, cross-sections 1 and 7). V to U-shaped gullies are found in intermediate sections of the gully network (Figure 4.10, cross-sections 3, 4 and 5). These gullies show a tendency to reach the U-shape, by means of processes as mass movements. V-shaped gullies, which reveal a more initial development stage and a higher rate of deepening in relation to linear retreat, are found in some gully heads (Figure 4.10, cross-section 2).

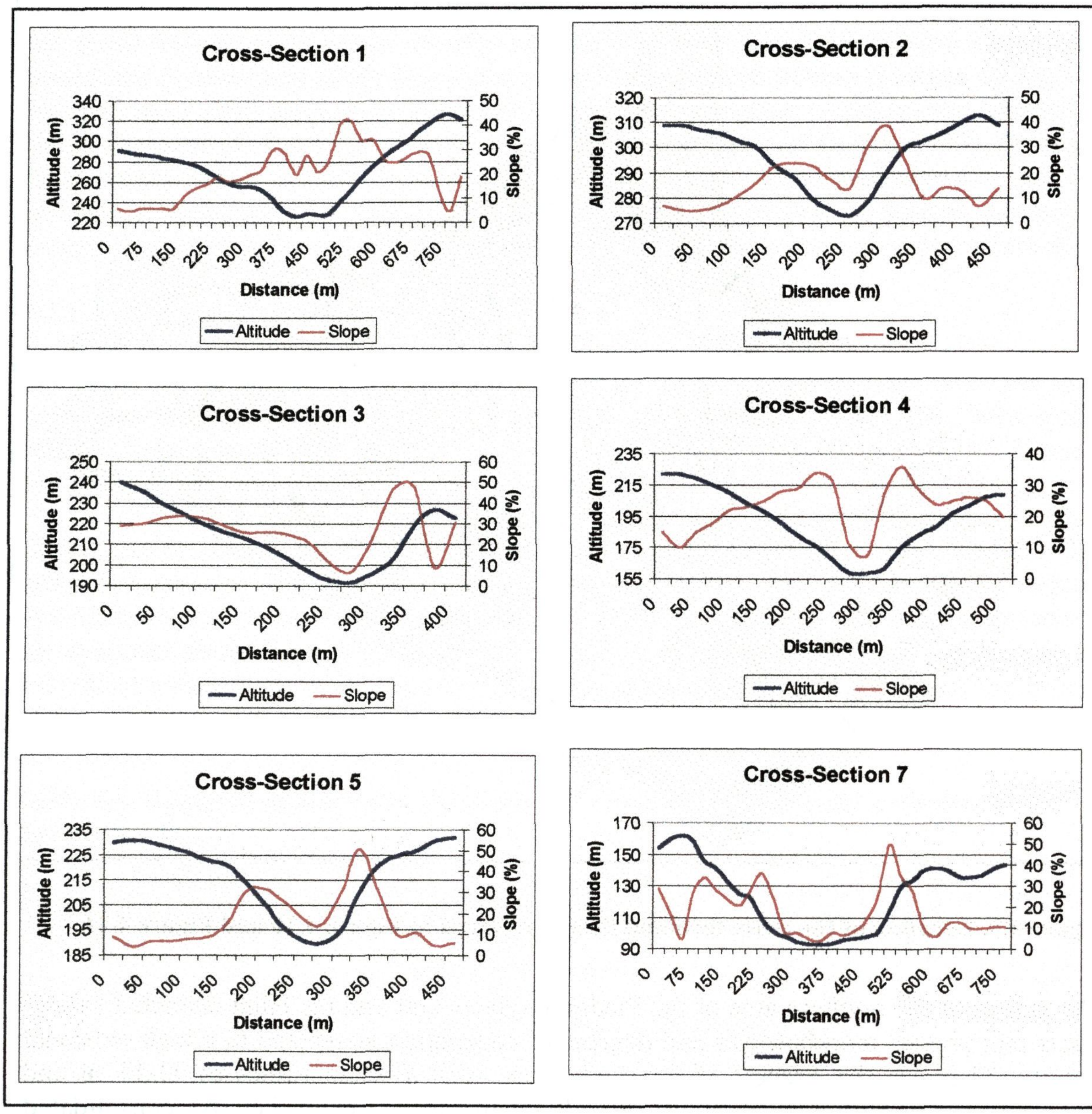

Figure 4.10. Cross-sectional shapes of large gullies in the northern area of the Piedmont-glacis unit and the High dissected valley-glacis unit indicated in Figure 4.9.

In the southern area of the Piedmont-glacis unit, gullies are few branched and less crenelated. This reveals a lower lateral retreat activity of gully walls. This is mainly due to the control produced by the conglomerates of the Riudevitlles river (Gallart 1980). The gullies have similar depths that in the northern area of the unit. Cross-sectional shapes are typically between V and U, with more rounded concave breaks in gully bottoms (Figure 4.11, cross-sections 13 and 23). Sections near the heads are V-shaped bottoms (Figure 4.11, cross-section 22).

The gullies developed in the Low dissected valley-glacis unit have a linear planar form, with very few branches. They are trenches excavated in the valley of existing water courses, with origin in the near mountains. These gullies are similar to the Type 4 of gullies as described by Imeson and Kwaad (1980). The typical cross-sectional shape is the

U-shape (Figure 4.11, cross-section 11 and 17). The main process controlling the retreat of sidewalls is bank erosion. Branches are scarce in the central part of the unit, which has low slope degrees, and they increase in the north and south borders of the unit, where slope degrees are higher. The average depth is around 6-8 m, much less than in the previously mentioned units, although in some sections gullies are up to 30 m depth.

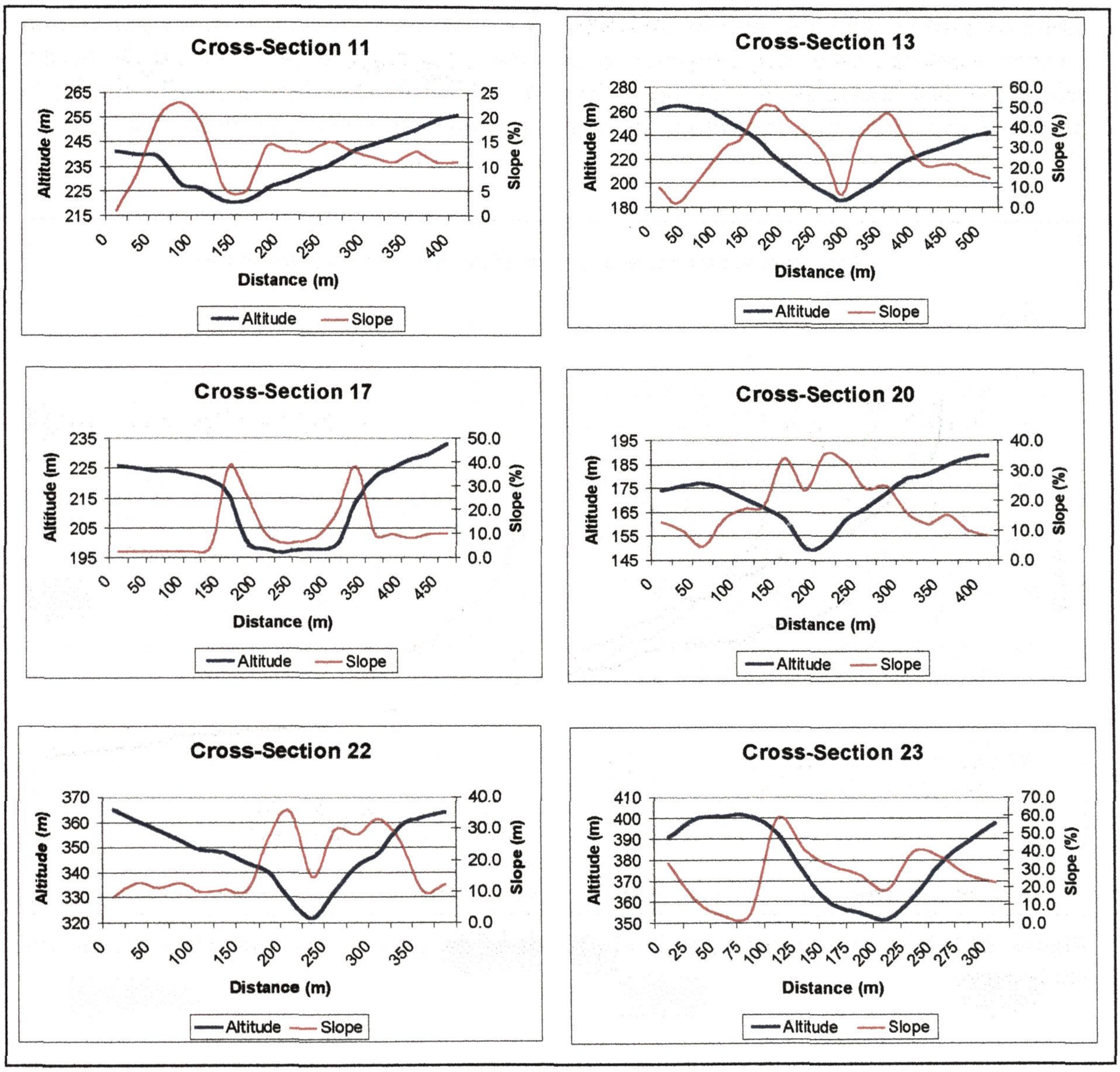

Figure 4.11. Cross-sectional shapes of the large gullies in the southern area of the Piedmont-glacis, Low dissected valley-glacis and Valley units indicated in Figure 4.9.

The gullies that cut the terraces of the Valley landscape unit have similar cross-sectional shapes as the above mentioned valley trenches, with an average depth of 8-10 m and maximums of 45 m (Figure 4.11, cross-section 20). They are short gullies, which have linearly retreated until the border of the terraces. In some cases they are advancing through the adjacent slopes where Tertiary calcilutites crop out.

Some relevant observations can be drawn from the analysis of the longitudinal-sections of the main rivers and tributaries in the study area (Figure 4.12). The base level of the area is in the confluence of the Llobregat and Anoia rivers (50 m over the sea level). Most of the gullies of the study area have they reference local base level in their confluence with the Anoia river or with one of its main tributaries (Riudevitlles river or Avernó arroyo). The gullies of the High dissected valley-glacis unit (Rierusa, Torres or Carrol), present a less stabilised profile than the gullies and arroyos of the Low dissected valley-glacis unit (Avernó, Romaní or Rovira). However, gullies that have reached the slopes of the border area of this last landscape unit (head of Rovira and Tarumbas) show a profile similar to Rierusa, Torres or Carrol, indicating the higher potential for erosion in those areas (Figure 4.12).

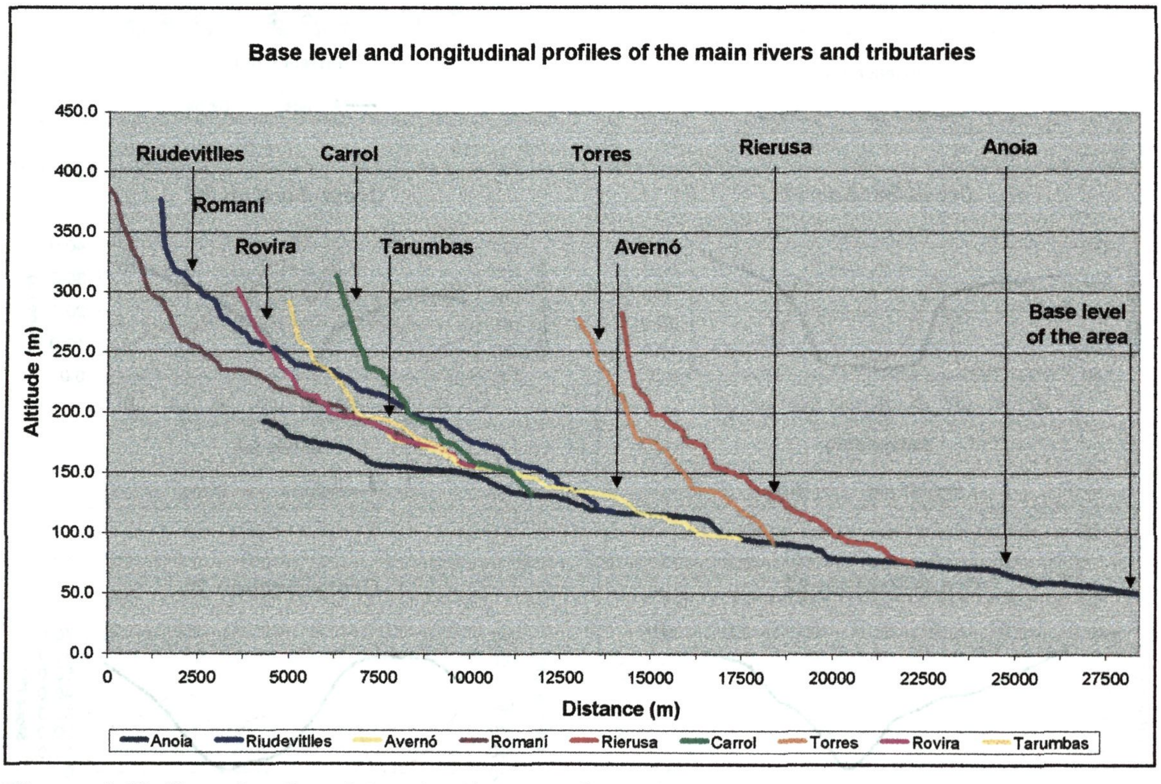

Figure 4.12. Base level and longitudinal profiles of the main rivers and tributaries in the study area.

In summary, the morphological analysis of the gully network of the study area reveals several important facts. First, and as it is recognised in geomorphology (Chorley 1969, Dunne *et al.* 1984, Van Zuidam 1985, Mulders 1987), the drainage network has developed in response to the erosive forces acting on the erodible materials that comprise the study area. The differences in drainage density and pattern among the landscape units mainly reveal differences in the underlying geologic deposits. Dendritic patterns are found were calcilutites are the main underlying materials, and parallel patterns where conglomerates perform a structural control.

Second, all the landscape units, except the Sierra Prelitoral mountains, present gully erosion. The highest degrees of erosion are found in the northern area of the Piedmont-glacis unit and in the High dissected valley-glacis unit. The lowest degree of gully erosion is found in the Valley unit. According to Zachar (1982 quoted by Stroosnijder and Eppink 1993), the degree of erosion in this last unit can be qualified as moderate. Nevertheless, terraces are frequently cut by gullies, being landforms with a high gully erosion risk.

Third, the landscape unit with the highest density of incipient gullies is the Low dissected valley-glacis. This, together with the observed incision of gullies in the infilled valleys, confirm the progression of gully erosion and a high present erosional activity in this unit. Particular attention must be paid to the development of gullies in the higher slope degree bordering areas.

And fourth, the analysis of the cross-sections revealed the main part of the gullies of the study area are in a stage of adjustment and remoulding of slopes by mass movements, circular slips, bank erosion, etc. The northern area of the Piedmont-glacis unit and the High dissected valley-glacis unit present the morphologies of gullies associated to a higher erosional activity. Also the longitudinal-sections of gullies in those areas are the less stabilised, indicating a higher potential for erosion. The land use types that exist in the area could significantly influence gullies do not reach a stable stage. Surface and sub-surface hydric processes that occur in the parcels feed the ongoing gully erosion processes, avoiding the stable stage is reached.

4.3.1.3. Erosional activity of the walls of large gullies

The major part of the gully-eroded area, 62.7% of the total eroded area, presents a vegetation of the type mixed forest or forested shrubland, with >60% vegetation cover (Figure 4.13). Those areas were classified as Semi-active – Stable (Figure 4.15). The 26.4% of the gully eroded area was classified as Active – Semi-active (bare walls or walls with a low coverage of grass and shrubs) (Figure 4.14).