Assessment of geological risk in the Canary Islands: the GeoMEP project

The assessment of the losses which may be potentially caused by a natural disaster in a given scenario is an essential exercise in the insurance industry for the estimation of the necessary financial resources to deal with the disaster. Since it is not possible to use statistical data, due to the low frequency of causative catastrophic events, the development of modelling techniques was increasingly generalized after the hurricane Andrew (August 1992) as a way to forecast the damage. GeoMEP, a loss evaluation method for geologic risks, has been developed on the base of an agreement of collaboration between the Geological and Mining Institute of Spain (IGME) and the Consorcio de Compensación de Seguros (CCS). In the preliminary stage, GeoMEP has focused on Canary Islands as a pilot project, which can be extended to other regions of Spain.

Miguel Llorente Isidro
Geological Risk Division, Geological and Mining Institute of Spain

> The Canary Island archipelago is a virtually unparalleled natural laboratory, not just for its geological origin or climate but also for the natural processes that take place as a result of the two.

1. Introduction

The Canary Island archipelago is a virtually unparalleled natural laboratory, not just for its geological origin or climate but also for the natural processes that take place as a result of the two. A third element, high population density combined with tourist appeal, makes the islands an ideal site for studying all manner of geological hazards. Such research contributes, on the one hand, to meeting the population's need for information on the natural dynamics of their immediate surrounds, and on the other, to the development of methodologies to assess possible outcomes.

Not all geological processes disrupt people's everyday lives. Those that may indeed have adverse effects are called *geological hazards*. The Canary Islands are subject to many such hazards, including earthquakes, floods and volcanic eruptions. *The foreseeable consequences of a geological hazard are known as "geological risks".*

In Spain the Consorcio de Compensación de Seguros (CCS, insurance compensation consortium), a public insurer, is entrusted with covering the losses caused by such risks. But if a hazardous event were to occur tomorrow, how could we determine what the economic implications would be? What liability should the CCS be prepared to confront? The Instituto Geológico y Minero de España (IGME, Spanish institute for geological surveys), in turn, has been conducting studies of natural risks since its founding in 1849, and has intensified that line of research considerably in recent decades. Prompted by a common interest in understanding natural risks, the IGME and the CCS have concluded an agreement to assess the geological risks in the Canary Islands (GeoMEP project) (1) to estimate the resources required to provision for flooding, earthquake and volcanic risk.

2. Geological risks

As noted, risks are merely the *foreseeable implications* of the future occurrence of a hazardous event, while losses may entail more than that. Experience has shown that after natural episodes, cause and effect can rarely be univocally and unequivocally related without resorting to the study of case histories and cascade effects. Lava flows, ash rain and explosions may be observed during volcanic eruptions, for instance. Similarly, if a very shallow, high magnitude earthquake strikes in a steeply sloped area comprising unstable materials, it is unthinkable not to expect landslides. A flood consisting only of the submergence of normally dry land would be an exception, for these events generally go hand-in-hand with river bank and subsoil erosion, changes in the course of the river and sedimentation. Moreover, natural hazards do not always constitute a problem per se, but trigger other adverse situations: one recent example is the 2011 nuclear disaster in Japan, caused by a tsunami that was set off by an earthquake. Cascade effects are events in which an apparently minor occurrence gives rise to a second with feedback effects, such as the spread of fires after earthquakes.

Natural hazards are studied for a sole purpose: *to reduce natural risks*. Meeting that objective calls for working to a series of premises, such as limiting the number of factors to be studied or their spatial and temporal scope. Risk studies necessarily address three factors through which the limitations imposed to reach a reasonable, well thought-out, numerical and rigorous conclusion about expected losses must be addressed.

These three factors are: hazard (H, or study of the hazardous process), exposure (E, or study of the value of the elements that may potentially be impacted by a hazardous process) and vulnerability (V or study of the relationship between loss and total value of the element exposed to a given hazard). These three elements are generally accepted to be inter-related as follows: R=H*E*V. The absence of any one of the terms in this equation would yield incorrect "risk stoichiometry", i.e., an apparent inconsistency in the definitions or a change in paradigm to reach a qualitative or partial solution to the risk equation. This approach is often adopted in light of the difficulty involved in solving the full equation. The essential term is H, hazard, for it defines exposure, E, from the spatial perspective. In other words, it identifies what would be subject to a hazard, and is the basis for calculating vulnerability, V, elements needed to determine the amount and type of impact and hence to asses the damage ratio. In the case at issue, the CCS is not liable for everything that is exposed (Figure 1), but only for the insured portion. In the Canary Islands, 70 % of all property and goods have some insurance cover.

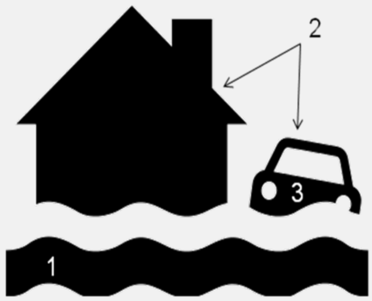

Figure 1. The first object of risk research is hazard (H; 1, flooding for instance), which determines what may be affected (E, homes, cars) to what extent (V; 2, 3: partial, total) and whether or not liability for insurance compensation would be incurred.

3. The method: flooding, seismicity and volcanism

While the use of the data on record, if any, to assess future consequences is tempting, it has proven to be a vain exercise, due both to the particular nature of (and cascade effects related to) specific events and to the speedy change to which an area's economic, social and natural variables are subject. The hazard calculated for a series of past events is not correlated to the damage recorded. Nonetheless, when the variables space, time, exposure and vulnerability are fixed and only hazard varies, the resulting curve trends non-linearly upward, with thresholds, such as the "desk effect" in floods (2).

Solving the risk equation is no trivial matter, and the first obstacle to surmount is data availability. If a natural hazard database were in place, the task would be far easier, for this is the area where most of the limitations arise. From there on, as much complexity may be introduced into the study as required in each case, pondering matters such as direct or indirect damage, social or structural topology or cascade effects. The number of variables and considerations to be included in risk studies, as well as the demand for such studies and society's capacity to contend with the uncertainties associated with the calculations involved, grow as science, technology and society in general move forward.

With all that in mind, the IGME, pursuant to its agreement with the CCS, has developed a method to fully solve the risk equation in a manner that, while balanced, is not wholly free of uncertainties and limitations, as listed below.

- **Limitations to the hazard variable**: the processes studied are practically "pure". The floods considered are concentrated and torrential, associated with riverbeds or ravines and induced by abnormally heavy rainfall; seismicity is tectonic and only the consequences of peak ground acceleration are assessed; and the volcanism hazard study covers only lava flows. The yearly likelihood of occurrence assumed is approximately 0.2 %, a ceiling traditionally specified in a number of Spanish rules and regulations on risks (3).

- **Limitations to the study of the exposed elements**: only direct tangible property damage is considered, and only in monetary terms.
- **Limitations concerning vulnerability**: vulnerability to flooding and seismicity depends on hazard at each site; in contrast, volcanic vulnerability is assumed to be maximum throughout.

4. Hazard

Certain features of the study of this first parameter are common to floods, earthquakes and volcanoes, while others are exclusive to each. The three shared pillars are: the application of mathematical models and numerical information, historic information, and geological information. Moreover, all these models and data are integrated into a single geographic information system (GIS).

The flooded area was determined using historical and geological data in addition to a numerical rainfall/runoff model and a model for determining the extent of flooding. The seismic hazard study of tectonic earthquakes (4) used a mathematical model to accommodate attenuation determined by distance and site parameters such as the types of materials involved and land relief. The volcanic hazard study took lava flow properties into consideration, along with the volume of earlier flows, applying a model that assesses the path and extent of future lava flows.

The seismic study conducted was associated with an occurrence in a specific area: a seismogenic geological structure, i.e., a structure able to generate earthquakes whose effects are propagated across the entire archipelago. As no other structure able to generate sizeable quakes has been identified, the seismic scenario is unique. In flooding and volcanism, however, the study of the area potentially affected involves deploying a model for randomising where rain may fall or a lava vent may open up. While in earthquakes only one possible event (a unique scenario) with a 0.2 % yearly chance of occurrence is identified, in flooding and volcanism the number of possible scenarios with the same likelihood is, if not infinite, very large and indeterminate because the events modelled, rainfall and lava emission, may take place anywhere on the map. In this study, several scenarios of the same likelihood were assessed with a view to ascertaining maximum loss.

Severity was another feature dealt with differently in each type of hazard. While in volcanism it was delimited by the path of the lava flow (spatial magnitude), in flooding, in addition to the potentially flood prone area, the depth at each point was factored into the model. For seismicity, severity was determined in terms of the ground acceleration across the archipelago, in turn converted into an intensity estimator (5).

The three methods integrated into the flood hazard study are described below (Figure 2).

- The **hydrological-hydraulic method** assesses rainfall and its transformation into runoff and flooded areas, which calls for entering the triggering event (intense rainfall) and information on other site-related variables. Since the immediate cause is intense rainfall, a scenario simulator built into the model characterises the mean potential scope of the event in terms of the number of basins affected.

- The **historic method draws** from the CCS loss history database to integrate historic information as an additional source of data on flood prone areas.
- The **geological method** supplements the findings of the two preceding methods with geomorphological information, identifying floodplains and improving results.

In addition to these three methods, data readily available from other sources (MAGRAMA, Spanish ministry of agriculture, food and the environment) were also entered.

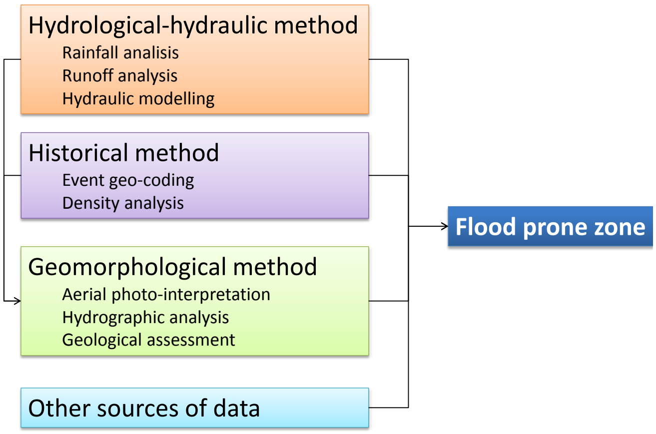

Figure 2. Method for delimiting flood prone areas

The hydrological-hydraulic method is diagrammed in Figure 3. Figure 4 shows two examples of how geomorphology can include and correct the information on flood prone areas where the algorithms used are unable to deliver a solution, while Figure 5 illustrates the method for studying past events.

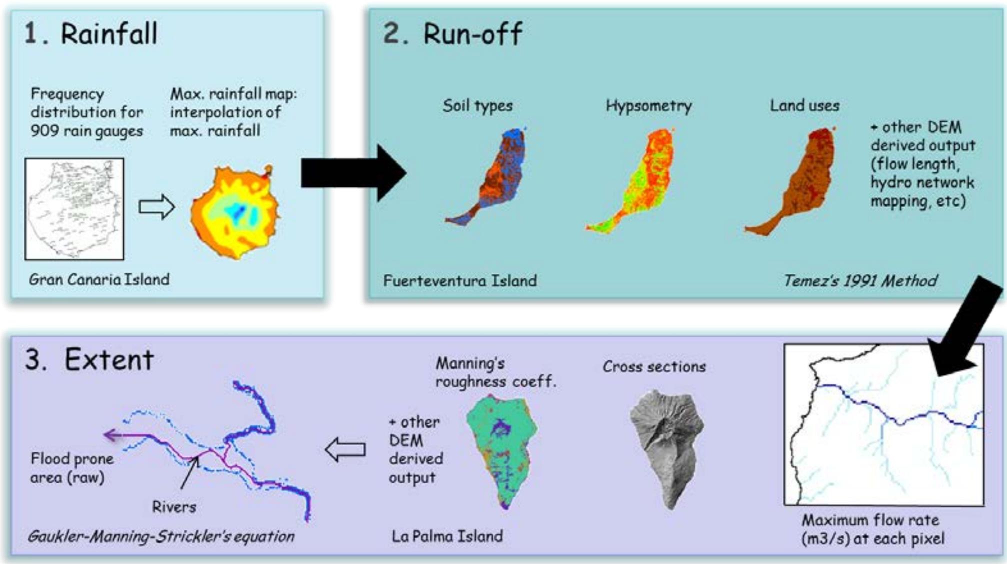

Figure 3. Application of the hydrological-hydraulic method

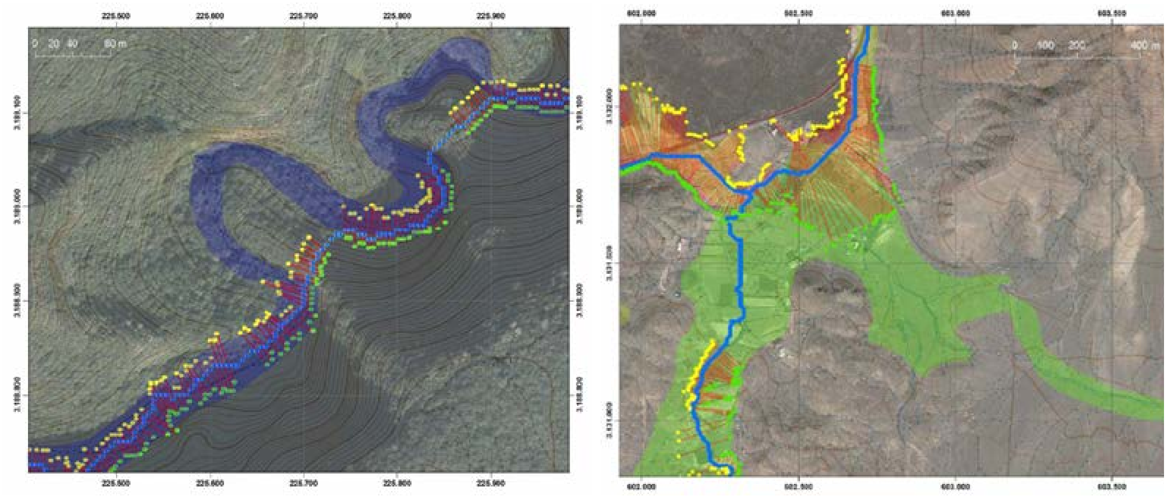

Figure 4. Example of geomorphological plots supplementing and improving on hydraulic

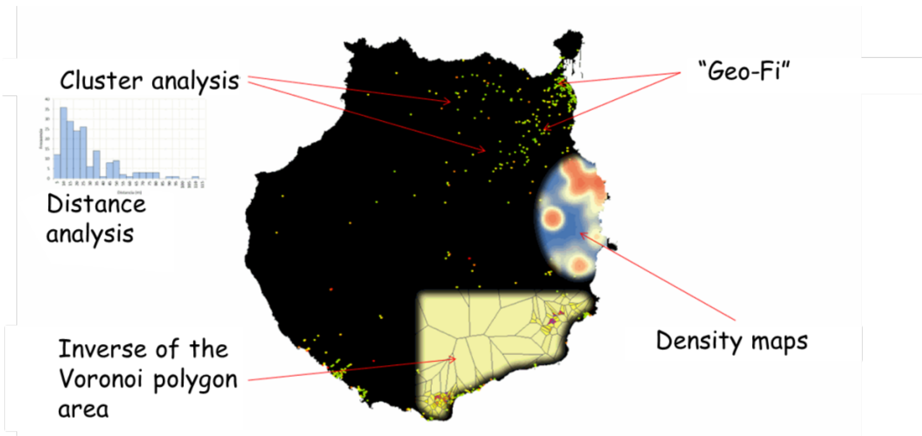

Figure 5. Historic process, begun by geo-coding events with different degrees of uncertainty, and studying inter-event relationships with cluster and distance analysis methods

The seismicity study comprised a regional analysis of the seismogenic areas and their seismic potential, followed by application of a model for calculating attenuation with distance, which yielded the distribution of the seismic acceleration that would be reached with the likelihood established. This distance analysis was supplemented with a model for taking other attenuation characteristics into consideration, such as site conditions, soil type and hypsometric gradient values as a measure of land relief.

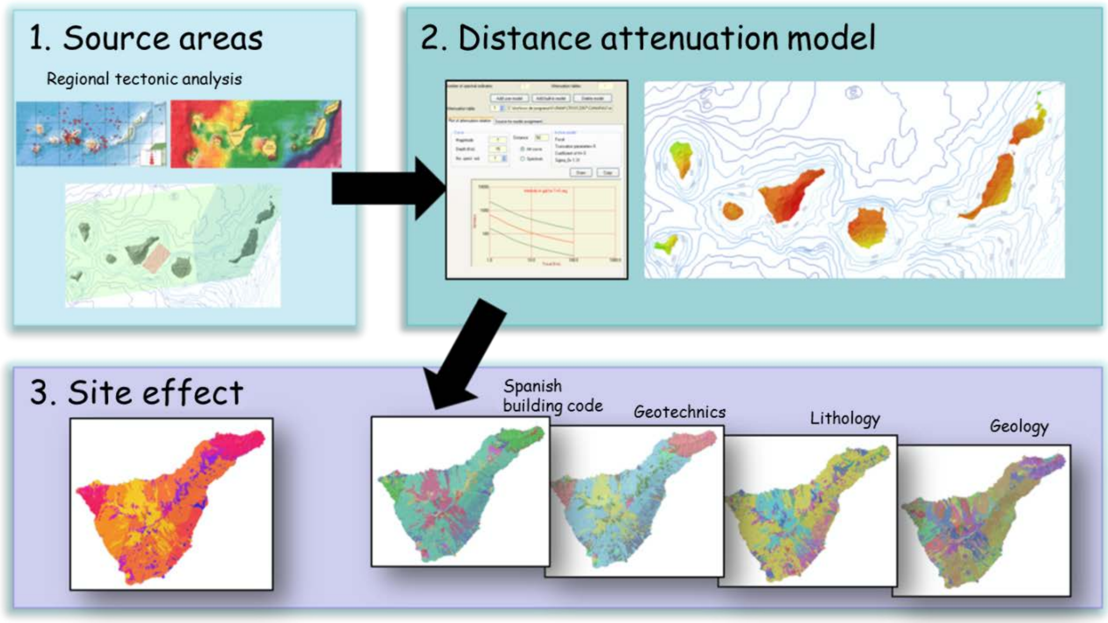

Figure 6. Methodological approach to studying peak ground acceleration

The IGME's VOLCANTEN project database was used for the volcanism study, which consisted of a probabilistic assessment of effusion vents. Randomly triggered lava flow scenarios were modelled with event simulation software. The methodology is depicted in Figure 7.

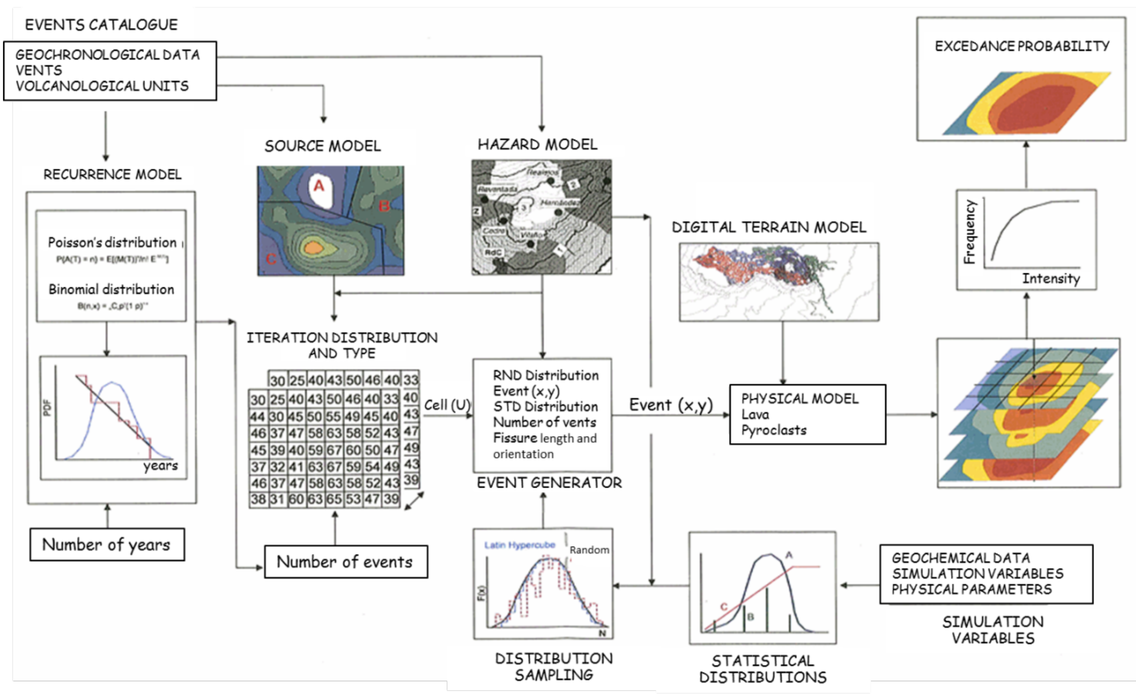

Figure 7. Method for determining lava flow scenarios

5. Exposure

Cadastre databases were used to study exposure. These databases include real estate appraisals divided into land value and building value. For flooding, seismicity and volcanism, the assumed insurable value was the value of the buildings (using a conversion factor to find the reconstruction value in the event of seismicity and flooding), plus a percentage to cover the value of the contents. While only the value of buildings was appraised for the seismic analysis, although including all the buildings on the archipelago (disregarding content losses), in the volcanism study both buildings and content located in the path of the lava flow were appraised for each scenario. In flooding, total exposure included the value of the movables in the ground and below grade storeys in buildings in the flooded area, and the buildings themselves only where a certain flood crest threshold was crossed (Table 1).

Table 1. Exposed elements included in the study

Case study	Exposure	
	Buildings	**Contents (movables)**
Flooding	Only ground and below grade storeys	Only movables in the ground and below grade storeys
Seismicity	Entire building	None
Volcanism	Entire building	All

Cadastre database cleansing operations for GIS analysis included the elimination or correction, as appropriate, of topological errors such as overlaps (plots sharing the same space), duplications (perhaps the result of past revisions), open polygons, polygons with negligible areas or none at all, and gaps. Another question that had to be addressed was the discrepancy between alpha-numerical and graphic records, more than likely the outcome of separate updating of the graphic and alpha-numerical divisions of the database. Once the databases had been cleansed, the total value of all the buildings on each cadastral plot was found to reduce the number of elements to be studied and ensure the confidentiality of the information processed.

6. Vulnerability

Cadastral plot vulnerability to lava flows was assumed to be 100 %; in other words, the damage to any plot affected by a lava flow would be equal to the value of the buildings standing on it and their contents. That assumption was an acknowledgement that infrastructures are not designed to bear either substantial horizontal loads or the temperatures reached by natural incandescent materials and that once the lava solidifies, the infrastructure is irrecoverable.

For seismicity, the reference adopted was the 1998 European Macroseismic Scale (EMS98), which grades expected earthquake damage by the theoretical intensity calculated. First the buildings were classified into one of the construction types set out in the EMS98 and, based on the intensity calculated for each building's centroid, a percentage of expected damage was deduced from the EMS98.

A similar criterion was applied for flooding. Content losses were calculated on the grounds of the expected flood depth in each plot and known damage thresholds, while the value of buildings was only included for elevations at which structural damage could be expected.

7. Flood Risk

Canary Island flood prone zones are normally narrow strips because the archipelago's non-permanent and torrential hydrology(6) and steep slopes have formed deep riverbeds and narrow valleys. The essentially flat areas on the coast, however, or where valleys have widened, may give rise to larger flood zones with shallower depths and lower flow rates than in medium and high reaches.

The findings showed that ground and below grade storeys account for nearly 65 % of the total value, while the value of all the scenarios considered amounts to less than 30 % of the total. In other words, over 70 % of the total value of all the property in the archipelago lies outside the flood prone areas defined in the model. However, the model developed showed that not all the zones where the chance of yearly occurrence is 0.2 % can be flooded at the same time. Scenarios were consequently defined to foresee losses in ways consistent with a 0.2 % yearly likelihood. The least favourable of all the scenarios thus constructed were chosen and divided into two groups, depending on whether a single basin or a group of basins would be affected, as summarised below.

a) The worst-case scenarios for each island and one basin only are listed in the following table:

Island	No. plots	Risk (mill.€)
El Hierro (EH)	240	2.35
Fuerteventura (FV)	320	262.02
Gran Canaria (GC)	636	235.17
Lanzarote (LZ)	2 500	73.86
La Gomera (GO)	539	21.03
La Palma (LP)	1 096	23.45
Tenerife (TF)	19 098	596.25

b) Where the area of influence covered by the event was forecast to affect one or more basins, the results, relative to the size of the island and the mean area affected by the events simulated, were as follows:

	10km of radio(1)		7% of the area(2)		10% of the area(2)		20% of the area(2)	
Island	**N.P.**	**Ri (mill.€)**	**N.P.**	**Ri (mill.€)**	**N.P.**	**Ri (mill.€)**	**N.P.**	**Ri (mill.€)**
EH	995	5,09	240	2,35	339	3,20	540	4,07
FV	1.049	291,48	578	290,62	792	291,09	901	291,22
GC	3.306	258,19	636	235,17	776	241,43	2.129	256,32
GO	1.579	28,29	539	21,03	584	21,30	596	21,32
LP	3.730	73,90	1.006	35,86	1.194	36,35	1.566	39,98
LZ	7.181	171,66	4.081	118,25	4.336	142,51	6.209	157,06
TF	28.202	666,09	23.163	643,84	24.798	685,62	29.577	716,02

N.P. is the number of cadastral plots affected.
Ri is the risk calculated.
(1) This value was obtained by selecting the basins intersecting an area of influence with a 10-km radius from the centroid of the island basin with the highest cumulative risk.
(2) The area, which is approximate, is the sum of the areas of the adjacent basins on the same slope as the basin with the highest cumulative risk.

8. Seismic risk

Only direct effects, i.e., damage to buildings as the result of ground vibration, were taken into consideration when estimating seismic risk. The most vulnerable categories (where damage would be most severe, grades A and B on the EMS98 scale) were found to be less abundant than the least vulnerable (grades C and D). For that reason, most of the potential loss was identified in groups C and D, while the value of the loss in grades A and B was under 20 %. The geographic distribution of all the losses, i.e., summing the values for the four types of construction studied, is mapped in Figure 8. As the map shows, the variable with the heaviest weight in seismicity studies is population distribution, for the most severe damage was located in the largest towns and cities. Moreover, the islands farthest away from the epicentre defined in the study (sited between Tenerife and Gran Canaria Islands) happen to be the ones with the smallest populations. The total value of insured loss in the event of an earthquake was calculated to come to 353.37 million euros.

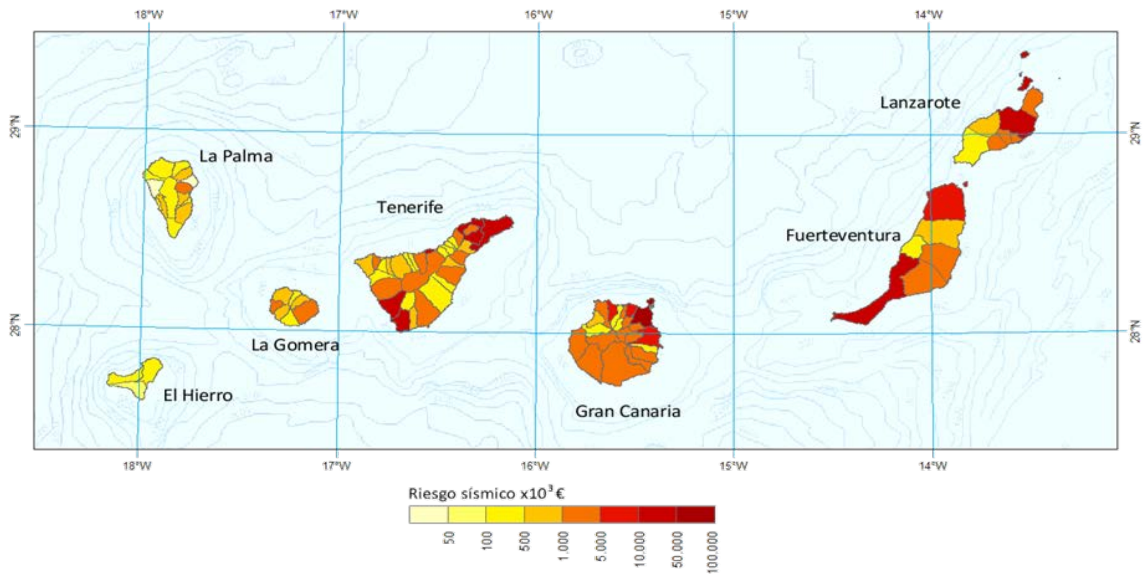

Figure 8. Distribution of seismic risk by town/city

9. Volcanic risk

One particularity that sets volcanic hazard off from flood and earthquake hazards is that by changing the volume of lava, one and the same vent can give rise to different scenarios. More than that, if lava viscosity is altered, the same vent with the same volume of lava may also give rise to different scenarios. And to complicate matters further, any given area may be affected by more than one scenario generated by different vents. Moreover, building volcanic scenarios involves such large volumes of data and such high costs that, at this writing, scenarios are only available for the island of Tenerife. The results of the present study were consequently confined to the possible implications of an eruption on that island. Be it nonetheless said that of the seven islands, six are volcanically active (only La Gomera is regarded as inactive). Furthermore, only the parts of the volcanoes above the ocean's surface were studied, for no data are available for the submarine portion of the volcanic edifices, which is by far the largest. The volcanic structures that form the Canary Islands rise from four to nearly eight thousand metres from the ocean floor, although little more than the tip emerges.

Twelve of the fourteen scenarios selected to assess their possible consequences were found to exhibit significant risk, as shown in the table below.

Scenario	Nº Plots	Part insured (€10)
c526_20	12.052	5.504,43
c525_19	11.215	3.612,02
c520_17	7.501	1.253,92
c555_25	4.896	784,52
c829_1	838	522,58
c394_1	1.330	505,39
c395_3	665	406,84
c262_4	1.467	321,06
c930_3	294	189,63
c295_4b	769	82,58
c484_2	50	4,22
c494_2	2	0,04

The two scenarios found to cause the greatest damage were C525-19 and C526-20 (Figures 9 and 10). While both would affect Puerto de la Cruz, they differed in the location of the lava vents, which conditioned the area covered and the path of the lava flow.

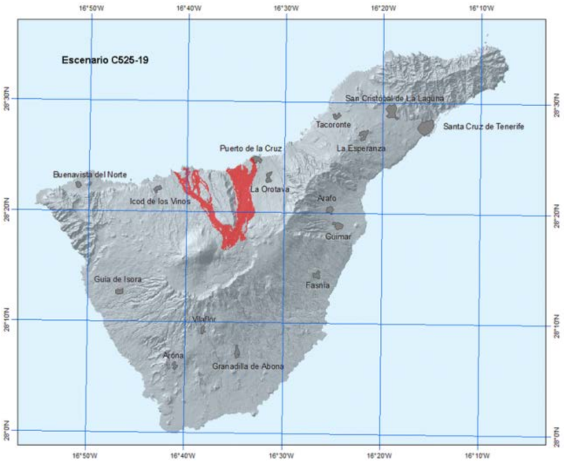

Figure 9. Scenario C525-19, with the second most damaging lava flow

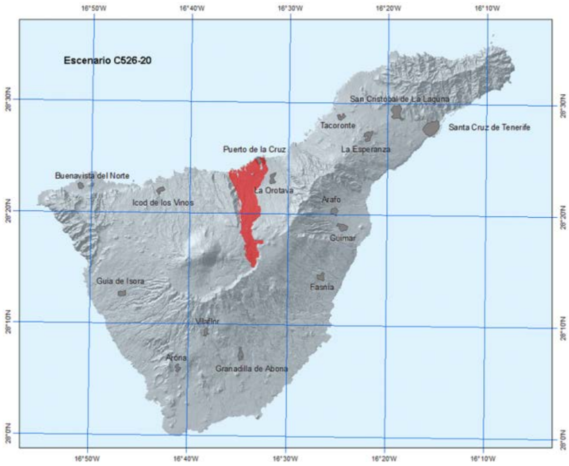

Figure 10. Scenario C526-20, with the most damaging lava flow

Conclusions

While the present study was limited by a lack of data of sufficient quality, it constitutes an initial store of useful information from which the CCS can estimate the resources that need to be provisioned. Moreover, the model developed is applicable to any other area of the country, inasmuch as it draws from readily available sources of information and because the methods applied are widely known and used.

The cadastre database is as relevant a source of information for risk studies as digital elevation models, for it yields uniform and impartial estimates. Moreover, it can be used to calculate key risk component parameters.

The flood and earthquake risk assessments performed in this study should be understood to be central or mid-range figures, given the aforementioned limitations.

The lack of data and the difficulty of interpreting the information available are the most prominent features of the calculations performed to determine volcanic hazard, which are consequently even more uncertain than in flodding and earthquakes. In any event, they should be viewed as minimum values, for volcanic episodes may induce other processes whose hazard is not assessed hereunder.

NOTES

(1) *GeoMEP, a method developed under the namesake project, is designed to assess geological hazard-induced loss. The pilot can be used to study risks in other regions of Spain.*

(2) *The so-called "desk effect" consists of the peak damage detected when floodwater reaches a depth equivalent to the height of desks, tables or countertops holding household appliances and goods.*

(3) *The standard way of expressing the likelihood of a natural event is its average occurrence over a number of years, known as the return period. An event that occurs on average once every 100 years has a 100-year return period, tantamount to a 1 % yearly or a 0.01 absolute likelihood. In Spain, events with 500-year return periods or greater, i.e., with absolute likelihoods of 0.002 or yearly likelihoods of 0.2 % or under, are regarded as extraordinary, although that does not preclude the consecutive occurrence of several such events.*

(4) *Seismicity is the propagation of an elastic wave across materials which, when it reaches the surface, may be perceived as ground vibration. It may be natural (as in earthquakes) or artificial (as generated by a heavy vehicle travelling at some speed). Natural causes include volcanic eruptions, meteorite impacts, ground motion and tectonic stress.*

(5) *Intensity was calculated from peak ground acceleration and expressed as per the 1998 European Macroseismic Scale. Ground acceleration is one way to assess the effect of earthquakes. Others include quake duration and wave amplitude and frequency.*

(6) *The Canary archipelago has no rivers that carry water year-round. The beds are dry most of the time, bearing water and sediments only during intense rainfall.*