Universitat Politécnica de Catalunya

Laboratori d' Enginyeria Marítima

Coastal Vulnerability to Storms in the Catalan Coast

Memoria presentada por

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Chapter 6

Coastal Vulnerability Assessment[c]

6.1 Introduction

The developed methodology to assess coastal vulnerability presented in the previous chapter was applied in this section at two spatial scales. The first one was a regional scale application, where the vulnerability of all the beaches of the Catalan coast to storm impacts was assessed. The second one was an application at a smaller scale. In this case, the spatial scale was given by the beach and thus, it was possible to estimate the differences in vulnerability along a given beach.

6.2 Regional scale assessment

The coastal vulnerability assessment done at a regional scale implies working at a spatial scale typically used by managers in the design of strategic plans. Consequently, more than making an analysis in full detail of a beach, the

[c] Edited and extended version of MENDOZA, E. T. & JIMÉNEZ, J. A. (2008) Regional vulnerability analysis to storm impacts in the Catalan coast, *Proceedings of the Institution of Civil Engineers: Maritime Engineering,* (in review).

desired objective is to identify zones with a determined behaviour in order to help in the decision making over the necessity of implementation of measures over protection/adaptation and/or mitigation. In this sense this application is oriented to show the ability of the developed methodology to help the coastal managers in this task.

As mentioned before, the application was done in the Catalan coast. The extents for this case are the sandy beaches which have an approximate extension of 260 km from the total 700km, and constitute the basic unit for the spatial description of the territory.

The key element, to apply the methodology at this scale is a tool which allows integrating the values of the response of the beach to storm impacts, along with the characteristics of each beach. Hence, this has been done by using a Geographic Information System (GIS) which is a useful tool that assembles, stores, manipulates, analyzes, and displays information about objects and events on the earth (see Figure 6.2.1).

This study applied the ArcGis 9.2, which has become one of the standards in GIS programs due its versatility in managing large amounts of spatial data and produce cartographic maps (http://www.esri.com/).

The GIS used a Universal Transverse Mercator (UTM) projection according to the European datum of 1950 corresponding to the North Zone 31 which is the standard used by the Institut Cartographic de Catalunya (ICC) .

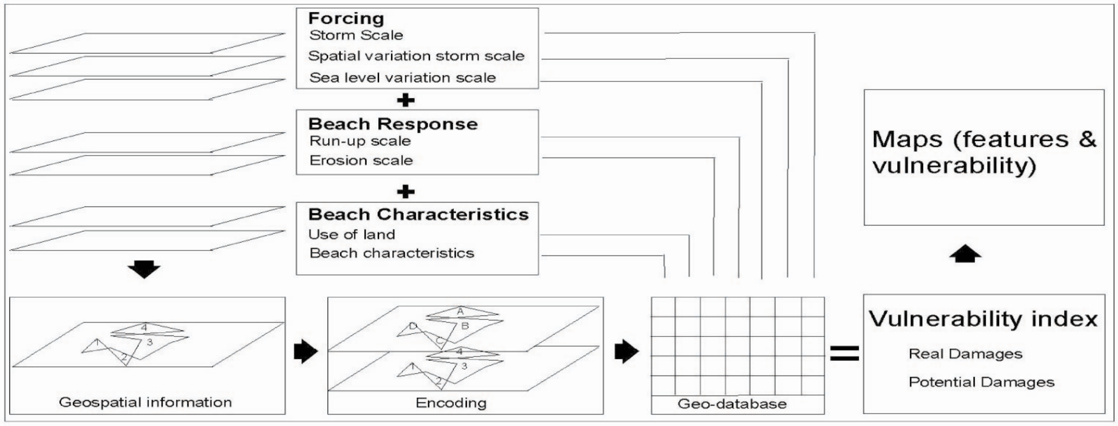

Figure 6.2.1: Integration of variables of the vulnerability index through a GIS.

6.2.1 Beach Database

The basic unit used in this framework is constituted by the beach, characterized in terms of the beach width, beach height, beach slope, beach type (reflective, dissipative), beach length, and beach orientation. This data was obtained from orthographic maps and corrected aerial photographs (orthophotos) at a 1:5 000 scale published by the ICC corresponding to the year 2004. For the purposes of visualization and representation of results, every beach was represented with a polygon (see Figure 6.2.2 left case).

The variables which characterized the beach and served as an input for the ***EVI*** and the ***FVI*** were the beach slope ($tan\beta$), the beach height (*BH*), and the beach width (*BW*). The beach slope conditions the intensity of the processes and was used to determine the beach type (ranging from reflective to dissipative).

The beach width was used for the ***FVI***; the minimum BW was selected instead of the maximum or mean values (Figure 6.2.3 left case) given that this option is the most conservative from the coastal manager stand point. For a given storm reach (the beach width to be eroded), the narrower the beach is, the more vulnerable the system will be. Thus, the analysis will serve the manager as a *“warning”* signal for damages in the beach.

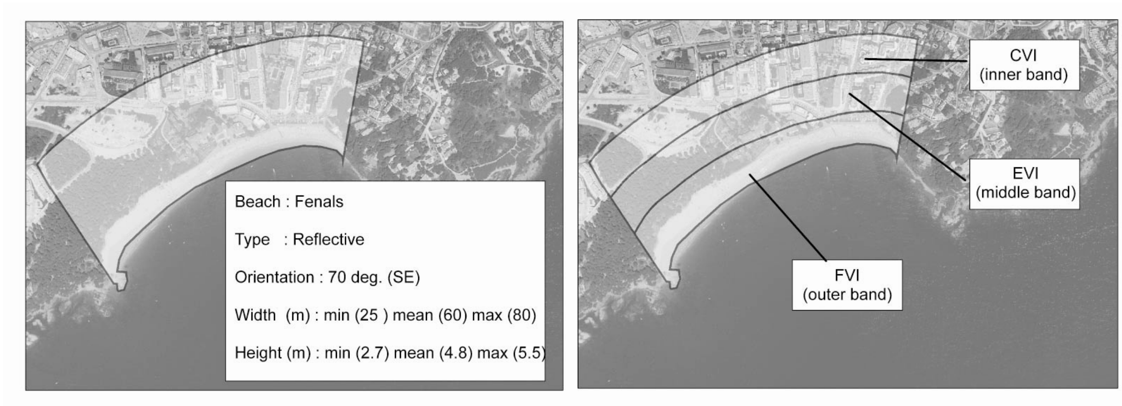

Figure 6.2.2: Polygon used to define a beach with basic information (left case) and beach divided in the ***CVI*** (inner band), ***EVI***, (middle band) and ***FVI*** (outer band) (right case).

As an example of the situation Figure 6.2.3 (left case) is a birds eye view of the beach, where the shaded area is the storm reach ($\Delta X + \alpha\sigma$). This diagram indicates that the left part of the beach has still some beach left, while on the right part the storm leaves no beach and might impact directly on the infrastructure situated in the back part of the beach, although the storm does not affect the beach in its entirety.

The beach height (used for the ***EVI***) controls the effects of inundation; in the case of the beaches with variable height the flooding effects would only happen in certain locations of the beach. Therefore, in order to obtain a representative value of the possibility of the back part of the beach to be flooded, the mean value was selected instead of the maximum or the minimum values (Figure 6.2.3 right case)

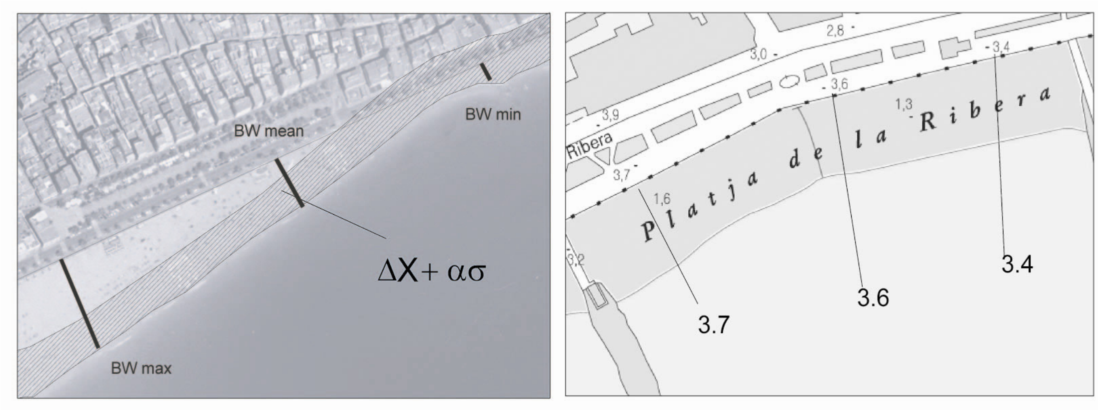

Figure 6.2.3: Diagram of variable beach width and storm reach.

The total 402 beaches were evaluated in terms of the ***FVI***, the ***EVI*** and the ***CVI*** for every storm class (I -V). For visual reasons every single beach was divided in three bands of approximately 100 m in width, the outer band (most sea bound) reflects the values for the flood indicator (***FVI***), the middle band reproduces the erosion vulnerability values (***EVI***), and the inner band shows the coastal vulnerability index (***CVI***) which is the integration of the previous two indicators whose values were assessed using table 5.2.1 (see Figure 6.2.2 right case).

With the selected representative values of beach height and beach width, we have the necessary input information to calculate the vulnerability indicators to obtain the ***EVI*** and ***FVI*** for each beach of the Catalan coast. However, in order to properly asses these indicators we also need to evaluate the spatial variability of the storms which will provide the proper intensity of the processes in each beach.

6.2.2 Spatial variability of the process

When the regional coastal variability to extreme events is assessed, two possibilities do exist. The first one consists in assessing the vulnerability along the coast assuming that the intensity of the process in each point is the maximum.

An example if this application in the vulnerability maps to hurricane impacts developed by the USGS (see http://coastal.er.usgs.gov/hurricanes/) where it is assumed that the intensity if the hurricane along the coast is the same. This approach implies to use the worst case scenario to derive conclusions on the need to take actions by the coastal manager. And thus the result would derive an overprotective policy.

The second approach consists in assessing the vulnerability in the area of study taking into account the potential variations in the intensity of the process along the coastal zone. This is the approach followed in this study to reproduce the physics of the process: there is a variation in wave characteristics along the Catalan coast during a storm impact (e.g. see Figure 6.2.4)

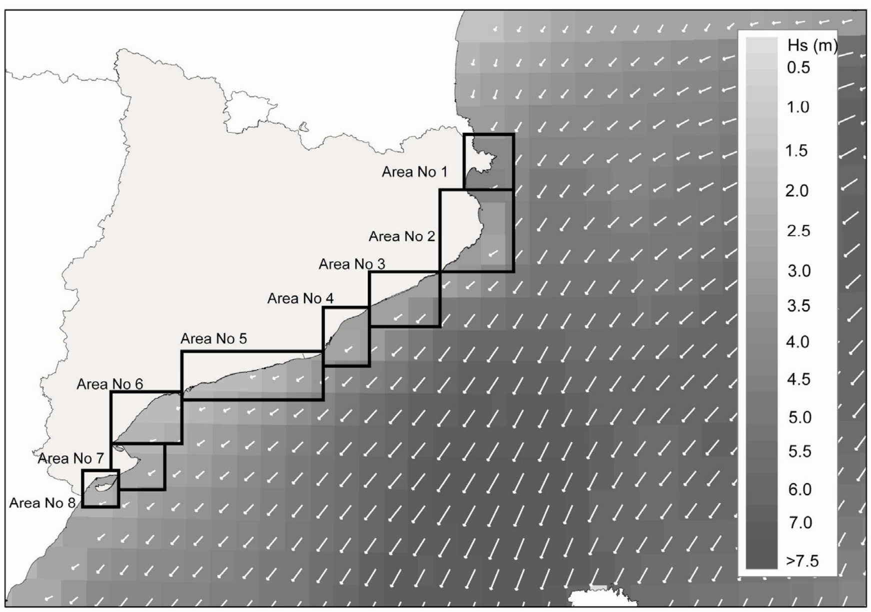

Figure 6.2.4: Spatial variability of wave height along the Catalan coast for an eastern storm.

Due to this the first task was to develop a simple methodology to reproduce the spatial variability in storm categories along the Catalan coast. Because the storm classification was derived from records in one point of the coast (in Area 7) the methodology has to be able to estimate the storm category in each wave data as a function of the data in Area 7.

This is done in four steps. The first step consisted in selecting representative E and S storms (the only ones with morphodynamic consequences) from all the measured ones, corresponding to each class. Once these storms were selected, the second step consisted in identify the same events in each geographical wave Area along the coast from the WANA dataset. The third step consisted in estimating an amplification factor for each Area with respect to the values in Area. To do this, the ratio of wave heights recorded for each class and each area with respect to the ones in Area 7 were obtained. The resulting values were then multiplied to wave heights for each class (Table 3.3.2) so as to observe which will be the final category in each wave area.

An example of this for a class V storm is given in Figure 6.2.5. In this case the storm remained classified as a class V along the entire coast with the exception of zones 6 and 8, whose classification decreased into a class IV.

Once having solved the variability “problem” concerning characteristics (database) and process (wave conditions), a remaining difficulty has to be solved. All the processes have been here simulated assuming normal incidence. However we shall find many places along the coast where the beach orientation with respect to the wave action is far from normal and, in some cases, the beach is also protected from the wave action. Although this difficulty can be easily solved at detailed scale by using a wave propagation model (including reflection and diffraction), a simple procedure has been here implemented to work at this scale (specially taking into account that instead of evaluating the impact to a specific storm, we are doing the analysis for storm classes).

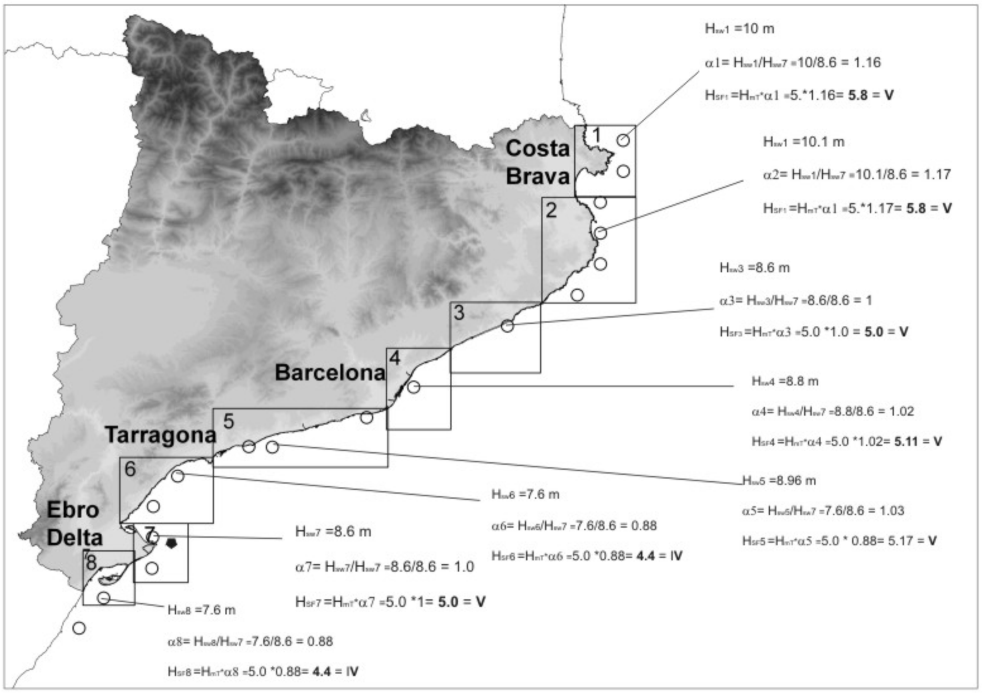

Figure 6.2.5: Spatial variability of *Hs* for a class V storm and re-classification of wave height.

The property concerned the coastal variability and orientation, meaning that the characteristics of all beaches contained within the Catalan coast were implemented into the beach database considering the protection and beach orientation.

To take into account the protection offered by geological or man made structures from the direct impact of the storm the vulnerability index is altered. Thus, when a beach is protected the vulnerability index was lowered two categories below the corresponding one (Figure 6.2.6 right case).

With respect to the beach orientation, we applied a similar approach. In this case if the relative angle of the shoreline with respect to the wave front direction (given by the offshore wave direction during the storm) is larger than $\pm 70^\circ$, the vulnerability index was lowered one category below the corresponding one (Figure 6.2.6 left case).

Figure 6.2.6: Beach spatial variability in the left case structures offer protection and on the right case an oblique impact from an eastern storm.

6.3 Regional scale results

The vulnerability assessment was made for each storm class (I through V) for E storms and two S storms (class I and II). Although the evaluation produced a vast amount of information, due to space reasons, here the results of a class V (extreme) storm impact are only presented. All the remaining cases are available in KML format attached in a compact disc (CD). This format can be viewed through the Google Earth software which is freely available in the internet.

The set of maps that contain the extreme storm assessment in the entire Catalan coast consists of 22 charts that are showed in Annex B. In this section, we illustrate the analysis for some selected beaches of the Catalan coast.

Figure 6.3.7 shows two sectors of the northern most beaches in the Costa Brava. The first sector is composed by Port Bou, en Goixa, des Morts and de les Portes beaches, which are basically embayed reflective narrow beaches (between 10 and 18 m wide) and beach heights between 2.6 and 3 m. As it was shown in chapter 4 these types of beaches are susceptible to suffer the largest erosion and higher run-up for each storm. In fact, the runup plus the associated storm surge for this type of storm and beach is quite elevated (3.6 m). This intensity in combination with beach height determine the corresponding ***FVI*** values to be *Very high* with the exception of Port Bou and de les Portes which were protected from direct storm impact and, thus, they were classified two categories below in a *Medium* value. The same situation happened for the ***EVI*** in which the beach retreat associated to this type of storm is of -22 m, this intensity in combination with beach width determined the corresponding ***EVI*** values to be *Very high* with the same modifications mentioned before. The integrated ***CVI*** reflects these two contributions. Thus, for exposed beaches a *Very high* value was obtained whereas for sheltered ones, the final value was *Medium*. In this case the combination of partial vulnerabilities is straight forward because both components (erosion and flood) are equal.

The second sector is situated further south and is composed by Rastell, Salatar, la Rovina and Empuriabrava beaches, which are reflective beaches, relatively wide (between 28 and 70 m) with the exception of Rastell (14 m) and present low heights (between 1 and 1.4 m). This last characteristic determined the corresponding ***FVI*** values to be *Very high*, with the exception of Rastell and Salatar which were protected from the direct impact of the E storm and thus, they were classified two categories below in a *Medium* value. In terms of the ***EVI*** the wideness of the beaches determined the corresponding values to be *Very low*, with the sole exception of Rastell whose narrow beach would originally be *Very high* but the protection features such a the groin and its orientation determined the ***EVI*** value to be *Medium*. The ***CVI*** is the weighed average of the two vulnerability indicators; therefore Rastell beach presented a *Medium* value, Salatar a *Low* value and lastly Empuria Brava and la Rovina a *High* value.

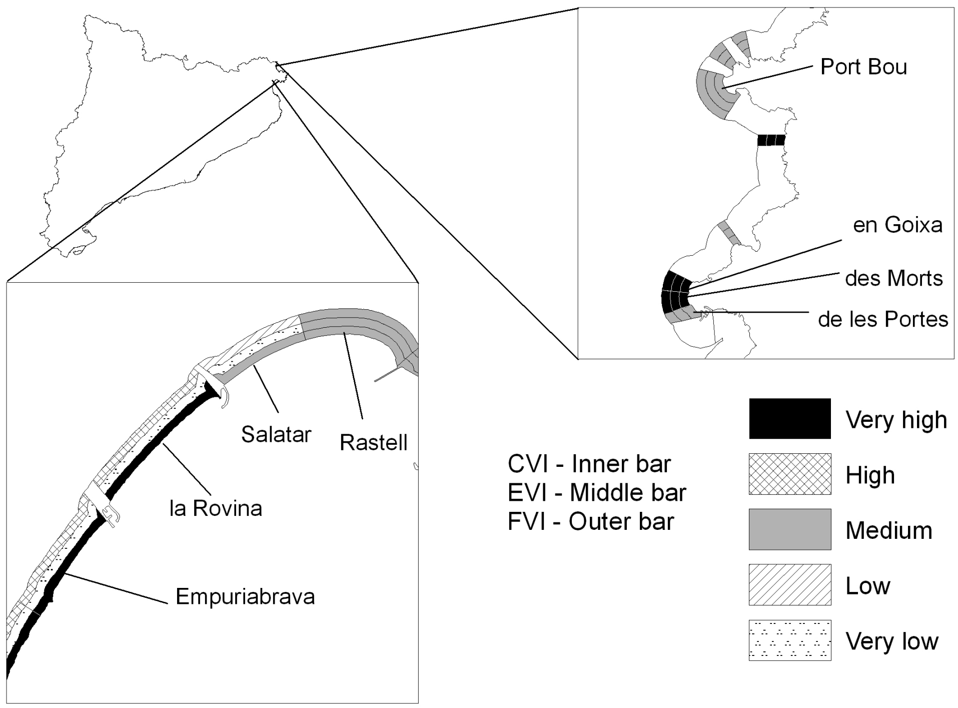

Figure 6.3.7: Coastal vulnerability assessment at a regional scale for a class V storm in Port Bou and Empuriabrava.

Figure 6.3.8 shows the results in the case of Fangar, Riumar, San Antoni and de Buda beaches in the Ebro Delta which are very wide open beaches (sometimes wider that 100 m) and extremely low laying (dissipative) with beach heights ranging between 1.2 and 1.4 m excepting Riumar (2.4 m). Although the designated flood potential value for dissipative beaches (1.8 m) is quite lower that the reflective ones, the low beach heights determine the corresponding ***FVI*** values to be *Very High*, with the exception of Riumar which was classified two categories below in a *Medium* value due to its higher elevation. The lower erosion values (-3.4m in beach retreat) present in dissipative beaches and the wideness of the Delta beaches determine the ***EVI*** value to be *Very low*. The integrated ***CVI***, resulted in *High* values with the exception of Riumar which was placed in a *Low* value.

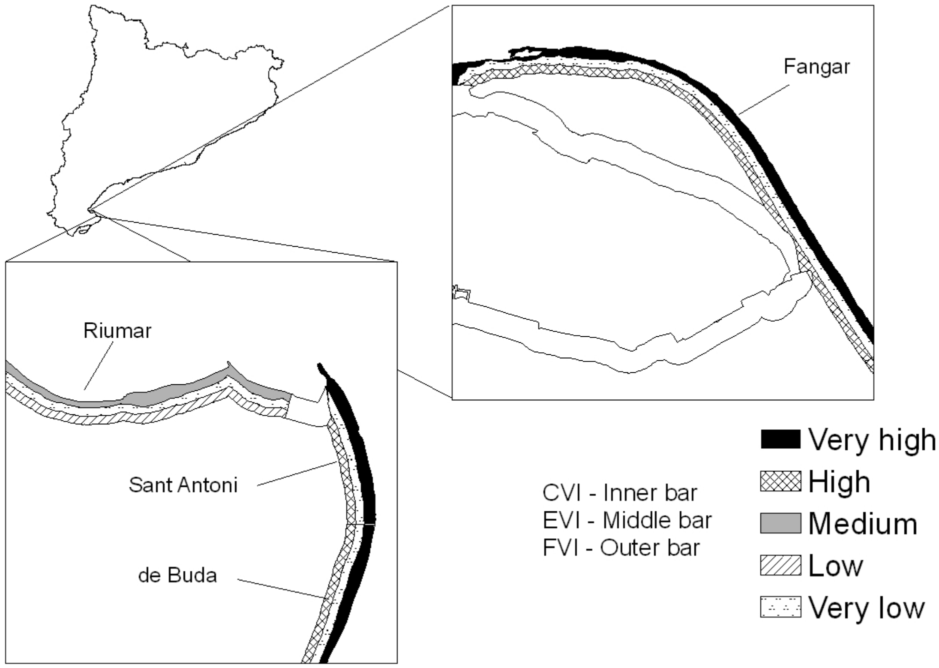

Figure 6.3.8: Coastal vulnerability assessment at a regional scale for a class V storm in the Ebro delta.

In the Fangar case, the inner coast will not be directly subjected to wave action during the storm. Thus, it is not expected that the beach should be eroded. With respect to inundation, the area will not be affected by run-up although if a storm surge would exist, this inner coastline will be inundated because it is very low and flat. In any case, we assume for this part that the inner beach is not directly affected.

An illustrative example of an extreme storm impacting on a city beach can be seen in Figure 6.3.9 which presents two cases. In the upper case Lloret and Fenals beaches and in the second case the Barcelona city beaches. All of them are embayed beaches and present a reflective profile.

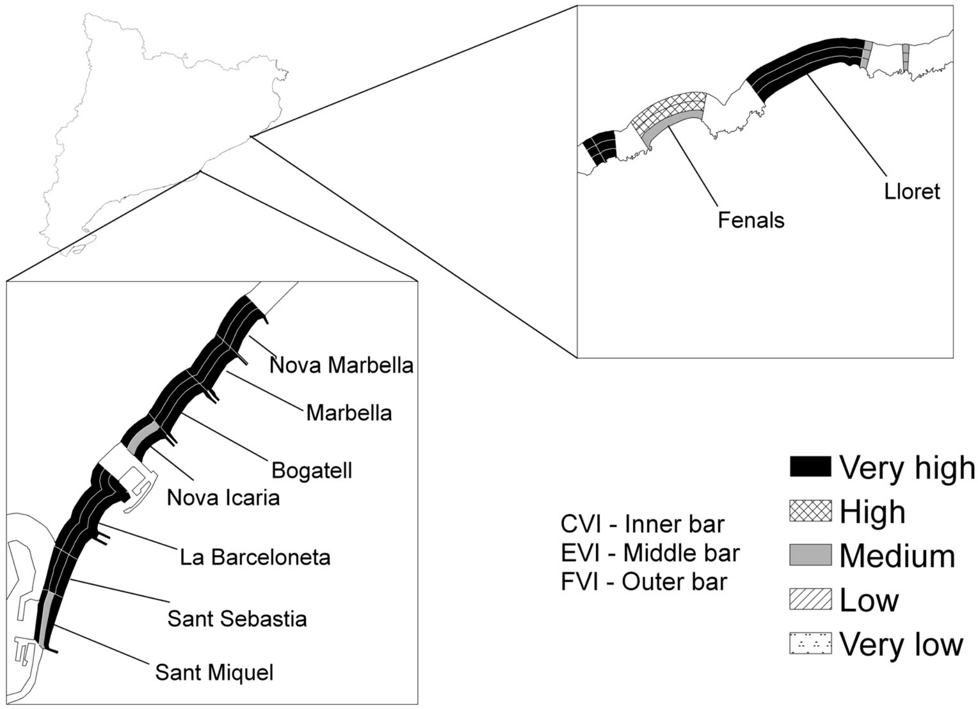

Figure 6.3.9: Coastal vulnerability assessment at a regional scale for a class V storm in Lloret del Mar and the Barcelona city beaches.

In the first case the beaches were relatively high (3.8 and 4.9 m) and narrow (12 and 25 m). As mentioned before the reflective profiles suffer the largest erosion and flood potential due to run-up and storm surge. For this reason the ***FVI***, corresponding to Lloret presented a *Very high* value, as for Fenals the higher elevation placed this beach in a *Medium* value. In terms of the ***EVI***, Lloret (12 m wide) presented a *Very high* value while the wider beach at Fenals determined the ***EVI*** to be *High*. The integrated ***CVI*** value was *Very high* for Lloret and *High* for Fenals.

In the second case all of the Barcelona beaches presented elevation values ranging between 2.9 and 3.2 m. Regarding the beach width, in Nova Icaria and Sant Miquel is of 30 and 40m respectively, while the remaining are between 10 y 20 m.

The ***FVI*** were *Very high*; the narrower beaches determined the ***EVI*** to be *Very high*, while the wideness of Nova Icaria and Sant Miquel placed them in a *Medium* value. The integration of the two variables determined the ***CVI*** values to be *Very high* in every one of these beaches.

The images in Figure 6.3.10 were used to compare in a qualitative manner the vulnerability assessment, the upper case shows an extreme storm (class V) that occurred in November 2001, impacting in Lloret del Mar and the Barcelona city beaches. In the first case the picture confirms the massive overtopping of the marine promenade, reaching the lowest parts of the buildings which were affected by flooding and sand from the beach. In fact, instead of the usual beach erosion mechanism where sand is eroded from the beach and transported seaward, the sand was carried landwards being deposited in the back part of the beach.

The middle and lower case images were obtained courtesy of the Coastal Monitoring Station in Barcelona (http://elb.cmima.csic.es). The middle picture shows in the forefront the Nova Icaria beach showing clear flood marks that reached the marine promenade but is wide enough so that the neighbouring promenade is not affected. In the back we observe that Bogatell suffered a direct impact of the waves in the adjacent infrastructure. The case of San Miquel and Sant Sebastia beaches (low case in the back) is not clear due to the distance from the camera. In the same picture in the forefront the Barceloneta beach, clearly shows the massive beach erosion and flooding, specially the section after the groyne.

Figure 6.3.10: Lloret de Mar beach (top case) and Barcelona city beaches Nova Icaria and Bogatell (middle case) and La Barceloneta (lower case) during the impact of a class-V storm on November 2001. (Barcelona images courtesy of the Coastal Monitoring Station in Barcelona. http://elb.cmima.csic.es).

Figure 6.3.11 summarises the results for the Catalan beaches for vulnerability indicators to class V and class IV storms. The figure represents the percentage of kilometres of beaches belonging to each vulnerability category for these storms.

For class V storms the most common value of ***EVI*** is *Very low* (68%) followed in percentage by a *Very high* value (17%). In terms of ***FVI***, the most common state is *Very high* (50%) followed by a M*edium* value with 22%. When the total vulnerability is considered, ***CVI***, the most common value is *High* (38%) followed by a *Low* value with 22%.

The same analysis was carried out for a class IV storm in order to compare the differences in overall vulnerability. Although class V is the most extreme event, classes IV are more frequent and are also extreme ones (see Figure 6.3.11). As expected, a slight decrease in the percentage of beaches belonging to the most vulnerable categories is obtained for each process. In terms of the ***EVI*** the most common state is *Very low* (76 %) followed by *Very high* with 11%, in terms of the ***FVI*** the most common state is *Very high* (32 %) followed by *Very low* with 26%, and in terms of the ***CVI*** the most common state is *High* (31%) followed by *Very low* (24%).

When comparing the two storm categories the *Very low* values dominated the ***EVI*** in class V storms and, when changing to category IV, this value continues to be dominant but decreased its percentage from 76 % to 68%. In terms of the ***FVI*** the dominance of the *Very High* values decreased from 50% to 32%. Finally, the *High* values were dominant at the overall ***CVI*** and decreased from 38% to 31% from a class V to a IV storm.

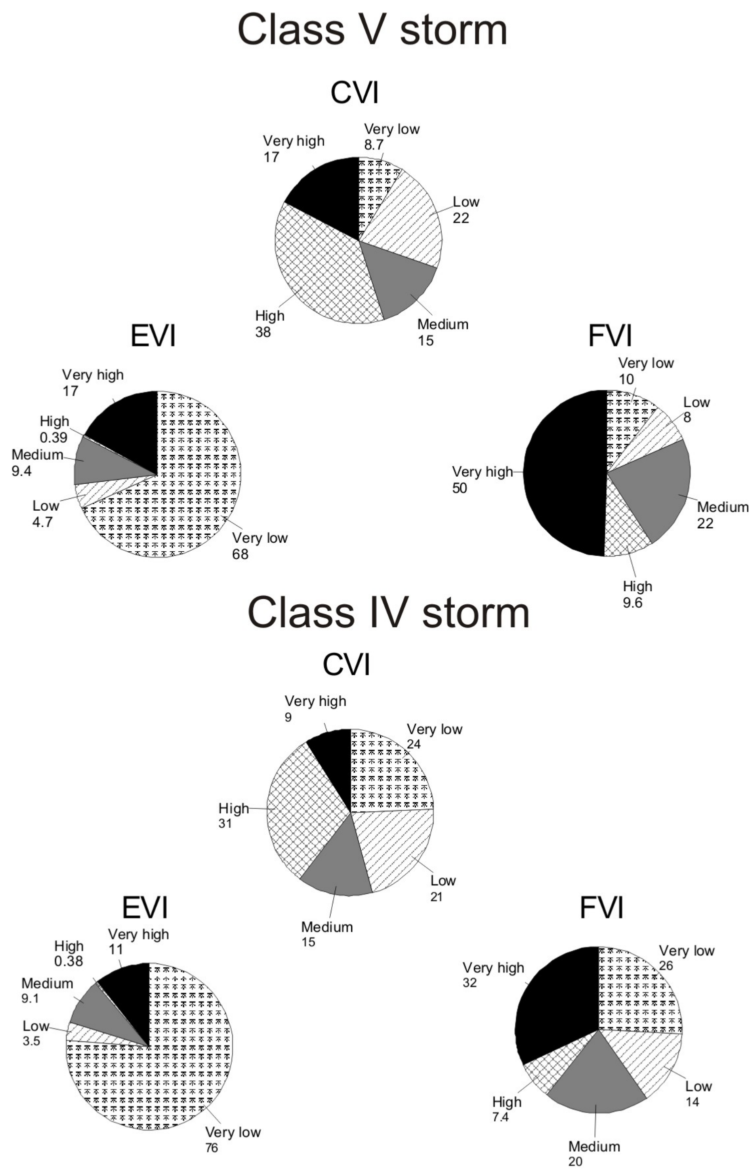

Figure 6.3.11: Percentage of Km of beaches belonging to a vulnerability category for a class V and a class IV storm.

To understand these results, the analysis is completed taking into account the spatial distribution of the vulnerability index. In the Annex B the detailed spatial distribution can be seen for category V storms (in the CD the other categories are included) because all the beaches are represented there we “integrate” these results to “coastal geographical units” in Catalonia.

Figure 6.3.12 shows the percentage of km belonging to a given vulnerability class for each index and for each geographical unit for the impact of a class V storm.

When we analyse the results obtained for EVI, it is evident a clear zonation. Thus in the N part of Catalonia (Costa Brava to Barcelona) we find most of the beaches belonging to the highest vulnerability. These are reflective beaches characterized by coarse sand and steep slopes. As it was showed before, they will be prone to experience the largest erosion in comparison with dissipative beaches.

As for the zones that presented the highest vulnerability values, the Costa Brava clearly shows the lowest values, because the beaches in that zone are mainly embayed and are usually partially sheltered from wave action. This difference is especially large when compared with the Maresme zone. Likewise the relatively lower vulnerability of the Maresme compared with Barcelona would reflect the existence of a significant number of beaches with a considerable width (e.g. beaches found updrift the ports) while in Barcelona the beaches are relatively narrow.

If we concentrate in the spatial variability of the vulnerability associated to flood (***FVI***), a similar pattern is observed, with the exception of the Ebro Delta zone. Therefore, same as before the zones with reflective beaches would be the most vulnerable given that the induced runup would be higher in this type of profiles. The *Very high* vulnerability values reflected by the Ebro Delta is largely due to the very low lying beaches found in the area, and eventough the runup is relatively low the probability of the beach to be flooded is quite high.

The integration of both variables through the ***CVI*** reflects a similar behaviour since the dominant *Very hig*h values of the ***EVI*** in the northern zone is added to the dominant *Very high* values of the ***FVI***, the southern zone is less vulnerable with the exception of the Ebro Delta which presents a *Very high* flood value and so the ***CVI*** is classified as *High*.

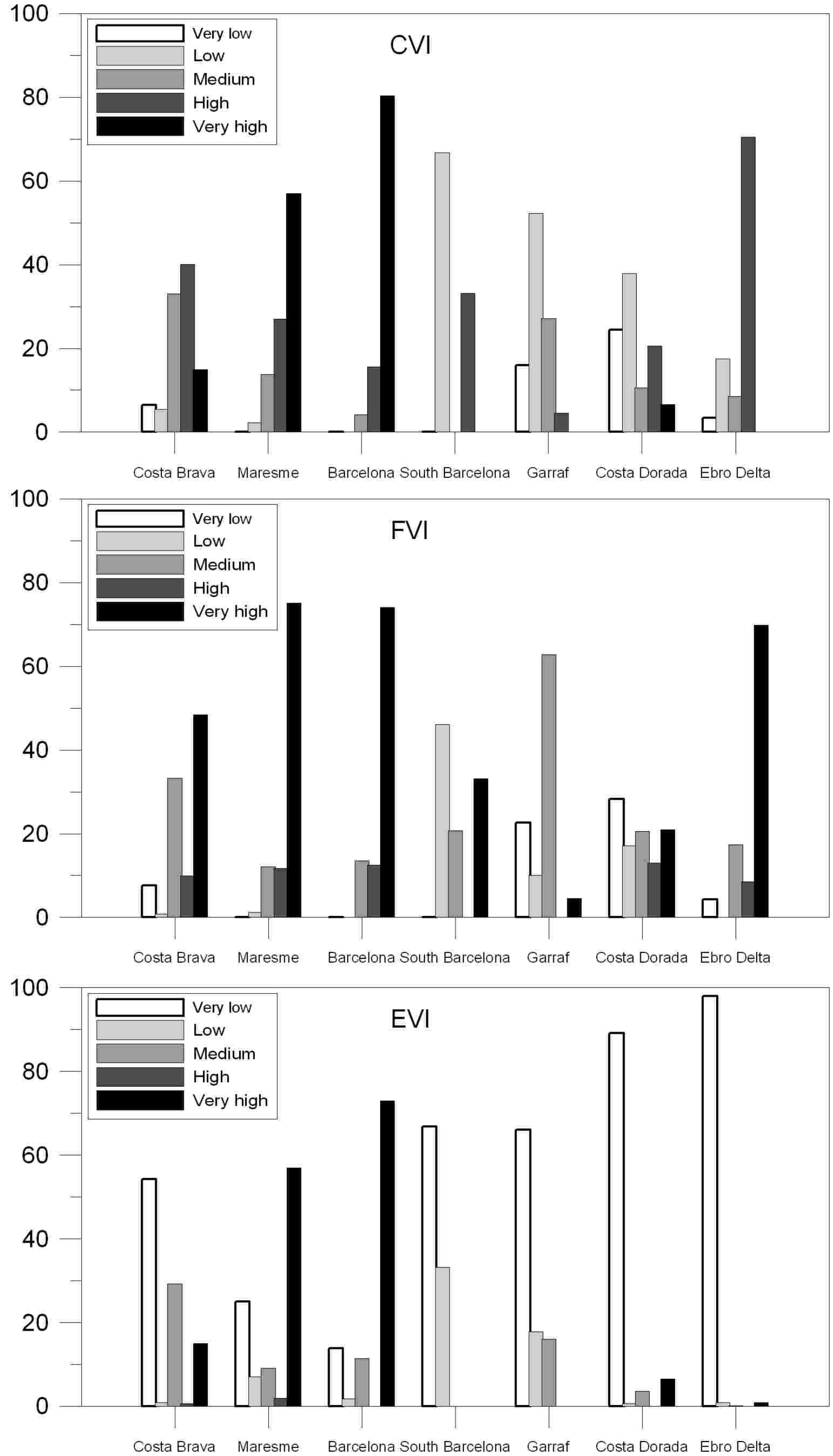

Figure 6.3.12: Percentage of Km of beaches belonging to a vulnerability category per coastal units for a class-V storm.

To properly interpret these results for the overall Catalan coast, we have to take into account the contribution of each geographical unit to the total coastline length of Catalonia. Thus, in Table 6.3.1 the corresponding contribution and coastal length for each section is shown. For example, the Maresme and Barcelona units present an important percentage (>50%) of *Very high* vulnerable beaches (***CVI***), but the first one represents 15% of the total coastline length and the second only represents the 5%.

Table 6.3.1: Coastal units presented in percentage and in length (km).

Unit	*Percentage*	*Length (km)*
Costa Brava	20	51
Maresme	15	39
Barcelona	5	14
S. Barcelona	7	17
Garraf	4	11
Costa Dorada	24	63
Ebro Delta	25	64

6.4 Conclusions and coastal management implications

Finally, taking into account those results, the coastal manager should be aware that the N part of the Catalan coast (from Barcelona to the north) is highly vulnerable to storm impacts. As a consequence, the presence of extreme events will impact the entire coast but these parts should be the most likely to be damaged. If we consider the flooding during these events, the extension of the high vulnerability areas increases in such a way that in all the geographical areas we will find *Very high* vulnerability. Thus, for preventing or combating problems related to inundation during storms, the dissipative beaches of the south have to be also considered. As a paradigm of this different behaviour (in comparison to erosion) the Ebro Delta behaves as a *Very high* vulnerability area to storm induced floods.

6.5 Local scale assessment

Differently from the previous assessment, the local scale assessment implies working at a much more detailed scale used by local beach managers. Consequently, this analysis requires full detail of a beach; where the essential objective is to identify zones within the beach in order to help in the decision making over the necessity of implementation of measures over protection-adaptation and/or mitigation.

The same methodology for the regional assessment was employed down-scaling it for the local application. Thus, the intensity results of the processes for each storm category, each beach and each area are maintained which are again combined with more detailed information of the beach to obtain the vulnerability distribution at a small scale (the source of variability is given by the beach dimensions and not by the variation in the process).

If we wanted to reproduce the variations of the process at a small scale this would be equivalent to model the morphodynamic evolution of the beach and this would be a complementary analysis.

The application was done in Malgrat del Mar beach as a case study. In essence, this small scale application consists in the evaluation of the respective vulnerability indicators in a detailed manner along the beach. In order to achieve this, we need the different widths and elevations along the studied beach. This information will be the source of variability of the vulnerability along the beach to the impact of a given storm.

Malgrat beach which is situated in municipality of Malgrat del Mar, to the south it borders with the municipality of Pineda de mar and to the North with the

Tordera River. In general terms the beach has an approximate length of 4.6 km, due to its large extension the beach was divided into two parts, the south and north section (see Figure 6.5.13).

The southern section has evolved to a developed community with a mixture of commercial and residential uses that are primarily seasonal and resort oriented, there is a significant presence of hotels and restaurants and even railway infrastructure in the back part of the beach which has promoted the vanishing of the dunes.

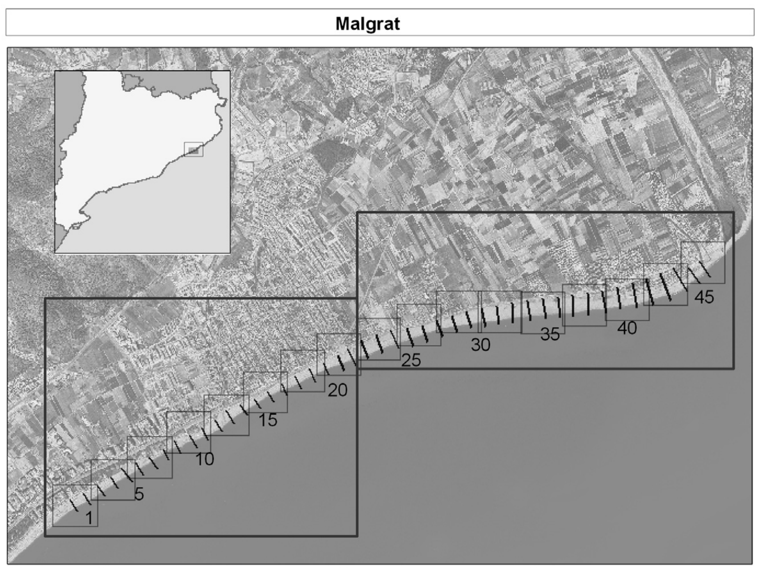

Figure 6.5.13: Location of Malgrat beach, divided in the south and north section.

The north section, presents a lower degree of development mainly of industry and some agricultural spots which have not totally invaded the waterfront. It must be mentioned the settlement of camping sites, which are basically situated in the area next to the Tordera river. This area is an open and wide beach that although no dunes are present, a small strip of vegetation still persists.

Again the integrating element was the GIS in which a Universal Transverse Mercator (UTM) projection was used according to the European datum of 1950 corresponding to the North Zone 31 and is the standard projection used by the ICC.

The basic unit used in this framework is constituted by the variability of the beach, characterized in terms of the beach width and beach height. In this sense the data was obtained from a topography survey made in December 2005. The variability given by the different beach heights (*BH*) beach widths (*BW*) characterized the beach and served as the input information for the ***EVI*** and the ***FVI***.

In order to obtain the desired topographic values (planimetry and altimetry a) a set of 8 control stations were established along the beach based on station 3659 (IGN-3er-ED50) from the National Geography Institute, using a Promark-2 Ashtech GPS in static mode for a time lapse of > 40 min.

With the control stations, DGPS measurements could be made in a kinematics mode (every two seconds) which for this study was conducted in December 2005. The data was managed following three steps: 1) they were first projected and corrected into the European Datum 1950 Northern region 31 (ED50 N31). 2) filtered discarding the data that presented altimetry errors > 30 cm. 3) and the remaining points were used to make Triangulated Irregular Network (TIN) (see Figure 6.5.14).

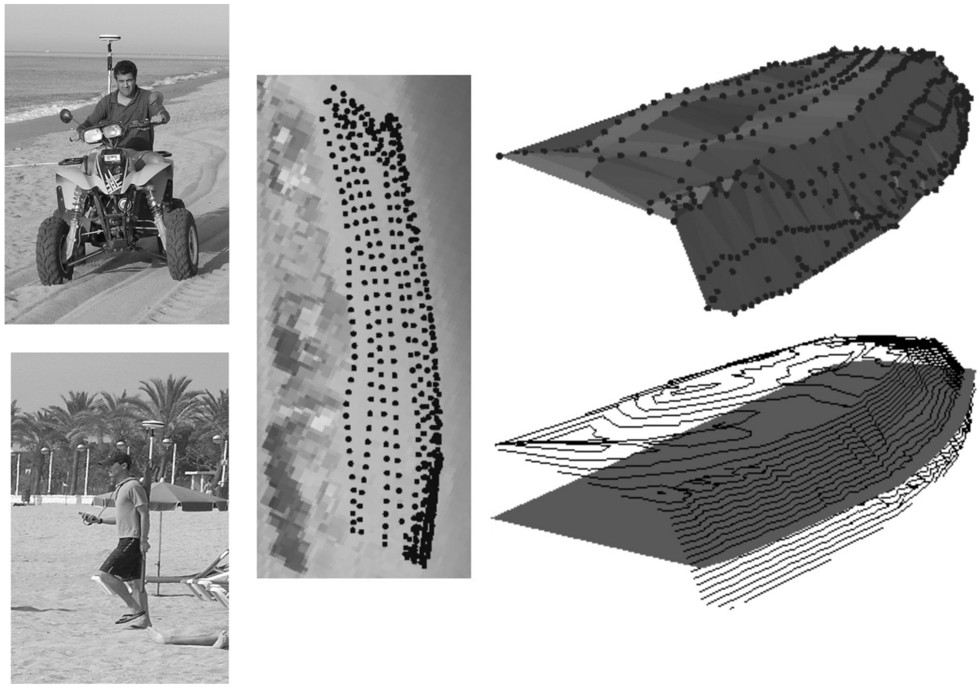

Figure 6.5.14: Methodology to obtain the contour lines at Malgrat beach.

A TIN is a set of adjacent, non-overlapping triangles, computed from irregularly paced points with x/y coordinates and z-values. The TIN data structure is based on irregularly spaced point, line, and polygon data interpreted as mass points and break lines. This data structure allows for the efficient generation of surface models for the analysis and display of terrain and other types of surfaces while preserving the continuous structure of features such as roads and buildings.

The TIN was used to obtain the contour lines of the beach. Contours are lines that connect points of equal value (such as elevation). The distribution of the lines shows how values change across a surface. Where there is little change in a value, the lines are spaced further apart. Where the values rise or fall rapidly, the lines are closer together (see Figure 6.5.14).

Once the contour lines were obtained, the beach was sectioned in a series of profiles separated approximately 100 m from each other and were numbered from south to north. The south section presented 22 profiles and the northern region 24 (see Figure 6.5.13). These were used to obtain the different height and width values along the Malgrat beach (Figure 6.5.15).

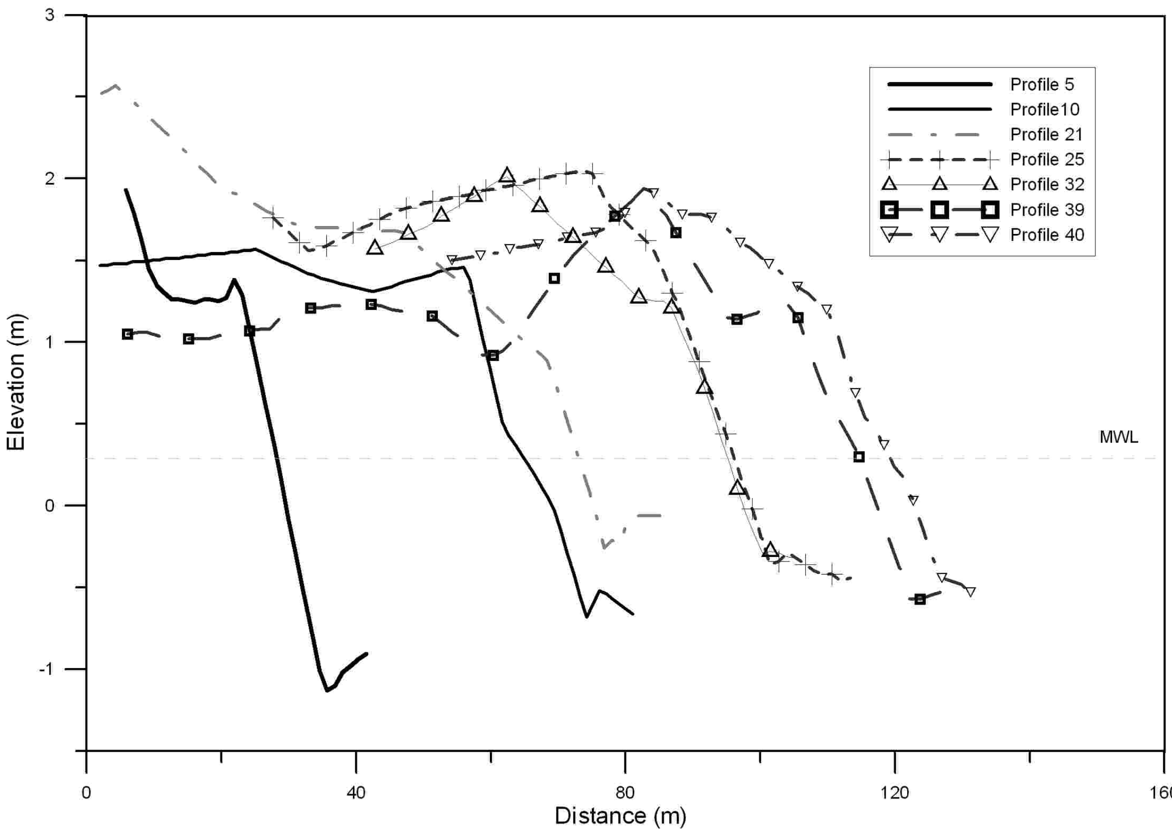

Figure 6.5.15: Profiles obtained in Malgrat Beach in December 2005 (see profile location in Figure 6.5.13)

6.6 Results for local scale analysis

The vulnerability assessment was made for each storm class (I through V) assuming that the storm will have the same impact along the entire beach

The results for the Malgrat assessment can be seen in two ways, using exclusively the **EVI** and the ***FVI*** values or visualizing the actual contour of the flood prone areas and the extension of the beach retreat for each storm class in a GIS map.

The first assessment can be seen in Figure 6.6.16, where the entire beach stretch is represented in 46 profiles and the influence of each storm category in terms of flood and erosion, these are presented from the weakest (type I) on top of the figure to the most energetic (class V) in the bottom of the figure.

In general terms and according to this figure Malgrat is a beach which is more vulnerable to flooding than to erosion. In terms of flooding, the impact of a class-I (weak) storm presents levels ranging from *Medium* to *Very high* values for the most southern profiles (1 through 17) being the second one the dominant value. The section contained by profiles 18 through 22 presented *Very low* and Low values. Further North, the section constituted by profiles 23 through 41, again ranged from *Medium* to *Very high*, being dominant the first value. From profile 42 to the limit of the beach (profile 46) the tendency was a *Very high* value.

For the most energetic storms (class IV and V) the flood levels corresponded to a *Very high* value for the entire beach.

Concerning the ***EVI***, the less energetic storms (type I, II and III) presented an over all value of *Very low* erosion with the sole exception of profile 46, which presented a *Medium* value under the impact of a class III storm. For the most energetic storms (type IV and V) the limits of the beach (profiles 1 through 8 and

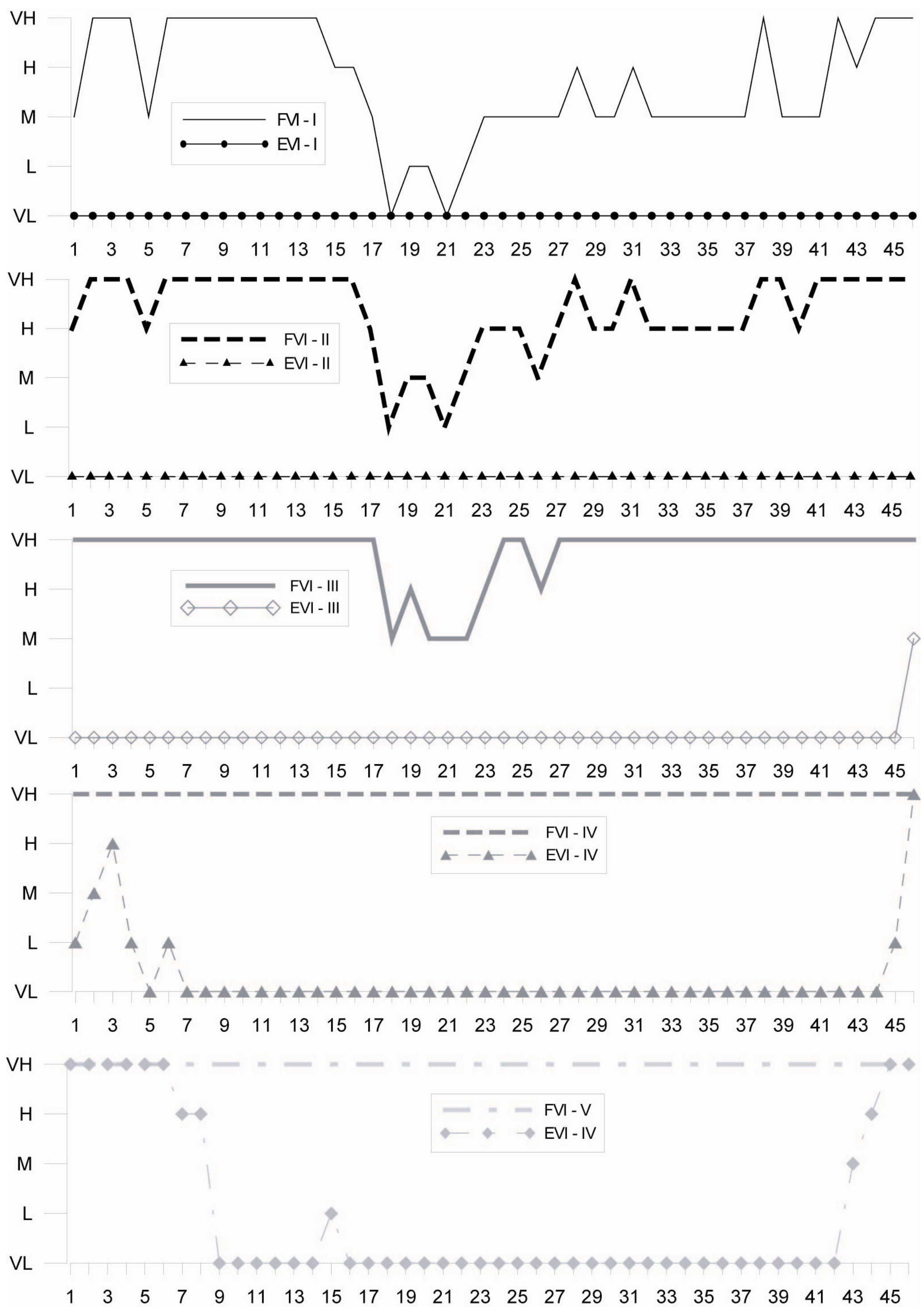

Figure 6.6.16: Flood and erosion vulnerability results for Malgrat beach

43 through 46) presented important variations, specially under the influence a the extreme storm in which the most common values were under the *Very high* classification.

Visualizing the same information of the contour maps through the GIS, provides a much more detailed vulnerability assessment. The complete set of maps for this analysis for the entire length of Malgrat can be seen in Annex C and the information is also provided in KML archives in the attached CD in order to observe them through the Google earth software.

The same behaviour is present in storm types II and III but increasing progressively in 1 level the vulnerability values until reaching the *Very high* level.

The most sensitive areas in terms of vulnerability are presented in Figures 6.6.17 and 6.6.18 (coloured figures can be viewed in Annex C) in which additional information such as type of infrastructure or natural areas situated in the back part of the beach is provided by the aerial photographs.

From the information in Figure 6.6.17 given by the photo which was made in 2004 and the Z = 0 contour line obtained in the December 2005, we observe that, the beach has become narrower specifically in profiles 1 through 3, the remaining profiles (4-6) presented relatively similar beach width values.

In terms of erosion, the areas between profiles 3 and 6 are very susceptible to erosion due to the narrow nature of the beach which may virtually disappear under the impact of a class IV and V storms. In terms of flooding the contour lines are very close to each other and so the flood is contained by the bordering infrastructure with the exception of the area between profiles 3 and 4 which might be flooded under a class V storm. Over all there is an eminent probability that the residential infrastructure might suffer the impact of the waves under the influence of the most energetic storms.

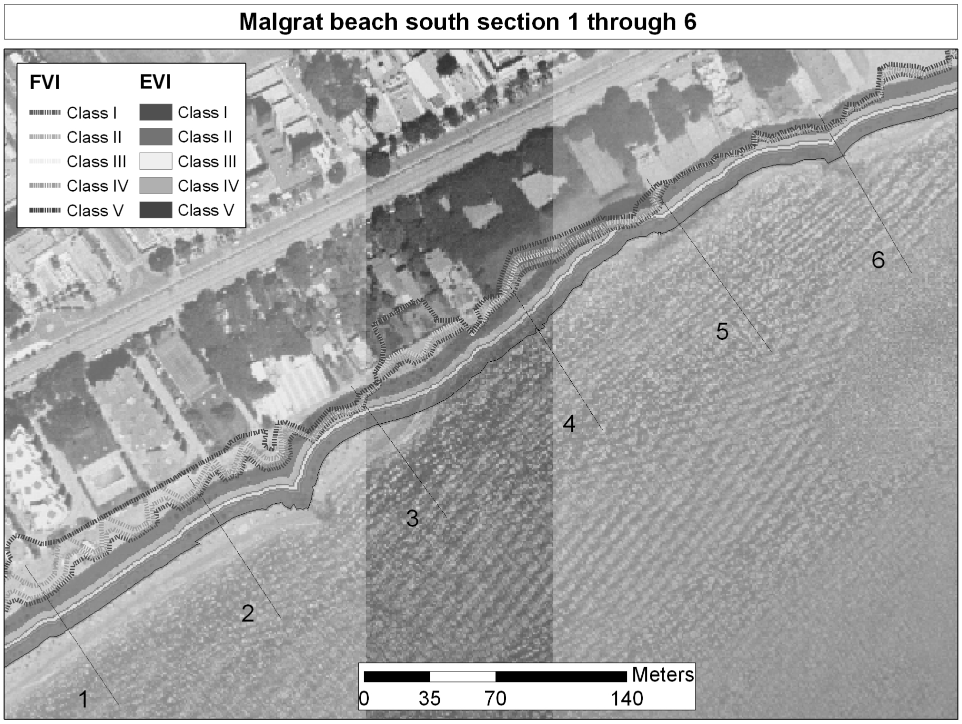

Figure 6.6.17: ***FVI*** and ***EVI*** assessment for Malgrat beach south section 1 - 6 for December 2005.

Although the area presented in Figure 6.6.18 is also sensitive, the case is quite different from the previous example. First of all the beach width has remained the same between 2004 and December 2005, with the exception of profile 46 which is situated in the Tordera river mouth and due to its nature it is constantly changing.

In terms of erosion, profiles 41 and 42 show that after the beach retreat under the most energetic storm (class V) the beach remains very wide. The case of profiles 43 through 46 is completely different, the beach is very narrow and can retreat up to the point were it can reach the bordering structures especially under the influence of an extreme storm.

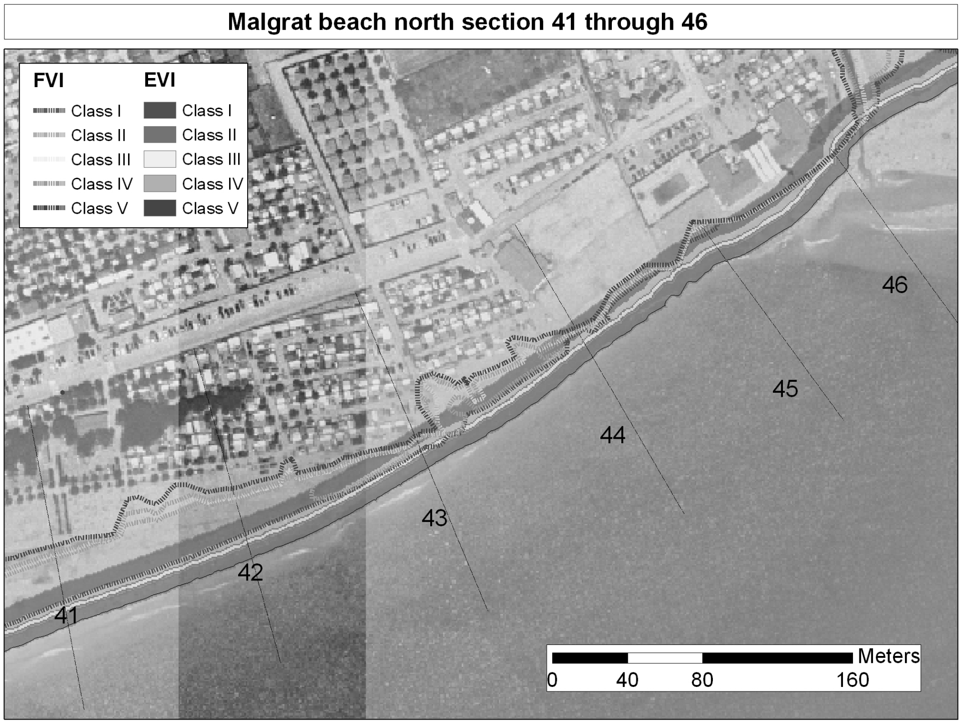

Figure 6.6.18: ***FVI*** and ***EVI*** assessment for Malgrat beach north section 41 – 46 for December 2005.

From a flooding perspective the contour lines show that again, profiles 41 and 42 would not present any inundation problems. This would not be the case for the rest of the profiles, specially the area between profiles 43 and 45 which is susceptible to flooding under virtually any storm type.

6.7 Conclusions and coastal management implications

Finally, taking into account the results, the local coastal manager should be aware that in terms of vulnerability assessment, Malgrat beach is more vulnerable to flooding than to erosion. During the less energetic storms (I through III) the central part is less vulnerable, but under the influence of the most energetic storms (IV and V) the entire beach is highly vulnerable, therefore, preventing or combating problems related to inundation during storms is recommended.

As for erosion, only the edges of the beach present a high vulnerability value for high energy storms. Within these areas, the south end has reached a full development in terms of housing and infrastructure. Therefore, an erosion mitigation plan is highly recommended. The most northern area presents mainly Camping facilities along with storage rooms; the recommendation in this area consists in moving the facilities and storage area inland in order to conserve sand and original vegetation with the aim to restore the natural environment.

It must be kept in mind that although this application provides useful information for the decision making process the detailed information is not always available and such information most of the time needs to be updated.