THE ROLE OF AN ACCURATE ESTIMATION OF EXPECTED DAMAGES IN FLOOD RISK MANAGEMENT. EXAMPLES FROM THE BASQUE COUNTRY (SPAIN)

D. Ocio[1], I. Villanueva[1], C. Stocker[2] and J.M. Sanz de Galdeano[2]
1. *SENER INGENIERÍA Y SISTEMAS S.A. Zugazárte, 56. 48930 – Las Arenas (Vizcaya) SPAIN*
2. *UR AGENTZIA/AGENCIA VASCA DEL AGUA. Orio, 1-3. 01010 – Vitoria-Gasteiz (Álava) SPAIN*

ABSTRACT: Dealing with a highly affected territory in terms of floods with a limited budget is always a difficult exercise of optimizing resources. In this scenario, flood protection policies must always be supported by a logical scheme in order to avoid any inequalities in allocating funds due to the subjective impact of recent episodes or to unjustified social demands. In accordance with the new European flood legislation, a comprehensive approach for flood risk management is presented here. It is organized in three different phases with the following aims: 1) to identify the areas that comprise the bulk of the potential damages within the studied region; 2) to prepare flood hazard maps in the selected areas with state of the art hydrological and hydraulic techniques, as well as to prepare flood risk maps including a detailed account of annual expected damages both in terms of affected population or likely casualties and of economic losses; and 3) to propose efficient structural measures starting with those that will reduce the overall flood risk quicker than others and to promote non-structural ones, such as early warning systems, reforestation, insurances, etc. In this procedure, an accurate calculation of flood damages is essential. Annual expected values must be close to reality if a proper cost-benefit analysis is to be conducted and its results regarded as valid. Once this is achieved, policy makers have a powerful tool to answer some critical questions, such as how to prioritize areas, which protection level is desirable or how to choose between protection alternatives. Some examples from the Basque Country (northern Spain) are provided.

Key Words: Flood damage, Cost-benefit analysis, Flood protection planning, Basque Country

1. INTRODUCTION

Two main factors can lead to high flood risks in a certain area: 1) an increase in the degree of exposure as a result of both a more extreme or concentrated rainfall patterns (i.e. climate change, Milly *et al.,* 2002) and a reduction of infiltration or detention rates in draining surfaces (e.g. deforestation, expansion of built-up areas, Bradshaw *et al.,* 2007), and 2) an increase in vulnerability due to a proliferation of urban or industrial settlements in flood-prone areas, either unauthorized or unaware of the existing risks (Mitchell, 2003). Either way, floods are nowadays the natural hazard with the greatest impact on population, causing each year many casualties and large economic losses (CRED, 2014). Consequently, authorities worldwide are intensifying their efforts to mitigate such a threat by first reducing currents risks with the implementation of structural and non-structural measures and second by averting future risks with a better territorial planning based on a detailed knowledge of the phenomenon. Nonetheless, it is quite common that funds available to do so are not large enough to reach a desired level of protection in a reasonable time, as was realized for example in the United Kingdom after the recent floods of early 2014.

In this scenario, decision-makers have to make difficult choices on where and how invest first so that money can be as much effective as possible, reaching the largest number of population and reducing potential damages rapidly. These decisions can easily be biased due to a partial knowledge of the phenomenon, the occurrence of recent major flood episodes in certain areas or the existence of social pressures. In order to address the problem in a more objective way, thus ensuring that money is allocated to the most relevant issues, cost-benefit analysis (CBA) is a common adopted tool. It is widely used to estimate and organize the inherent tradeoffs of projects taken by public authorities to increase general welfare (Kopp *et al.,* 1997). Although more oriented to the approval of individual projects, it can also help to prioritize a set of measures with a shared aim but different implementation areas. However, its application in flood management programs has been often hindered by a lack of information regarding the profitability (net benefits) of mitigations actions. Therefore, CBA should always be accompanied by an accurate estimation of flood losses in monetary terms if reliable decisions are to be made. In the absence of this and facing a limited budget, many policy makers would be reluctant to commit significant funds for risk reduction, but continue spending considerable money into post-disaster response (Benson and Twigg, 2004).

CBA has been nonetheless criticized because of its excessively economic dimension (Baram, 1979). However, if combined with the identification and consideration of other relevant factors that can influence the feasibility of a certain project (p.e. environmental and social impacts), it becomes a unique tool for a rational decision-making. Besides, there are different ways of monetizing the non-monetary losses, for instance, the contingent valuation by surveying the willingness to pay (Venkatachalam, 2004) or the application of insurance values. Anyway, CBA provides a structured and a priori unbiased method for selecting optimal strategies, above all when information on different choices is homogenous.

In order to fully exploit this technique within flood management policies, a great effort has to be made first to improve our knowledge of both the degree of exposure and the vulnerability of the territory, the former by conducting better or updated flood hazard studies and the latter by obtaining a more accurate distribution of potential damages. In addition, theoretical expected flood damages must be contrasted as much a possible with real data of historic episodes if an adequate comparison with prevention costs is to be achieved (Apel *et al.,* 2009)

A comprehensive approach for flood prevention policy-making is presented here based on the framework provided by the European Union Flood Directive (2007) The method further develops and enhances the mandatory assignment by extensively application of CBA principles. Although originally designed for the Basque Country (northern Spain) it is valid for any region or country around the world where authorities must deal with large flood problems with certain budgetary constraints. The method is divided in 3 phases: 1) a preliminary flood risk assessment in order to identify the areas that concentrate the bulk of the potential damages, 2) the preparation of detailed flood hazard and flood risk maps in the selected areas, and 3) the preparation of a flood risk management plan where flood problems are addressed by means of structural and non-structural measures. Examples of its use in the Basque Country are presented to better illustrate the procedure.

2. PROPOSED METHODOLOGY

2.1 Identifying high flood risk areas

In regions where floods are frequent, a simple spatial statistics can signal the areas where flood damages are higher. However, this statistic must rely on a long enough record if the analysis is not to be biased against the most recent events. Furthermore, the older the flood episode the more likely that it will be characterized by a simpler, more general spatial definition with very limited quantitative information on real damages. This will also cause that areas hit lately by floods, which will have been widely covered by mass media and emergency services, will score higher in comparison. These trends will be obviously exacerbated in regions where floods are less frequent. There are two more problems while trying to identify high flood risk area based on historical information. On one hand, it cannot take into account the mitigation effect of flood protection measures implemented recently. On the other hand, if there has been a change in vulnerability (p.e. the development of a new residential neighborhood in a flood-prone area) but no significant flood has occurred, the flood risk will be underestimated.

As an alternative, the so-called exposure method, where flood risk is the product of flood hazard by flood vulnerability, is proposed (de Moel *et al.,* 2009) in order to conduct a preliminary flood risk assessment that can cover the full river network. As a simplified approach, the method encourages the use of existing or easily obtained information. Nevertheless, if a homogenous and unbiased analysis is pursued, the completion of a new set of studies with a common methodology is strongly advised. The required steps are the following:

- Establishment of the study network, which at least should comprise zones that have undergone floods in the past, river stretches with existing flood hazard studies and other streams with a drainage area over a certain threshold and where the presence of vulnerable elements in the geomorphological floodplain can be indicative of potential damages;

- Delimitation of the flood-prone areas corresponding to 10-yr (high probability), 100-yr (medium probability) and 500-yr (low probability) return periods by means of hydraulic modeling. Depending on the main channel and floodplain geometries or interaction, a 1D or 2D simulation will be needed (Villanueva, 2007). Either way, a simple model based on available topographic information without the consideration of structures, a roughness distribution as a function of land use and a regional hydrological approximation for obtaining design discharges will be enough;

- Characterization of flood vulnerability related to the maximum potential damage, i.e. assuming that there is a complete loss of an element if it is included in the flood-prone area regardless of the flood magnitude (depth, velocity and duration) Ideally economic losses should be considered as well as the affected population by using some kind of theoretical or empirical valuation. A composed risk index should be determined by imposing weights depending on the relevance of each component in the particular region of study;

- Determination of simplified annual expected damages by multiplying the likelihood of each flood event (inverse of the return period) by the related composed risk. These values must be associated with identical spatial units, for example with a subdivision of the river network into stretches of a certain length, so that they can be compared in equal terms;

- Selection of the river stretches with higher flood risks. To do so, they are ordered from higher to lower flood risks and accumulated afterwards. A threshold is then adopted so that river stretches appearing before it comprise a certain selected percentage of total potential damages in the region; and,

- Areas with high flood risk are spatially defined by joining high flood risk river stretches with hydraulic criteria.

The final set of high flood risk areas can be then contrasted with historical information to avoid possible mistakes. Remarkably, there is no need to conduct a more detailed analysis in this phase as only relative values are of interest. The simplifications adopted, while cannot result in a realistic estimation of flood risks in absolute terms, will affect all areas in the same way, enabling the comparative exercise that is only required to select the areas that enclose the majority of potential flood damages.

2.2 Improving flood hazard and flood risk characterization

Once the high flood risk areas have been selected, the knowledge on flood hazard (flood extent and magnitude) and flood risks (real annual expected affected population and economic losses) must be improved. This will typically involve a detailed hydraulic modeling based on the best estimation of peak discharges and the best available topography. It has to represent reality accurately and thus, it has to consider the effect of all structures (bridges, weirs, dikes, etc) and obstacles (buildings and embankments), and be preceded by a visual reconnaissance in order to properly estimate roughness coefficients (Wright et al., 2008). If possible, a calibration process must be conducted by comparing simulation with historical information on flood extent and depths.

Unlike in the previous phase, flood damages must the calculated thoroughly. They must represent actual losses and so, all theoretical estimations must be adjusted against historical data as much as possible. In this case, the magnitude of the flood has to be taken into account while calculating damages. The usual way to do so is by applying damage functions (Penning-Rowsell and Green, 2000) that relate inundation depth, flow velocity and flood duration with the economic losses (either in absolute values or as a percentage of total damage)

Finally, expected annual losses should be obtained now based on a better approximation of the complete damage-probability curve, which means that more return periods (i.e. probabilities) have to be simulated. The area under this curve represents the aimed value, as in:

$$E[D] = \int_0^\infty D(p) \cdot dp \qquad [1]$$

where *p* is the probability and *D(p)* the damages corresponding to that probability. Figure 1 provides the classic four-part diagram summarizing the inter-relation of hydrology, hydraulics and economics as the basis of calculating expected annual flood damages.

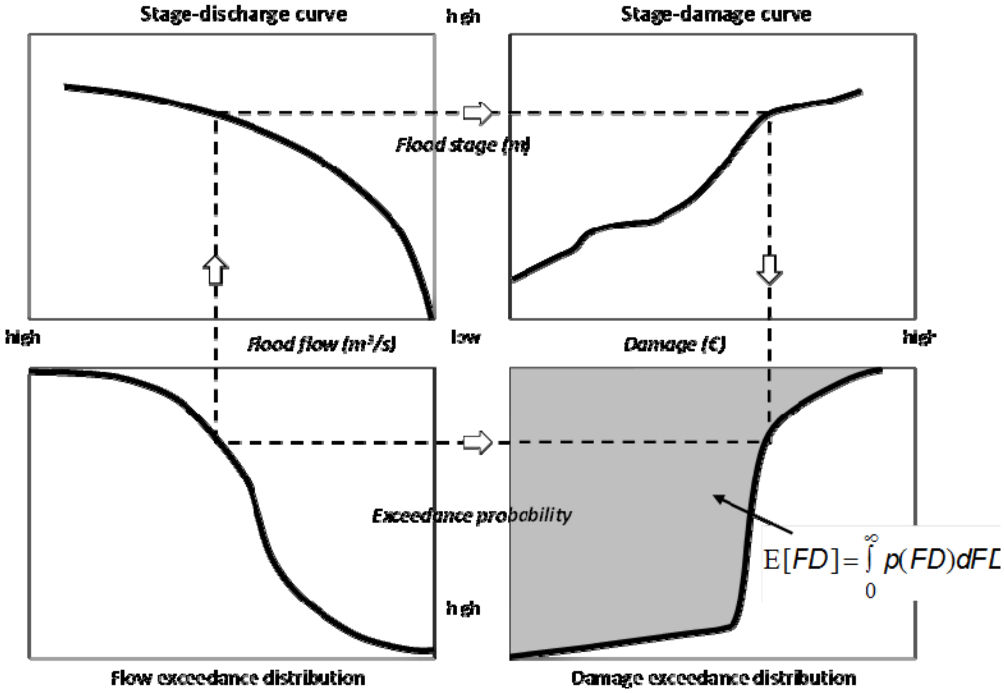

Figure 1: Schematization of annual flood damage estimation

If possible, these annual losses should be distributed spatially so that zones that concentrate damages in the studied area can be identified, which will help to propose effective mitigation measures in the subsequent phase.

2.3 Selecting and prioritizing protection measures

The new detailed knowledge of the phenomenon facilitates the development of a reasoned flood risk management plan. This plan should include the optimal solutions for the identified problems taking into account that a complete degree of protection is not always feasible or approachable (Morita, 2008), that the selection of alternatives must rely on the incurred costs and the expected benefits and that limitations in money and time imply the need of a temporal programming of mitigation actions. Given this, the proposal and application of non-structural measures, such as the implementation of flood early warning systems, the modification of the operation rules in key reservoirs or the support to reforestation policies, should be stressed out. Although they seldom can avoid all damages by their own, they are undoubtedly the most cost-effective solutions due to the low investment required while possess indifferent or positive environmental and social impacts (Kundzewicz, 2002). In addition, although this sort of plan is usually more focused on alleviating current risks, it should be accompanied by regulatory changes to ensure that no more risks will appear in the region as results of new urban developments.

The available estimation of flood damages and CBA will then enable the following tasks:

- Prioritization of interventions. Starting with a certain return period of protection, measures can be proposed to totally avoid damages in each high flood risk area, the economic profitability of which can be compared in order to identify the areas where acting will result in a greater reduction of global damages per unit of money invested. Based on this, a temporal prioritization can be obtained. However, apart from economic values, the impact of measures on population safety has to be taken into account too, for example by introducing the number of people at risk for the return period of analysis as an indicator of social benefits. This will result in a bivariate chart where areas can be represented and ordered.

- Establishment of the desired degree of protection. Adopting a lower degree of protection will obviously mean less expensive solutions, whereas benefits will decrease as flood damage will prevail (but diminished to a certain extent) for return periods over the design one. CBA will indicate when adopting this strategy is economically preferred;

- Definition of phases within a certain high flood risk area. Within a certain area, some zones will concentrate the majority of the risk, allowing a finer spatial differentiation of interventions;

- Selection of the optimal alternative. For each phase and area, several alternatives can be proposed that will reach the same level of protection while comprising a different set of works. Deciding which one is the most desirable will imply that a multicriteria analysis must be conducted. Together with technical, environmental and social issues, the economic profitability of each alternative is arguably one of the most relevant factors; and,

- Assessment of non-structural measures. The effect of a flood early warning system in reducing the vulnerability of the territory or of reforestation policies in decreasing peak discharges can be also measured economically.

Structural measures will typically change the stage-discharge curve while modifying the operation rules of a reservoir for example will change the flow exceedance distribution. Either case, the damage-probability curve will vary and can be compared with the current one in order to obtain the expected benefit as the difference between future and current damages. From the different methods to compare these benefits with the related costs in order to establish the profitability of an alternative, the benefit-cost ratio (BCR) is proposed here due to its straightforward meaning. The BCR represents the expected benefit per each money unit spent. A ratio over 1 means that the alternative is profitable and vice versa. It is calculated as follows:

$$BCR = \frac{\sum_{t=1}^{n} \frac{B_t}{(1+r)^t}}{I + \sum_{t=1}^{n} \frac{C_t}{(1+r)^t}} \qquad [2]$$

where *B* is the benefit per year, *I* is the initial investment, C are the annual operation and maintenance costs, n is the repayment period, which is set to 100 years given the nature of the solutions, *t* is the time of the cash flow and *r* is the discount rate, which is set to 3% due to the public ownership of the works.

3. APPLICATION TO THE BASQUE COUNTRY

3.1 Region of study

The Basque Country is located in northern Spain. It is divided from East to West by the Cantabrian Cordillera, with elevations over 1,000 m.a.s.l. and laying no more than 40 km from the seashore. To the North, narrow and steep valleys run towards the sea with torrential features, whereas a plateau with an altitude around 600 m.a.s.l is found to the South (see Figure 2A). The northern façade is temperate and humid. It benefits from warm sea temperatures due to the presence of a branch of the Gulf Stream reaching the area. The weather is also dominated by westerly winds that carry humid air from the ocean. As a result, mean average rainfall ranges from 1200 to 2000 mm per year decreasing only slightly in summer (García de Pedraza and Reija Garrido, 1994). Within this typical pattern, very intense, stationary and persistent storms can take placed caused by a combination of a warm sea, an unstable surface atmosphere and cold air at higher altitudes. Those situations are the major threat in terms of floods in the region. As an example, in August 1983, 500 mm in 24 hour were recorded in some locations of Biscay leading to a major flood that was thought to exceed a 1,000-yr return period causing a devastating impact on population and properties (see Figure 2B). There were 39 casualties and 800 M€ of economic losses (DFB, 1984). This particular rainfall pattern is accompanied by a territorial model highly focused on the bottom of the valleys. Floodplains, which are quite narrow, are packed with built-up areas (see Figure 2C). In the second half of the 20th century when there was an economic boom in the region, the lack of flat terrain forced people to build near the rivers, unaware of the risk this could imply for them. As a result, the Basque Country experiences recurrent and sometimes catastrophic floods.

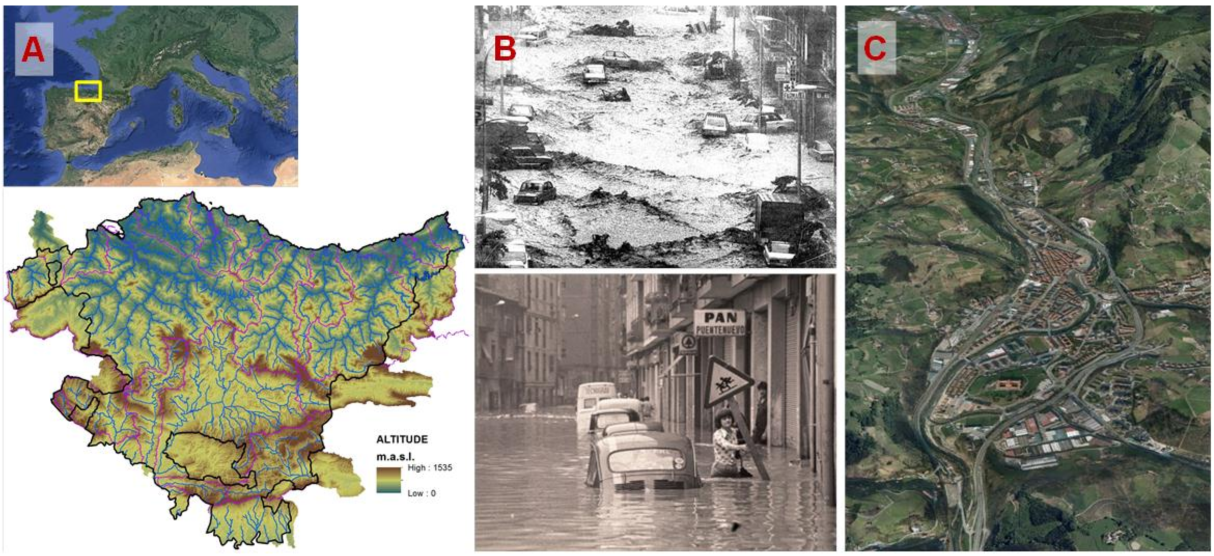

Figure 2: A: Location of the Basque Country and topography of the region; B: Effects of the August 1983 flood; C: Example of the occupation of floodplains (town of Tolosa)

3.2 Preliminary Flood Risk Assessment (PFRA)

Although there are records of flood events in the region that are dated to the 15th century, only until recently the information about historical flood episodes has been systematically gathered. This fact, together with the significant changes in the vulnerability in the last decades as a result of urban growth, made the regions ideal for the application of the exposure method. First, a study river network was defined comprising 2,525 km and including streams with a drainage surface over 5 km^2. Flood-prone areas for 10, 100 and 500-yr return periods were delimited along that network by means of 1D hydraulic simulation (HEC-RAS model) based on a Digital Elevation Model with 1 m grid and 10-15 cm accuracy in height derived with LiDAR techniques. Where available, existing flood hazard studies were used.

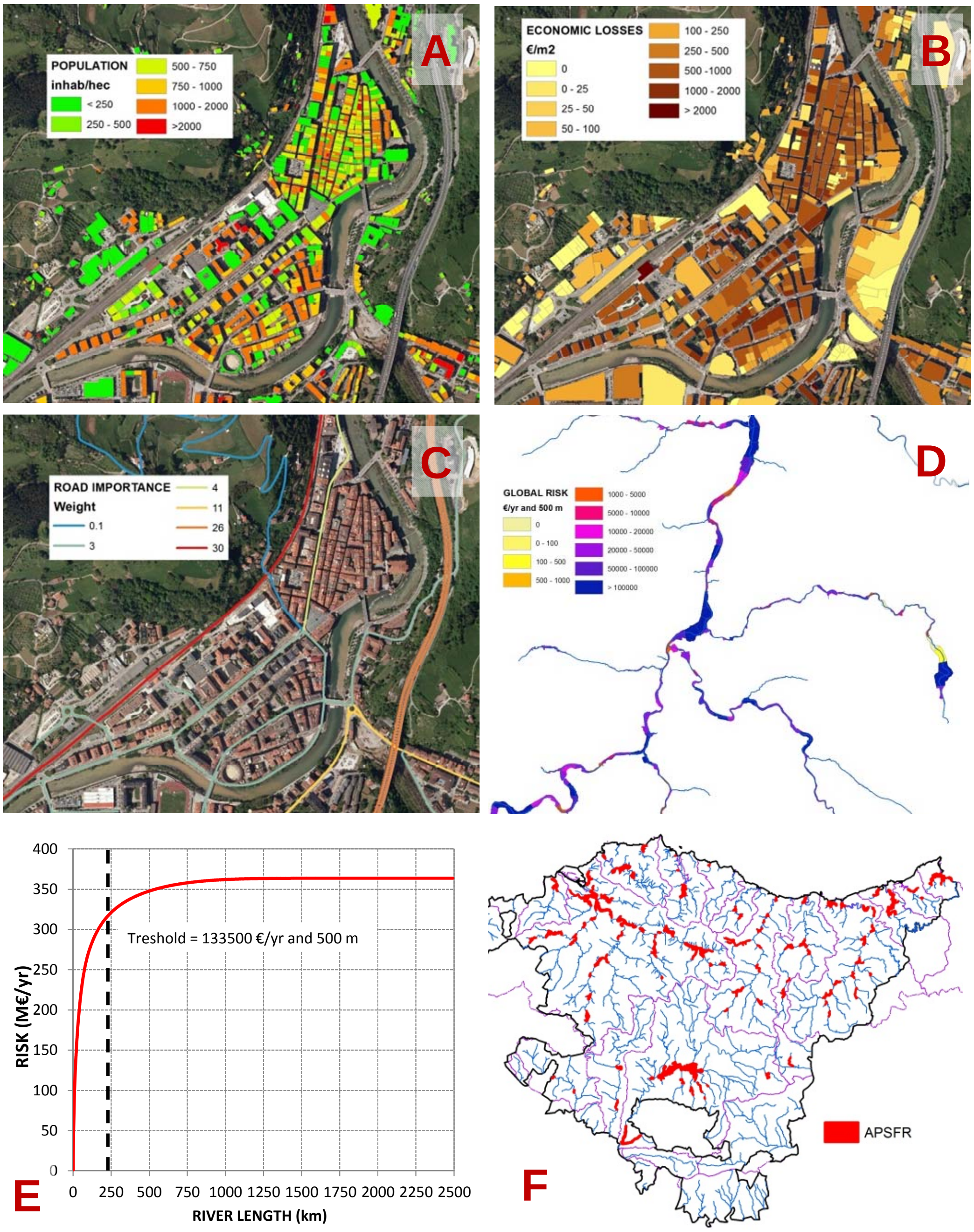

Figure 3: A: Population living in each building (town of Tolosa); B: Maximum damages to properties (town of Tolosa); C: Importance of roads (town of Tolosa); D: Example of discretization of global risk (Oria basin); E: Accumulated global risk vs. accumulated river length; F: Location on selected APSFRs

Vulnerability was established as the combination of 1) the population living in flood-prone areas, assigned to each residential building by the Basque Statistical Office (see Figure 3A); 2) potential economic losses related to each residential and industrial land plot were fixed as land registry construction values for basement and ground floors, multiplied by a coefficient representing the content value (see Figure 3B); and 3) potential economic losses for each interrupted communication route as a function of its relevance (see Figure 3C) In order to estimate a combined risk index, only population living in ground floors (roughly a 20% of the total) were accounted for, whereas an average compensation value per affected inhabitant of 15,000 € was adopted based on statistics of insurance companies (CCS, 2009). In order to consider the larger economic losses related to industrial or commercial activities due to the value of the damaged goods, construction values in those cases were multiplied by a factor between 1 and 2 depending on the number of employees provided by the Basque Statistical Office. Average daily traffic (ADT) values were used to assign relative weights to each type of road and an estimated repairing cost of 50 € m^{-1} was established for secondary municipal roads in the Gipuzkoa province, used as the standard unit (ADT of 500 vehicles per day). Finally, policy-makers decided to include an augmentation weight of 8 to population due to its greater importance in comparison with economic losses.

After incorporating the probability, total annual expected risks reached 364 M€ yr^{-1} and were distributed along the river network in stretches of 500 m (see Figure 3D) Accumulating risks related to each river stretch in ascending order, an increasing monotone curve was obtained. As observed in Figure 3E, this curve starts with a sharp rise corresponding to the addition of the river stretches that hold the higher risks and rapidly tends towards an asymptote. This means that risks are concentrated in a small part of the river network. In fact, by adopting a minimum value per stretch of 133,500 € yr^{-1}, which is associated with no more than 195 km of rivers, a 85% of the total risk is taken into account. That value was the final selected threshold. Based on it and by applying a continuity criterion, 91 areas with potential significant flood risk (APSFRs) were identified (see Figure 3F), comprising a total length of 441.5 km. These areas were then compared with the available historical information with very positive results and finally validated by different administrations with responsibilities in the matter.

3.3 Preparation of Flood Hazard and Flood Risks Maps

Before attempting to propose protection measures, the characterization of flood hazards and flood risks in each APSFR was improved. In the case of flood hazards, a more detailed definition of the river channel was obtained by topographic surveys (including the bathymetry) and merged with the available DEM for defining the floodplains. The geometry of bridges, weirs and levees was also obtained. In addition, a new hydrological study was conducted. It involved an hourly stochastic generation of rainfall and temperatures, regionally calibrated and with spatial coherence, that was applied during 500 years to a the distributed and continuous hydrological TETIS model (Vélez, 2001) resulting in long flow series along the river network that could be treated statistically as if they were flow records belonging to gauge stations (Cowpertwait *et al.,* 2013) The new geometry and flood discharges were then used to delimitate flood-prone areas for 2.33, 10, 25, 50, 100 and 500-yr return periods by means of 1D (HEC-RAS model) and 2D (IBER model, Bladé et al., 2014) hydraulic simulations. Flood depth and velocity distributions with 1 m resolutions were also calculated. The results were adjusted by geomorphological techniques, thus limiting the existence of errors.

On the other hand, the characterization of flood risks was made as follows:

- The population affected was calculated like in the PFRA. However, the expected number of casualties was obtained here following the “Flood Risk to People” methodology (DEFRA, 2006) as a function of flood magnitude (depth, velocity and the presence of debris), area vulnerability (lead time, type of buildings and existence of early warning systems) and people vulnerability (percentage of population over 65 years)

- Maximum structural damage to buildings was established like in the PFRA (the average residential and commercial values were 176 € m^{-2} and 292 € m^{-2} respectively) Maximum damage to contents was fixed to a 50% of the structural damage for residential uses and between a 50 and 150% for economic ones (as a function of the number of employees). Unlike in the PFRA, real damages were obtained here taking into account flood depth by using the stage-damage curve shown in Figure 4A. This curve was derived by adapting the US FEMA (2001) and UK FHRC (2010) estimations to the Basque Country reality. This was made by comparing theoretical results with known damages in some major floods such as the August 1983 event for the whole northern façade and the November 2011 for the Urumea basin.

- Damages to vehicles were determined by applying a ratio of vehicles per inhabitant derived from municipal statistics to the population living in each building and an average compensation of 4,500 € per affected vehicle provided by the public insurance consortium for the 4 more recent floods in the region. Vehicles were considered lost if flood depth exceeded 30 cm.

- Damage to communication routes was estimated like in the PFRA. Costs related to cleaning and emergency services were added as an extra 15% of total economic losses (FHRC, 2010)

As a result, expected annual losses of 1.4 casualties per year and 92.9 M€ per year were obtained. The former figure was consistent with the existing records (99 casualties from 1933 to 2009) while the latter is coherent with previous annual estimations for the region (98 M€ yr^{-1} for the 1987-2002 period and 123 M€ yr^{-1} for the 2004-2033 period, in IGME and CCS, 2004) The spatial distribution of economic losses (to building plus vehicles) was also obtained (see Figure 4B) to help defining phases within each APSFR.

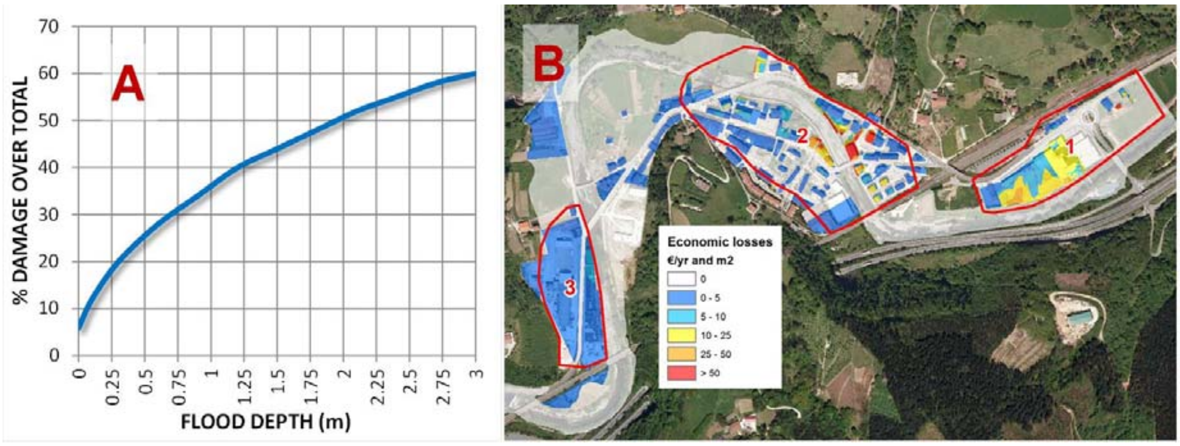

Figure 4: A: Stage-damage curve used in the study; B: Spatial distribution of annual expected damages in the town of Legorreta. Numbered zones represent phases within the PDFRA.

3.4 Preparation of the Flood Risk Management Plan

With the identification of APSFRs, the detailed hydraulic simulation of flood hazards and the reliable estimation of flood risks, decision-makers possess the necessary tools to develop a reasoned investment plan. At a first step, priority should be assigned to each APSFR so that their need on intervention can be placed in time in relationship with others. The aim of this exercise is to start with the most cost-effective measures, thus allowing a quicker reduction of global risks. Decision-makers may have the temptation to begin with areas where flood risks are higher. However, they might entail significant investment costs as a consequence of their extension and/or the entity of the required protection measures, which as a whole could mean a lower economic profitability. In order to ensure a well-based decision in the Basque Country, simplified structural measures were proposed in a set of 40 AFSFRs corresponding to the ones that comprise 85% of the total affected population and total economic losses while ranked decreasingly as a function of risk per unit of length. A 100-yr return period of protection was established initially as it was the default value indicated in the legislation in the absence of better estimations. Related investment costs were calculated based on the main units of work and by applying percentages to account for other secondary elements. Annual maintenance costs were set to a 0.75% of the initial investment costs. By using equation [2], the BCR was obtained in each case. On the other hand, the social benefits of the intervention were defined by the population affected in a 100-yr return period flood. Based on these two variables (economic profitability and human risks), Figure 5A shows the position of each APSFR. Interventions are more desirable to the right and to the top of the chart. A boundary line was established by decision-makers identifying the 20 APSFRs that must be addressed in the short-term (i.e. the next 6-years cycle of hydrological planning)

Focusing on each selected APSFR, the analysis began by assessing if a 100-yr return period of protection would be appropriate or if a lower or higher objective would be preferred instead. This was accomplished by calculating the BCR of the measures needed to reach different levels of protection and by taking into account other factors such as the remaining population at risk or the environmental feasibility of the related works. The possibility of a phased execution was also considered so that higher level of protection can be gain incrementally in future planning horizons. As an example, in the town of Legorreta, a 50-yr return period was selected. The related BCR was 2.75 in contrast with those of 100 and 500-yr return periods, which were 2.1 and 0.70 respectively. Adopting a 50-yr return period allow less aggressive structural measures and reaching a reduction of 91.9 % in the potential affected population.

Once the return period of protection is fixed in a APSFR, the next step consisted of the selection of zones within the area where risks were higher and where problems should be addressed first (see Figure 4B) By doing so, decision-makers can opt to postpone the protection of low risk zones so that the available budget can be allocated to the most serious problems. For instance, in the case of the town of Legorreta the old quarter (zone nº2) enclosed a 68% of the total damage.

For each zone, two or more alternatives were proposed and verified by means of hydraulic simulation. Their individual economic profitability was then obtained by estimating their benefits as the reduction of expected damages and by defining investment costs based on a better definition of required works. Technical, environmental and town planning issues were also analyzed in order to select the optimal solution. The process involved a public consultation so that a wide consensus could be gained. In the case of zone nº2 in Legorreta, 2 alternatives were proposed (see Figure 5B). One comprised the demolition of two secondary structures, the replacement of a post-medieval bridge and lateral protection dykes, while the other did not touch the post-medieval bridge but required river training with both rectangular and trapezoid sections. The BCRs were 8.8 and 4.3 respectively, which together with the environmental impact of modifying the river ecosystem recommended selecting the first alternative after consulting with the heritage conservation authorities.

On the other hand, non-structural measures were also considered. In fact, the Basque Water Agency in collaboration with the civil protection services has recently implemented a flood early warning system with the aim of increasing warning times in a region where the hydrological response is rather quick. In addition to the potential reduction of casualties as a result of public awareness, the effect of this tool can be also measured economically by applying a reduction in the expected damage to the content of buildings and to vehicles as a function of warning times (Chatterton and Farrell, 1977; Carsell *et al.,* 2004; Parker *et al.,* 2007) In the case of Legorreta, reductions of a 20% in annual expected economic losses and of a 70% in annual expected casualties were estimated.

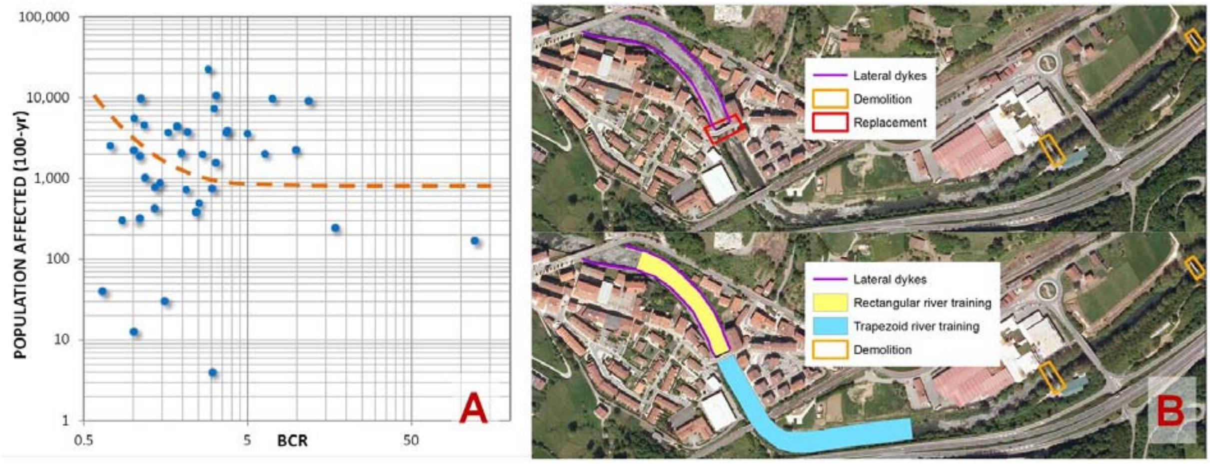

Figure 5: A: Prioritization of alternatives based on BCRs and population affected in the 100-yr flood; B: Alternatives proposed to mitigate flood risk in zone nº2 of Legorreta.

4. CONCLUSSION

Preparing a reasoned investment plan to mitigate flood risks is a challenging exercise when the required funds exceed the allocated budget. Decision-makers should then rely on objective tools in order to avoid any bias and sustain their choices. The methodology proposed here represents a systematic approach to the issue that makes extensively use of CBA, thus further developing the EU legislation. It is nonetheless based on a reliable knowledge of the phenomenon, above all on a detailed estimation of related potential losses that must resemble reality as much as possible. Without it, the procedure would be flawed and lead to inadequate results. A special attention should be put then in characterizing the different kinds of damages and in their contrast with available historical information. The methodology, which has been successfully applied to the Basque Country (northern Spain) can easily be used in other parts of the world that share the same problems.

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