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,

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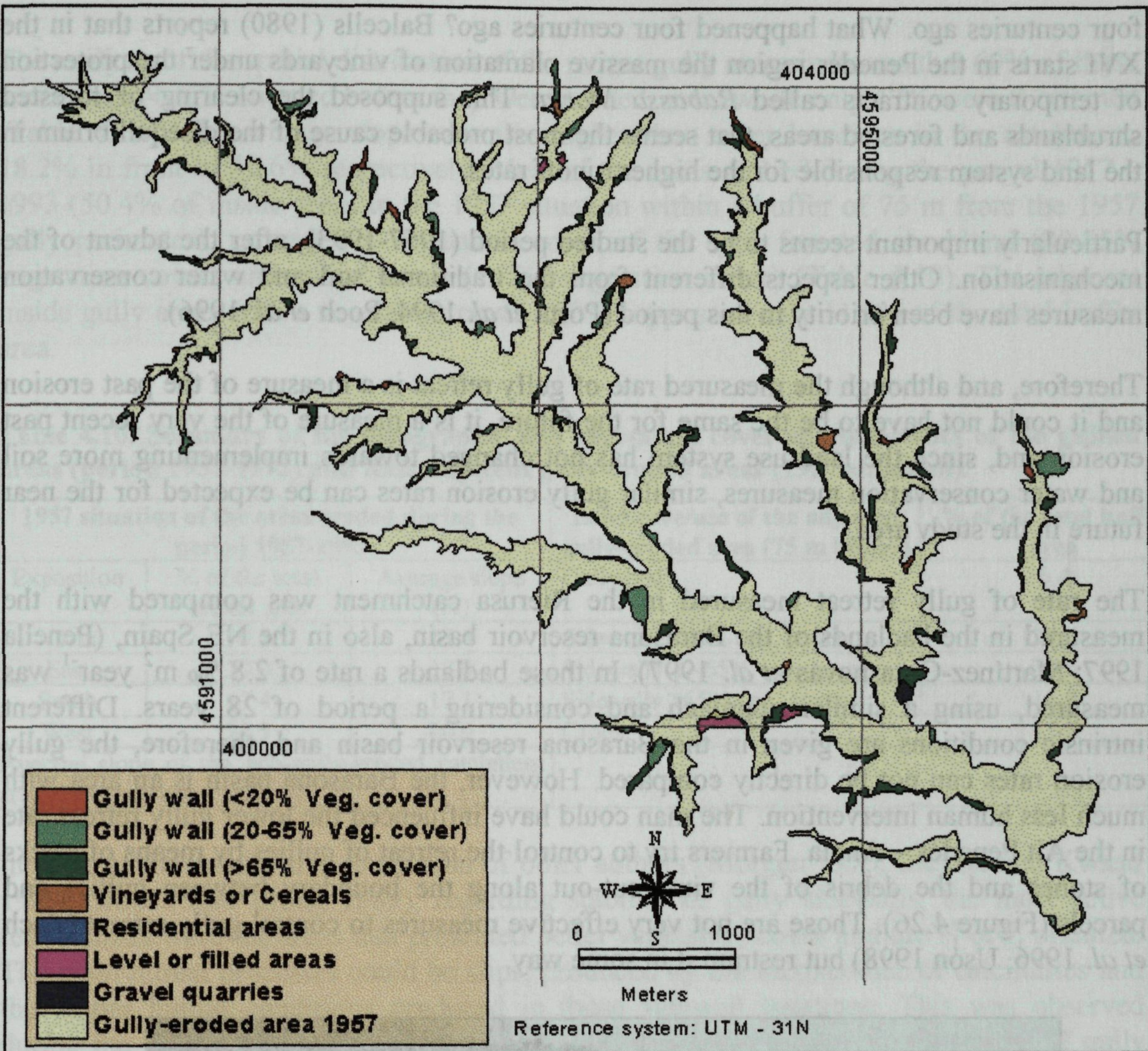

Figure 4.25. Areas of the Rierusa catchment affected by the retreat of gully walls during the period 1957-1993, and land cover/use class in the 1993 situation.

The total area affected by the retreat of gully walls, in the considered period of 36 years, was 76.57 ha. It supposes a rate of 2.12 ha year^{-1} or, if referred to the area of the catchment, of 0.9 ‰ m^2 year^{-1}. The linear retreat rate of gully walls suposses 0.2 m year^{-1} along the perimeter of the gullies of the Rierusa basin.

If the computed retreat rate was maintained, it last 840 years to the whole Rierusa catchment to be affected by gully erosion. This is only a very hypothetical prediction, since only the last 36 years were considered to compute the erosion rate. If the retreat rate is applied in a reverse way, the hypothetical start of the gully development in the study area could be estimated. Accordingly, it indicates gully erosion had started 320 years ago. This date is again very few probable, since the start of the incision of the Rierusa gully system is most sure contemporary to the incision of the Anoia river. However, it reflects the rate of gully erosion in the study area has not been always the same. In the recent past, the study area suffered one of the highest gully erosion rates of its history. It seems to be the consequence of a break in the equilibrium of the landscape system, that could have started four centuries ago. What happened four centuries ago? Balcells (1980) reports that in the XVI starts in the Penedès region the massive plantation of vineyards under the protection of temporary contracts called *Rabassa Morta*. This supposed the clearing of forested shrublands and forested areas, that seems the most probable cause of the disequilibrium in the land system responsible for the higher runoff rates.

Particularly important seems to be the studied period (1957-1993), after the advent of the mechanisation. Other aspects different from the traditional soil and water conservation measures have been priority in this period (Porta *et al.* 1994, Poch *et al.* 1996).

Therefore, and although the measured rate of gully retreat is a measure of the past erosion and it could not have to be the same for the future, it is a measure of the very recent past erosion and, since the land use system has not changed towards implementing more soil and water conservation measures, similar gully erosion rates can be expected for the near future in the study area.

The rate of gully retreat measured in the Rierusa catchment was compared with the measured in the badlands of the Barasona reservoir basin, also in the NE Spain, (Penella 1997; Martínez-Casasnovas *et al.* 1997). In those badlands a rate of 2.8 ‰ m^2 $year^{-1}$ was measured, using a similar approach and considering a period of 28 years. Different intrinsic conditions are given in the Barasona reservoir basin and, therefore, the gully erosion rates can not be directly compared. However, the Barasona basin is an area with much less human intervention. The man could have influenced the lower gully retreat rate in the Alt Penedès – Anoia. Farmers try to control the retreat of gullies by means of stacks of stones and the debris of the vines'cut-out along the boundary between gullies and parcels (Figure 4.26). Those are not very effective measures to control gully retreat (Poch *et al.* 1996, Usón 1998) but restrain it in some way.

Figure 4.26. Stack of stones in the boundary between a gully and a parcel in order to avoid the retreat of the gully sidewall.

The analysis of the spatial distribution of the retreat gully areas indicates that 60% of these areas were N or E oriented before they were eroded, meanwhile only 17% were S oriented (Table 4.10). The average slope was also higher than other locations in the catchment, 18.2% in front of 12.6% respectively. Most of the areas gullied during the period 1957 – 1993 (50.4% of inside areas in the 1957 situation within a buffer of 75 m from the 1957 gully perimeter), presented a vegetation cover of the type forested shrubland (20-65% vegetation cover) and mixed forest (>65% vegetation cover) (Table 4.10). The adjacent inside gully areas with a vegetation cover <20% suppossed only 11.8% of the total buffer area.

Table 4.10. Summary of the topographic and vegetation cover characteristics of the gullied areas (period 1957-1993) and their adjacent gully-eroded areas (1957 situation).

1957 situation of the areas eroded during the period 1957-1993			**Land cove/use of the adjacent gully-eroded area (75 m buffer)**	**% of the total buffer area**
Exposition	% of the total retreat area	Average slope (%)	Gully bed	6.4
North	30.2	17.4	Sidewalls <20% veg. cover	28.0
East	29.9	18.0	Sidewalls 20-65% veg. cover	38.6
South	17.4	17.3	Sidewalls >65% veg. cover	11.8
West	22.5	20.0	Crops	15.2
Average slope of the non-gully-eroded catchment area (1957 situation): 12.6 %				

In front of the results and conclusion of other authors (Morgan 1973, Imeson and Kwaad 1980, Crouch and Blong 1989), regarding stability of gully sidewalls, the most active retreat areas were the areas that presented better vegetation cover and are N or E oriented. The main retreat processes could be slips, produced by the incoherence of calcilutites and the higher humid conditions produced in those sidewall locations. This was observed during the field observations regarding the main processes related to the retreat of gully walls in the study area.

4.3.2.2.2. Filling of gullies

The pressure on agricultural land since the seventies to build-up recreational-urban and industrial areas has faced with the recognition and distinction of the quality of the wines and "cavas" produced in the Alt Penedès – Anoia. The last has revalued the main agricultural use of the land: vineyards, that now find less terrain for new plantations. The only way of expansion is to use marginal areas as inside gully areas after their filling and levelling (Figure 4.27 and Figure 4.28). In the Rierusa catchment, and for the considered study period, 38.79 ha of gullied areas were filled (Table 4.9). It represents the 6.4% of the gully-eroded area. The big investments that imply such a fillings and levellings sometimes have only a short life. The first high intensity rainfalls may produce the collapse of the filled areas.

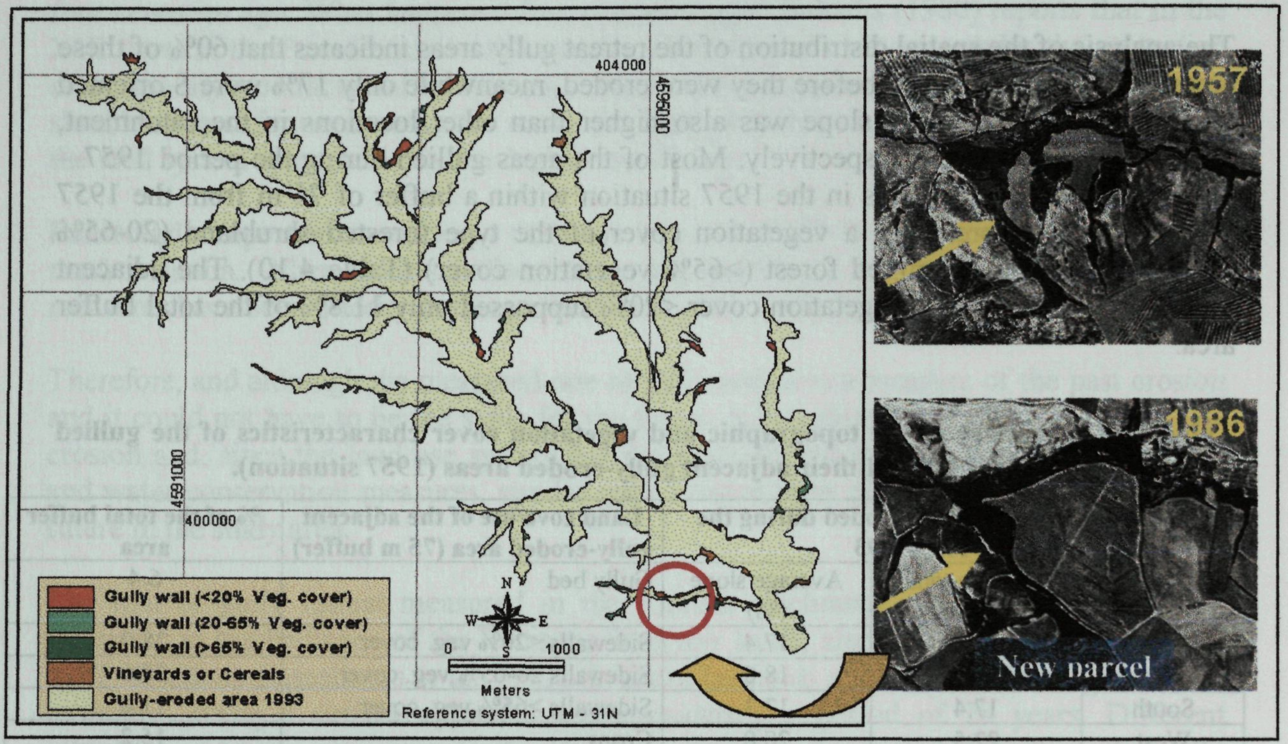

Figure 4.27. Gully-eroded areas in the Rierusa catchment that were filled during the period 1957-1993 and example of a new parcel after filling some gully-eroded areas.

Figure 4.28. Left: New vineyard parcel after the levelling of an old parcel and the filling of part of a gully (left) in the Rierusa catchment. Right: Filled gully.

4.3.2.2.3. Land cover/use changes in the intersect gully areas

The mapped changes in the intersect gullied areas in the Rierusa catchment are represented in (Figure 4.29) and in the matrix of changes (Table 4.9). The total intersect gullied area was 565.4 ha.

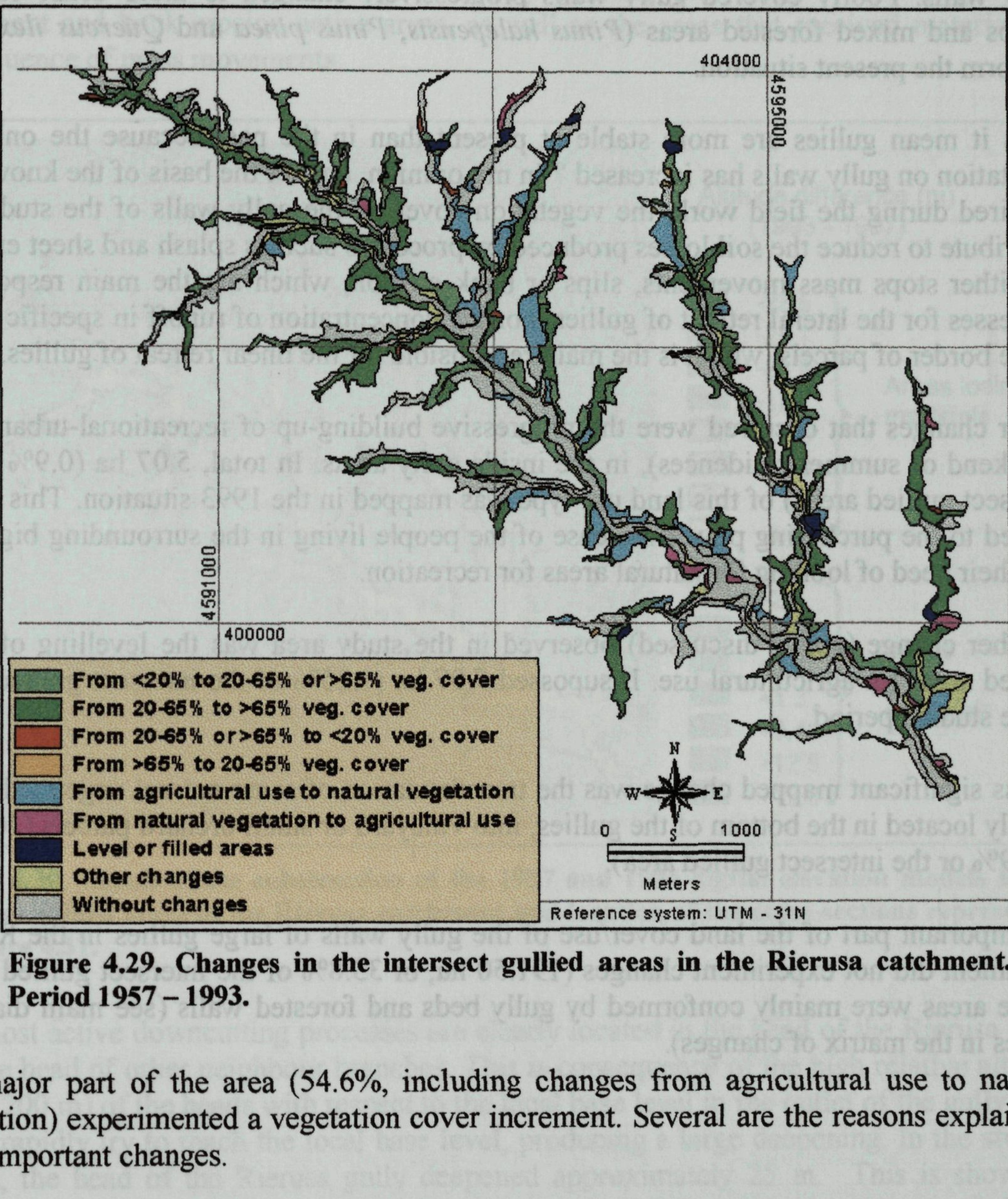

Figure 4.29. Changes in the intersect gullied areas in the Rierusa catchment. Period 1957 – 1993.

The major part of the area (54.6%, including changes from agricultural use to natural vegetation) experimented a vegetation cover increment. Several are the reasons explaining these important changes.

In the fifties the economy of the area was centred on the agricultural exploitation of the land. Even high slope degree areas inside gullies had been terraced and vines had been planted. Vegetation on gully walls was also used for grazing. It is the reason gully walls present a poorer vegetation cover in the image of the fifties.

After the advent of the mechanisation, at the end of the fifties and during the sixties, high slope degree areas inside gullies stop being cultivated because their exploitation is no longer economic. In a parallel way, the neighbour area of Barcelona experiments an important industrial prosperity, that influenced the socio-economic life of the area.

Agriculture went on being the main activity but not the only one and not under the same perspective. The increase of the purchasing power of the population influenced the demand of higher-quality products, that made a more specialised and technical agriculture. It involved marginal areas stopped being profitable for agriculture and were abandoned., Extensive grazing was also reduced, decreasing the pressure on vegetation growing on gully walls. Poorly covered gully walls progressively changed to more dense forested shrubs and mixed forested areas (*Pinus halepensis, Pinus pinea* and *Quercus ilex*), that conform the present situation.

Does it mean gullies are more stable at present than in the past because the only fact vegetation on gully walls has increased ? In my opinion, and on the basis of the knowledge acquired during the field work, the vegetation cover on the gully walls of the study area contribute to reduce the soil losses produced by processes such as splash and sheet erosion. It neither stops mass movements, slips or bank erosion, which are the main responsible processes for the lateral retreat of gullies, nor the concentration of runoff in specific points at the border of parcels, which is the main responsible for the linear retreat of gullies.

Other changes that occurred were the progressive building-up of recreational-urban areas (weekend or summer residences), in the inside gully areas. In total, 5.07 ha (0.9% of the intersect gullied areas) of this land use type was mapped in the 1993 situation. This is also related to the purchasing power increase of the people living in the surrounding big cities and their need of looking for natural areas for recreation.

Another change (above discussed) observed in the study area was the levelling of some gullied areas for agricultural use. It supossed 7.07 ha (1.25% of the intersect gullied area) in the studied period.

A less significant mapped change was the transformation of some natural vegetated areas, mainly located in the bottom of the gullies, into vineyard or small orchard parcels (10.7 ha, or 1.9% or the intersect gullied area).

An important part of the land cover/use of the gully walls of large gullies in the Rierusa catchment did not experiment changes (191.50 ha, or 33.8% of the intersect gullied area). These areas were mainly conformed by gully beds and forested walls (see main diagonal values in the matrix of changes).

4.3.2.3. Rate of material losses in the Rierusa catchment

4.3.2.3.1. Rate of material losses in the intersect gullied areas

The subtraction of the 1957 and 1993 digital elevation models in the intersect gullied areas, is shown in Figure 4.30. This figure clearly presents the most downcutting, mass movement and bank erosion active areas, as well as the areas that received materials as consequence of mass movements.

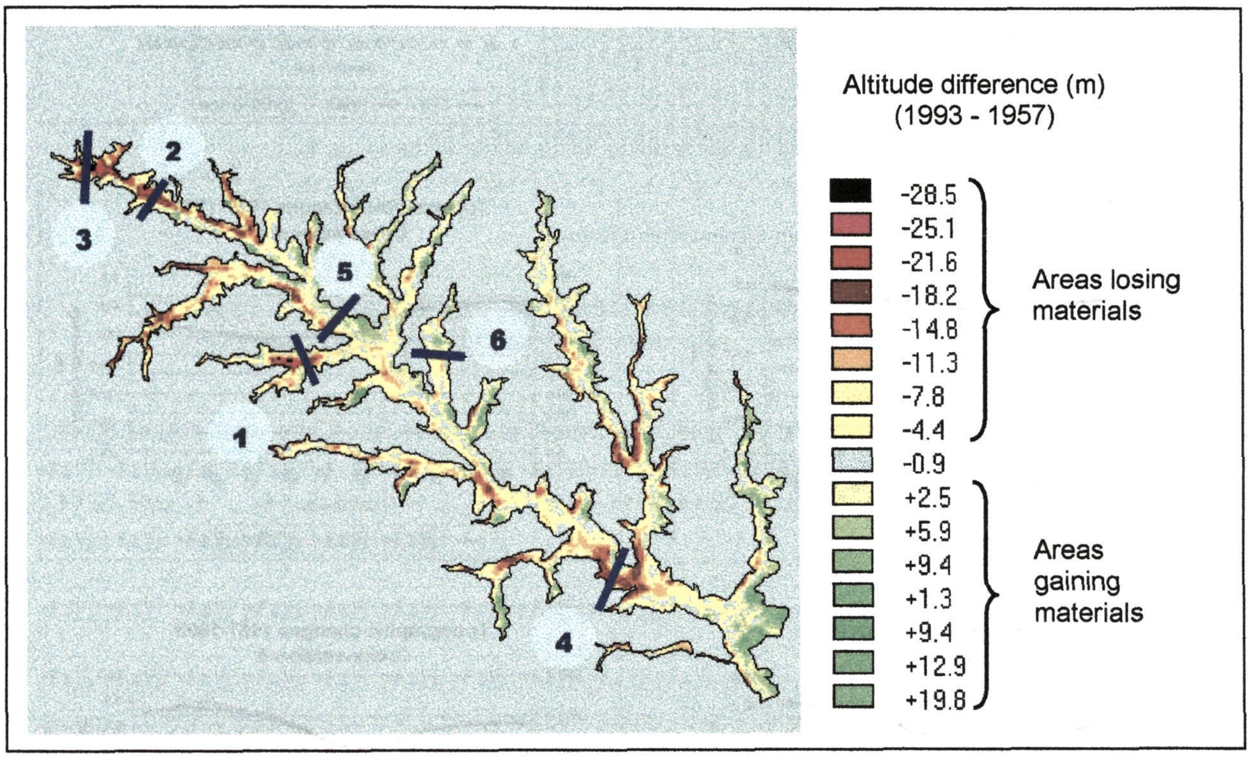

Figure 4.30. Result of the substraction of the 1957 and 1993 digital elevation models in the intersect gullied areas of the Rierusa catchment and location of the cross-sections represented in Figure 4.31.

The most active downcutting processes are clearly located in the head of the Rierusa gully and the head of other neighbour branches. This is consequence of the high relative altitude (up to 200 m) of the heads with respect to the local base level in the outlet of the gully. The heads rapidly try to reach the local base level, producing a large deepening. In the studied period, the head of the Rierusa gully deepened approximately 25 m. This is shown in cross-sections 1, 2 and 3 in Figure 4.31. Other areas presented high erosion activity as consequence of downcutting and mass movements produced by the undercutting of the walls by stream flows (cross-section 4 in Figure 4.31). Other areas did not present significant changes (cross-sections 5 and 6 in Figure 4.31). These areas are usually located in the central and the proximal sections of the gully (near the main outlet), where the longitudinal profile is more stabilised.

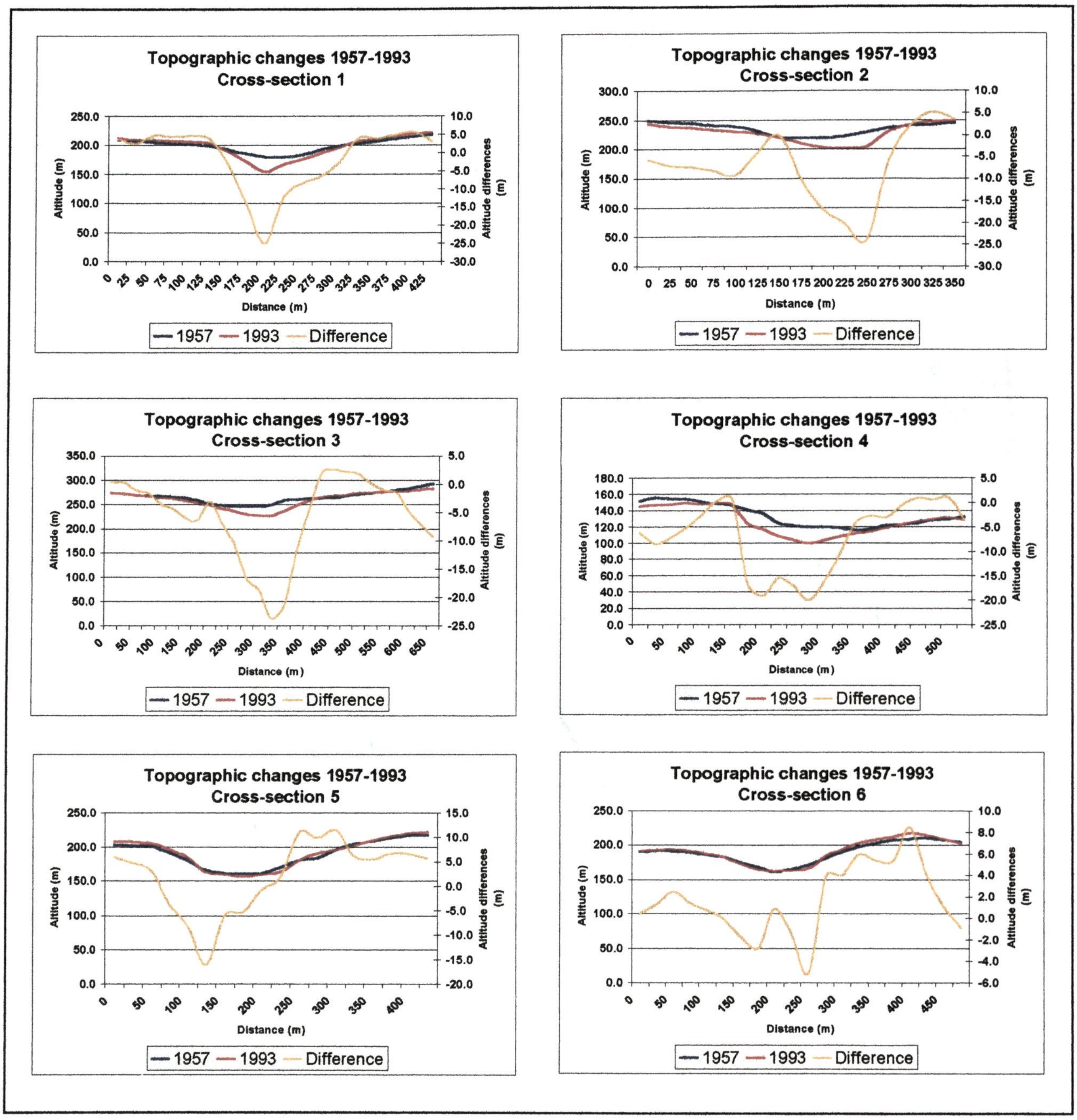

Figure 4.31. Cross-sections of the 1957 and 1993 digital elevation models and of the altitude differences of representative changes produced in the Rierusa catchment.

The altitude differences in the intersect gullied areas presented a negative balance. This indicates loss of materials has occurred during the studied period. From this balance, the volume of material losses can be computed. Only the altitude differences within the range X±3SD and X±0.5SD (where X is the mean value of the differences and SD is the standard deviation), were considered in order to minimize errors in the overlay of the DEMs (Figure 4.32).

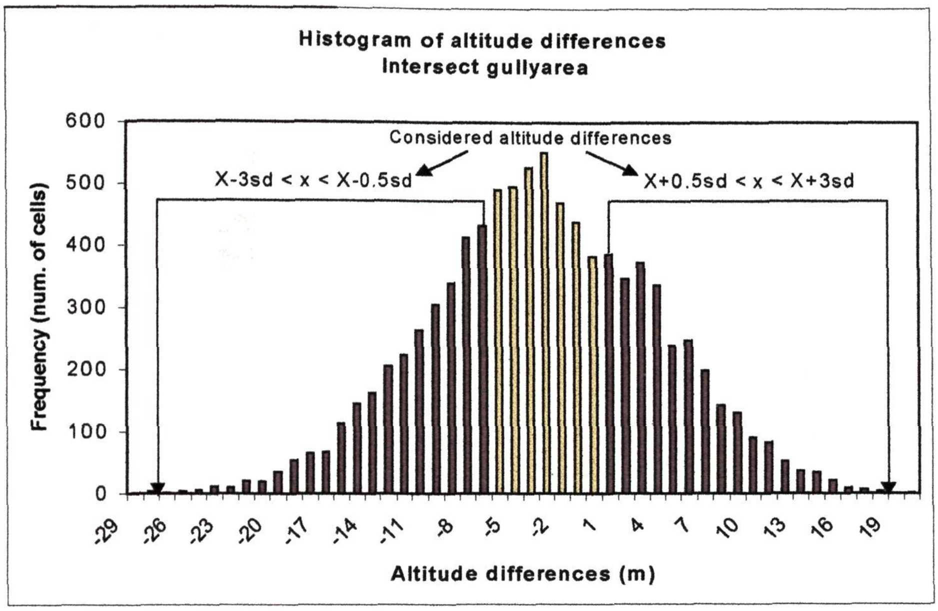

Figure 4.32. Histogram of the altitude differences in the intersect gullied areas and considered altitude differences.

The erosion rate was computed then by multiplying the sum of the altitude differences of each cell, the area of a grid cell and the average bulk density value of the eroded materials (1735 km m^{-3}, see section 4.2.2). The so computed erosion rate in the intersect gullied areas was 992.6 Mg ha^{-1} $year^{-1}$.

4.3.2.3.2. Rate of material losses in the retreat gully areas

The same procedure was applied to compute the erosion rate in the gullied areas during the period 1957-1993 (Figure 4.33). In these areas, the loss of materials reach 366.5 Mg ha^{-1} $year^{-1}$. This value is rather lower than the rate in the intersect gullied areas, since the mass movements and slips, responsible for the retreat of gully walls, usually produce short displacements of materials and lower altitude differences are computed.

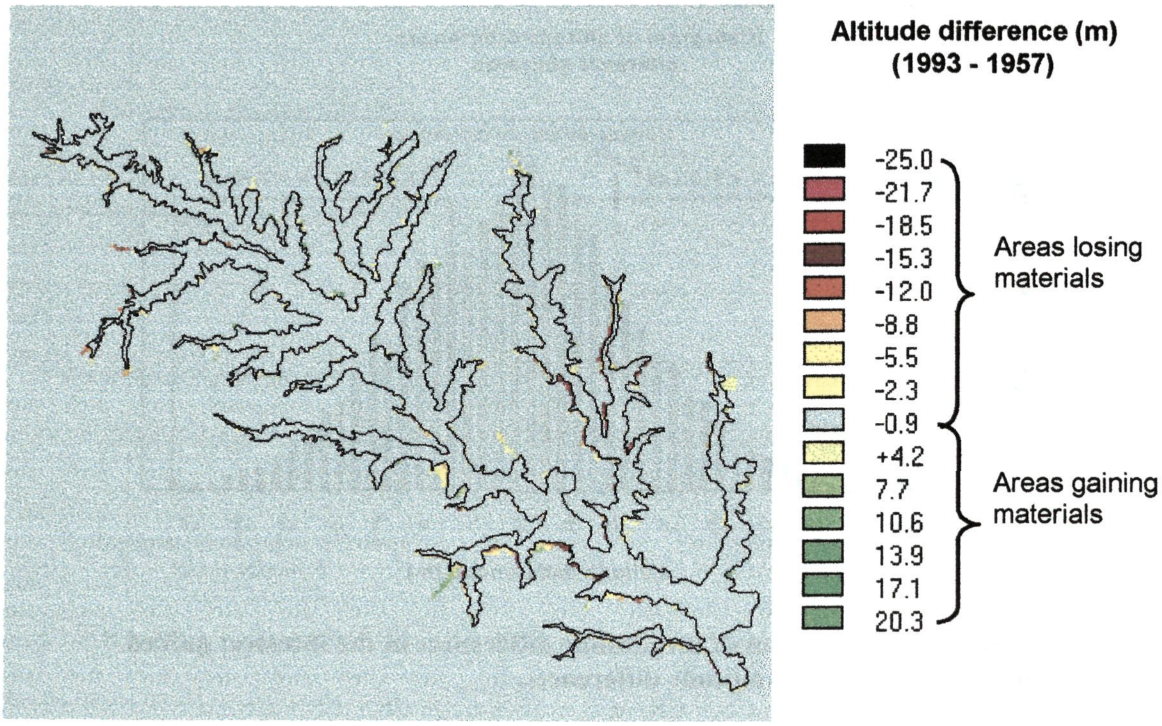

Figure 4.33. Result of the substraction of the 1957 and 1993 digital elevation models in the areas affected by the retreat of gully walls in the Rierusa catchment.

4.3.2.3.3. Total rate of material losses in the Rierusa catchment

The total rate of material losses in the Rierusa catchment in the period 1957-1993 was computed as a weighted average of the losses in the intersect areas and the losses in the retreat areas. This rate was 917.9 Mg ha^{-1} $year^{-1}$, or 238.7 Mg ha^{-1} $year^{-1}$ if referred to the total area of the Rierusa catchment.

In comparison with gully erosion rates measured by other researchers in different areas of the Mediterranean basin, as for example the 190 Mg ha^{-1} $year^{-1}$ measured in badlands in the SE France (Bufalo and Nahon 1992), or the 302-455 Mg ha^{-1} $year^{-1}$ measured in badlands in the Barasona reservoir basin in the NE Spain (Penella 1997, Martínez-Casasnovas *et al.* 1997), the estimated rate of 917.9 Mg ha^{-1} $year^{-1}$ in the gullies of the Rierusa catchment is rather higher. The reason is erosion rates, as in the above mentioned cases, only include soil losses from overland flow. In the present case study, the resulting rate includes the losses produced by several erosion processes: overland flow (that produces sheet erosion), downcutting (that produces gully deepening and widening), headcutting (that produces extent of gullies into ungullied headwater areas), mass movements and bank erosion (that produces undercutting and falling of sidewalls).

The estimations of material losses could not be validated with sediment yield measurements since there were not gauging stations in the study area. Nevertheless, the implemented analysis technique, based on the comparison of digital elevation data, produced realistic results (Figure 4.31). This comparison only shows significant changes in the gully affected areas. The computed erosion rates are not directly comparable with rates from other areas since the last ones only account for overland flow erosion processes.

4.3.3. Risk of gully erosion

The existence of gullies in the study area is a clear reflection of the state of erosion. The computed growth rate in the recent past indicates the severity of the problem. Since the intrinsic and extrinsic conditions have not changed, it is expected gully erosion continues in the near future with similar erosion rates.

Two situations were considered with respect to gully erosion risk in the study area: a) the prediction of existing gully erosion at parcel level and b) development of existing gullies by headcutting and retreat of sidewalls.

4.3.3.1. Prediction of existing gully erosion at parcel level

The results of the application to the entire study area of the empiric-stochastical gully risk model (Meyer and Martínez-Casasnovas 1998) in two sample catchments of the Alt Penedès – Anoia is represented in Figure 4.34.

The probability map shows significant differences on the predicted of existing gully erosion in the different landscape units of the Alt Penedès – Anoia. These differences are the reflect of distinct relief characteristics.

The landscape unit with the highest probability of existence of gully erosion is the High dissected valley-glacis. It has a probability degree between 80-100 % in 80.9 % of the mapped unit (out of non-agricultural land) (Table 4.11). High probability degrees are also generalised in the northern area of the Piedmont-glacis unit and in the southern area. In this last case, high probability values appear in the slopes of the residual plane surfaces. Those areas are usually conformed by complex undulating to hilly slopes and by concave moderately steep and steep slopes.

Table 4.11. Observed frequencies of the probability classes of existing gully erosion at parcel level in the different landscape units.

Landscape unit	Probability class				
	0 – 20 %	20 – 40 %	40 – 60 %	60 – 80 %	80 – 100 %
Piedmont-glacis North	10.9	8.5	7.2	6.0	67.4
Piedmont-glacis South	6.1	6.4	6.8	5.0	75.7
High dissected valley-glacis	6.4	4.9	4.4	3.4	80.9
Low dissected valley-glacis	28.4	21.1	10.3	4.7	35.5
Valley	22.6	18.3	10.0	5.2	43.9

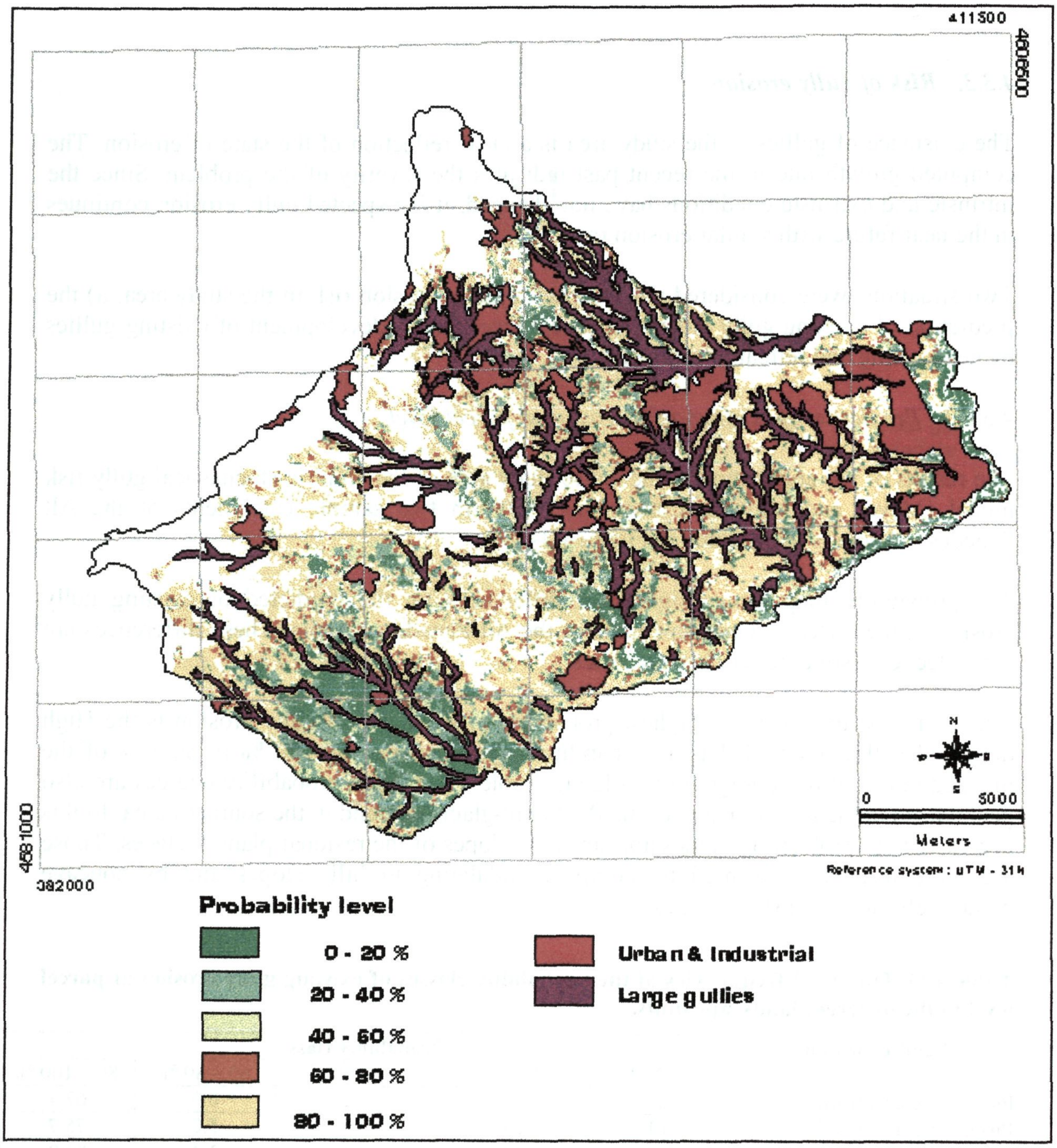

Figure 4.34. Probability of existing gully erosion at parcel level. (Based on the existing gully erosion prediction model of Meyer and Martínez-Casasnovas 1998).

The landscape units with the lowest risk degrees are the Low dissected valley-glacis and the Valleys. Part of those units also show a high probability value. Particularly relevant is the southern area of the Low dissected valley-glacis unit, that is the north face of the water divide between the Foix and Romaní basins. This area is characterised by higher slope degrees than in the rest of the area, which are responsible for the higher probability of gully erosion. In the valleys of the Anoia and Riudevitlles rivers high probability of gully erosion exist on the slopes that connect terrace levels.

The applied model reflects, under similar lithologic and cropping system characteristics, topography is the main responsible for gully initiation in the Alt Penedès – Anoia. The more complex the slopes and the higher the slope degrees the higher is the probability to find gullies in agricultural parcels. The application of this model can be useful to the locate the areas where concentration of runoff with a sufficient power to produce gully erosion is produced. From this information preventive and control measures can be planned.

4.3.3.2. Risk of development of existing gullies

The risk of development of existing gullies by retreat of gully walls was assessed by means of an evolutive model. It integrates the knowledge acquired during the field work and the results of the data analysis: multi-temporal image analysis (factors associated with the retreat of gully walls), existing gully erosion modelling, and gully-prone materials and infrastructure barriers (section 4.2.3.2).

The integration of the above mentioned factors produced the friction surface of Figure 4.35. In this friction surface the values represent the facility/difficulty with which gullies can move towards ungullied headwater areas. For a given ungullied location, a low friction value indicates a higher possibility a neighbour gully reach that position than if the location presents a higher friction value. In other words, areas with low friction values are areas with prone conditions for the retreat of gullies.

The application of the Idrisi cost-distance function from the 1993 gullied areas to the friction surface, produced a grid with the predicted cost of movement of the bordering gullied areas towards ungullied headwater locations (Figure 4.36). This model tries to predict how gullies would growth in the near future from the observed recent past pattern. It is expected that gullies growth distinctly in areas with different terrain characteristics.