A new Volcanic managEment Risk Database desIgn (VERDI): Application to El Hierro Island (Canary Islands)

S. Bartolini *, L. Becerril, J. Martí

* Corresponding author. Tel.: +34 934095410.
E-mail address: sbartolini@ictja.csic.es (S. Bartolini).

Abstract

One of the most important issues in modern volcanology is the assessment of volcanic risk, which will depend – among other factors – on both the quantity and quality of the available data and an optimum storage mechanism. This will require the design of purpose-built databases that take into account data format and availability and afford easy data storage and sharing, and will provide for a more complete risk assessment that combines different analyses but avoids any duplication of information. Data contained in any such database should facilitate spatial and temporal analysis that will (1) produce probabilistic hazard models for future vent opening, (2) simulate volcanic hazards and (3) assess their socio-economic impact. We describe the design of a new spatial database structure, VERDI (Volcanic managEment Risk Database desIgn), which allows different types of data, including geological, volcanological, meteorological, monitoring and socio-economic information, to be manipulated, organized and managed. The root of the question is to ensure that VERDI will serve as a tool for connecting different kinds of data sources, GIS platforms and modeling applications. We present an overview of the database design, its components and the attributes that play an important role in the database model. The potential of the VERDI structure and the possibilities it offers in regard to data organization are here shown through its application on El Hierro (Canary Islands). The VERDI database will provide scientists and decision makers with a useful tool that will assist to conduct volcanic risk assessment and management.

© 2014 Elsevier B.V. All rights reserved.

1. Introduction

Volcanic risk assessment and management are complex issues due largely to the nature, variety and availability of the data they handle (De la Cruz-Reyna, 1996). The quality of the data will determine the evaluation of the volcanic risk, which is an essential part of risk-based decision making in land-use planning and emergency management. The first step in the evaluation of volcanic risk consists of obtaining and organizing all pertinent data derived from disciplines such as geology, volcanology, geochemistry, petrology and seismology, as well as vulnerability and socio-economic information relating to the elements that are potentially at risk. Some of the most relevant issues include how and where to store the data, in which format should it be made available, and how to facilitate its use and exchange. Thus, it is essential to design an appropriate database that is specifically adapted to the task of evaluating and managing volcanic risk.

The design of an appropriate database for risk assessment and management should aim to organize all the available and necessary information on volcanic risk assessment in a standardized way that is easy to consult and exchange.

As in any other field, the first step in designing a database for volcanic risk assessment and management is the definition of its architecture. This must allow for effective interaction between the different information fields and offer users a clear vision of its internal organization and rapid access to its contents. Nevertheless, it will be the quantity and quality of the information contained in the database that will determine the reliability and validity of the final risk analysis. Subsequent steps will consist of the creation, maintenance and updating of all data related to volcanic risk. It is important to ensure that the database will be able to evolve freely from a simple to a more complex structure and be updated when new data are available.

To facilitate its operability and the visualization of the data the database must be integrated into a GIS (Geographic Information System). A GIS is an organized integration of software, hardware and geographic data designed to capture, store, manipulate, analyze and represent georeferenced information (Longley et al., 2005). In recent years, the use of GIS and the improvement of the modeling of volcanic processes have become useful tools in volcanic hazard and risk assessment. In fact, susceptibility, hazard, vulnerability and risk maps have been generated using GIS tools (Pareschi et al., 2000; Felpeto et al., 2007; Barreca et al., 2013) and can be represented in a GIS environment as a support for spatial decision making (Cova, 1999).

Furthermore, thematic volcanic risk maps can facilitate land-use planning and appropriate actions required during emergencies. In fact,
hazard and risk maps are key tools in emergency management: the former depicts the hazard at any particular location, while the latter shows the spatial variation of both hazard and vulnerability (Lirer et al., 2001).

To date, the databases used in volcanology have been created to store and analyze different types of information and have been employed to analyze, for example, (1) the impacts of volcanic phenomena on people (Witham, 2005); (2) potentially active volcanoes situated in regions of high geodynamic unrest (Gogu et al., 2006); (3) collapse calderas (Geyer and Martí, 2008); (4) volcano monitoring data that include instrumentally and visually recorded changes in seismicity, ground deformation, gas emission and other parameters (WOVoDat (Venezky and Newhall, 2007)); (5) global volcanic unrest (Phillipson et al., 2013); and (6) active faults on Mt. Etna (Barreca et al., 2013). In particular, efforts have been made to construct a Global Volcanic Risk database of large magnitude explosive volcanic eruptions (LaMEVE (Crossweller et al., 2012)). However, none of the existing databases is based on a simple architecture that contains all the necessary information for volcanic risk analysis and management.

Here we present Volcanic management Risk Database design (VERDI), the architecture for a geodatabase for volcanic risk assessment and management. The rationale behind constructing this database is the need to create a comprehensive structure including all known or identified fields that might contribute to the assessment of volcanic risk. The database also aims to make the task of volcanic risk management easier for decision makers. Currently, relevant data are stored in a variety of different formats and are not always easily accessible. Thus, this new way of compiling extensive data aims to provide an accessible and useful structure that will facilitate information sharing and risk assessment. This new database has been designed to work in a GIS environment.

The ultimate aim of VERDI is to create a platform for expanding, updating and sharing information that is open to the incorporation of new data. In the future, a website could be set up to make it a truly user-friendly application.

In this paper, we also present an example of the applicability of VERDI, taking as example the island of El Hierro (Canary Islands, Spain). We show how all the available data necessary for conducting a preliminary risk assessment can be integrated and discuss the limitations of existing data and the inherent advantages in storing data in the proposed form.

2. VERDI architecture

A simplified version of the VERDI database design structure is shown in Fig. 1. The full version of the VERDI structure and the user manual will be published online on the website of the CSIC Barcelona Volcanology Group (http://www.GVB-csic.es/).

The design of the database has taken into account the type of data required and possible inter-relationships in order to avoid duplication. The first steps in the creation of the database model were the collection of metadata, the analysis of the required features and the calculation of the expected output responses. This phase included the creation of information groups and the definition of the table fields and the relationships between tables.

In order to optimize the accurate evaluation of volcanic risk, VERDI contains 13 information groups regarding past and current volcanic activity and the associated hazards and the potential vulnerability of the elements that may be affected by such hazards. The information included in each group is recorded in individual tables. Additionally, VERDI includes spatial features that can be visualized with a GIS application. The rationale behind the VERDI architecture is based on the principle that all the information concerning the evaluation of volcanic risk should be comparable, consistent and available for future comparisons and data analyses.

In the following subsections we offer a brief description of each information group and the type of data included therein.

2.1. GroupCore

GroupCore is the central group of VERDI and represents the metadata information of all the actions that could be incorporated into the database as new data. This group governs the recorded information added to each group of the database, thereby controlling the insertion of new data.

The tables contained in this group are ACTION, ACTION_TYPE, PROJECT, REPORT and SUPPORT (see Fig. 1 in Supplementary material 1): ACTION and ACTION_TYPE correspond to actions and the type of actions, respectively, that generate new data (volcanic event, fieldwork, bibliography, etc.); PROJECT is a reference to a project undertaken by an institution such as a ministry or an institute; the REPORT table describes the action and includes information about the project related to the action; and SUPPORT adds information about the entity that is managing or funding the project.

2.2. GroupVolcano

This group contains information about the volcano or the studied volcanic area and includes data on the volcanic event itself, the characteristics of the type of volcanism and the magnitude of the event (Fig. 2).

The table VOLCANO provides general information about the location of the volcano and volcanic area, which will normally be associated with spatial information included in a shapefile of polygons or in raster images. Spatial features contain a folder with additional information such as Digital Elevation Models (DEMs), hillshades and orthophotos.

VOLCANO_TYPE completes the information about the volcano and identifies different types and features of volcanoes (stratovolcano, shield volcano, extinct volcano, etc.). ERUPTIVE_EVENT provides information about eruptive events including date and location and enables the volcano stratigraphy of the volcano and the study area to be obtained.

ACTIVITY_TYPE characterizes the eruptive behavior of the volcano thus: Hawaiian, Strombolian, Vulcanian, Pelée/Plinian, Plinian, Ultra-plinian and/or Caldera. The size and magnitude of the eruption are contained in the VEL_MAGNITUDE table, which includes parameters such as volume, column height, fragmentation index, dispersion index, Dense-Rock Equivalent (DRE), magnitude (Pyle, 2000) and the Volcanic Explosivity Index (VEI) according to Newhall and Self’s (1982) classification.

2.3. GroupSusceptibility

Volcanic susceptibility (i.e. the probability of vent opening) represents an important step in simulating eruptive scenarios and developing hazard maps (Martí and Felpeto, 2010). Thus, GroupSusceptibility contains information on all structural elements such as vents, dykes, faults, fractures and eruptive fissure-alignments obtained from both geological and geophysical studies. The location of gas emissions or water springs, as well as thermal anomalies related to the volcanic activity, are also included in this group. All of these elements enable susceptibility maps in long-term analyses to be generated. During volcanic unrest episodes, real-time monitoring information – in particular regarding the location of the volcano-tectonic seismicity and surface deformation – can be added to permit the susceptibility to be re-evaluated. This group also contains a GEOPHYSICS subgroup with information on structural geophysics that includes data derived from structural studies using different geophysical techniques such as self-potential, tomography, magnetometry, magnetotelluric and gravimetry. This type of geophysical data is useful in susceptibility analyses and in both short- and long-term hazard evaluations. In addition, it is useful for studying dispersed volcanic fields and their relation to local tectonics (Barde-Cabusson et al., 2014) and can thus facilitate a complete analysis of the probability of future activity in monogenetic
fields and improve understanding of the internal structure of composite volcanoes (Rout et al., 1993; Blakely et al., 1997; Connor et al., 2000; Kiyosugi et al., 2010).

Moreover, in both short- and long-term hazard assessments the monitoring and interpretation of geophysical parameters such as temporal gravity changes, seismicity and ground deformation can benefit from integration with structural geophysical data. Fig. 3 shows the organization of this group.

2.4. GroupHazard

GroupHazard contains basic data for computing volcanic hazards to be employed in simulation models that take susceptibility information into account. This group constitutes the information on which territorial and emergency plans should be based and has been divided into LONG-TERM and SHORT-TERM subgroups (see Fig. 4).
The tables of the LONG-TERM hazard subgroup contain mainly data regarding the products generated during the past activity of the volcano. The information required comes mainly from geological and historical records and laboratory analyses. This subgroup includes the following information split into different tables: magma and volcanic products (lava flows, pyroclastic deposits, etc.); petrological and geochemical data from volcanic rock samples; grain-size classification of pyroclasts based on sieved samples; and morphometry.

The SHORT-TERM hazard subgroup tables contain monitoring data collected during an unrest episode. These data are useful for short-term hazard assessment in which also the monitoring data are taken into account. The information is usually organized in terms of volcanic monitoring networks (seismicity, deformation, gas, thermal, groundwater, remote sensing images, etc.).

2.5. GroupMeteorology

GroupMeteorology includes the information required for the analysis of wind profiles, atmospheric parameters and precipitation data (see Fig. 2 in Supplementary material 1). These parameters are very important...
as inputs for ashfall simulations. Other important parameters included in this group are related to the atmospheric diffusion coefficient, the eruption style and the grain-size classification. Ashfall simulations are very useful in volcanic risk assessment and consider the impact of volcanic ash not only on the population and infrastructures but also on aircraft safety (Johnson et al., 2012).
2.6. GroupLaboratory

GroupLaboratory contains information supplementing the GroupSusceptibility and GroupHazard groups that relates to the laboratories in which sample analyses are conducted. This group specifies the kind of samples used, the analytical tests applied and the results obtained (see Fig. 3 in Supplementary material 1). This group is important for controlling the quality of data used to characterize the expected type of eruption (e.g. lava composition) by means of the analysis of past products.

2.7. GroupDevice

GroupDevice provides information about the measurement devices in tables such as PETROLOGY, SELF_POTENTIAL, MONITORING, and WIND. A large amount of information in the database is obtained through the use of instruments such as seismographs and microscopes and the DEVICE table (see Fig. 4 in Supplementary material 1) contains the names, models, types and functions of these devices.

2.8. GroupVulnerability

This group includes all the elements that could be affected by a destructive volcanic event. Vulnerability is the potential of exposed elements to be directly or indirectly damaged by a given hazard (Scaini et al., 2014). There are many types of vulnerability – physical, infrastructural, social and economic – and in combination they constitute the vulnerability of the system (Menoni et al., 2011). Physical vulnerability due to volcanic activity has been widely observed and studied, in particular in recent decades (Blong and McKee, 1995; Annen and Wagner, 2003; Spence, 2004; Baxter et al., 2005; Spence et al., 2005; Gomes et al., 2006; Martí et al., 2008; Zuccaro et al., 2008; Scaini et al., 2014).

Thus, the VERDI database includes administrative divisions, infrastructure networks (TRANSPORT, ELECTRICITY, and WATER_SYSTEM tables), as well as a socio-economic table that includes POPULATION information, FACILITY, BUILDING and LANDUSE (Fig. 5). A LAND_USE classification is included because correct land-use planning is fundamental in minimizing both loss of life and damage to property (Pareschi et al., 2000). The information contained in this part of the database is very important in the organization of evacuation plans, the reduction of potential losses caused by the impact of volcanic and associated hazards, the design of land-planning measures, and the evaluation of potential economic losses.

2.9. GroupCosts

GroupCosts (see Fig. 5 in Supplementary material 1) represents the huge economic losses (human life, infrastructure, property, productivity, etc.) that volcanic activity can cause. Estimating the economic costs associated with volcanic eruptions is very difficult due to their duration and the variety of the types of impacts (Annen and Wagner, 2003). However, the quantitative estimation of economic losses is of primary importance when providing mitigation recommendations aimed at reducing damage (Spence et al., 2005).

The ECONOMIC_LOSSES and VOLCANO_IMPACT tables refer to the economic and human losses evaluated after a volcanic crisis and the economic impact for a specific volcanic event. The third table, SCENARIO_IMPACT, represents a support table that allows a cost evaluation to be added when a volcanic hazard scenario is computed and enables the human losses expected during a volcanic crisis to be calculated.
2.10. GroupManagement

GroupManagement (see Fig. 6 in Supplementary material 1) is a useful group for decision makers and risk managers that should include ideally all types of emergency services (police, fire department, Red Cross, NGOs, etc.), although in most cases Civil Protection bodies will take responsibility during a volcanic crisis. Volcanic crises require continuous close collaboration between Civil Protection bodies and scientists in order to best analyze observational and monitoring data, to evaluate short-term hazards, to draw up plans for optimizing existing monitoring networks, to install new instruments and to provide advice in decision making (Bertolaso et al., 2009).

2.11. GroupReferences

GroupReferences contains contact information for key people and institutions, as well as bibliographic references (see Fig. 7 in Supplementary material 1) related to the data contained in the database. This group is important for obtaining the reference for any input into the VERDI database and thus enables the origin of the data to be known; in this way, if necessary, the person or team in question can be contacted if there is any explanation needed for the data introduced.

2.12. GroupModels

GroupModels contains examples of hazard-modeling tools. It includes the most relevant available software and a summary of both the required main input parameters and the output formats.

In recent years, new tools have been developed for generating hazard and risk maps, evaluating long- and short-term hazards, simulating different eruptive scenarios and designing evacuation plans. Examples of these tools include QVAST (Bartolini et al., 2013), VORIS (Felpe et al., 2007), a model for lava flow simulation (Connor et al., 2012), HASSET (Sobradelo et al., 2014), BET_EF (Marzocchi et al., 2008), BET_VH (Marzocchi et al., 2010), HAZMAP (Bonadonna et al., 2002; Macedonio et al., 2005), FALL3D (Costa et al., 2006; Folch et al., 2009), TEPHRA2 (Connor et al., 2001), PUFFIN (Patra et al., 2013), VOLCFLOW (Kelfoun and Druitt, 2005), TITAN2D (Sheridan et al., 2005) and EJECT (Mastin, 2001).

Simplified schematic tables are given in the Supplementary material 2 with the main input parameters required for the above-listed tools.

2.13. GroupResults

This group contains all the results and outputs derived from different simulations and analyses obtained using the database information. This group should facilitate the exchange of information that will be useful for future comparisons, analysis of data, and evaluation of volcanic risk.

3. VERDI usefulness: case study of El Hierro

One of the main obstacles when attempting to develop a robust database is the lack of quality, well-gathered data. This issue can be made simpler and easier in part by selecting small areas in which to test the operability database. With this aim in mind, a pilot project to check the feasibility of VERDI was set up with information available from the island of El Hierro (Canary Island, Spain).

The second step involves the collection of volcano-structural data via fieldwork measurements and bathymetric information, as well as the analysis of geological maps, orthophotos and aerial photographs, and remote sensing tools (Becerril et al., 2013). Once the whole volcano-structural elements have been assembled, they can be geo-referenced on the DEM. These data represent the starting point to geo-referenced on the DEM. These data represent the starting point to evaluate the susceptibility and to simulate different eruptive scenarios to go forward in the reduction of the risk.

In fact, the susceptibility map, i.e. the spatial distribution of new vent openings, is based on the analysis of the aforementioned volcano-structural data. One of the tools that facilitates this type of analysis is QVAST (Bartolini et al., 2013) (the main input parameters required are specified in the Supplementary material 2). All necessary data for conducting the susceptibility analysis is contained in GroupSusceptibility. In our example, we need to collect as much data as possible to improve the accuracy of the spatial probability of a new vent opening. In the case of El Hierro, data referring to past vent locations, dykes, eruptive fissures and faults are used. For example, to compile information related to
vents, we refer to the table VENT (Fig. 3) in the *GroupSusceptibility* that contains information about all known emission centers on the island. This table contains the information about the name of the volcano edifice, its coordinates (X, Y, Z), and additional description details. Also, the geometry of the elements is defined and permits to visualize the vents as point features and use them in QVAST to obtain the smoothing parameter value, that is, the most important parameter in the kernel density estimation to determine the shape of the probability density function (see Bartolini et al., 2013). This procedure needs to be also carried out with the other volcano-structural elements and the final susceptibility map is computed assuming a non-homogeneous Poisson process. All the PDFs for each volcano-structural data are combined in a weighted sum and the result is the final susceptibility map. The map obtained for the onshore distribution of future volcanic eruptions of El Hierro Island is shown in Fig. 7a. The total susceptibility map is available in Becerril et al. (2013). The result is a GeoTIFF raster file (map) in which each pixel has a value that represents the probability that it will host a new emission center.

Once the susceptibility map has been drawn up, eruptive scenarios for hazard assessment can be computed. In Becerril et al. (2014), different eruptive scenarios such as lava flows, ashfall and pyroclastic density currents (PDCs) were considered and enabled a qualitative volcanic hazard map to be generated. Here, we show (Fig. 8) a lava flow simulation probability map using VORIS tool (Felpeto et al., 2007) that requires different types of input parameters that can be found in VERDI, related to the past eruptive activity (see Supplementary material 2).
probabilistic lava flow model applied is based on the assumption that topology and flow thickness play major roles in determining lava paths (Felpeto et al., 2007 and references therein). Input parameters required by the model include a Digital Elevation Model (DEM), maximum flow lengths and thickness of the flow. In the case of our example, simulation was run over a DEM with a cell size of 50 m. We assumed flow lengths of 15 km and 3 m of thickness, corresponding to the average value of individual flows measured in the field according to Becerril et al. (2014).

All the information obtained during fieldwork, which also comes from the bibliography or from the devices, is vital in determining these parameters. The simulations were run for all cells in the DEM and the sum of the 5000 iterations provided a map with the probability for any particular cell of being covered by a lava flow (Fig. 8).

Once the distribution of the eruptive scenarios has been developed, Civil Protection is then able to evaluate the most likely eruptive scenarios for the island and their impact on the population and other exposed features. For this, relevant data on elements such as population and transport networks must be obtained for analysis. For example, population data for El Hierro can be downloaded from the website of the Instituto Nacional de Estadística (INE, http://www.ine.es/). Data on transport networks can be obtained from the IGN website and OpenStreetMap (http://downloads.cloudmade.com/), the latter a tool used by public administrations, NGOs and even Civil Protection bodies to manage in the aftermath of disasters such as the Haiti earthquake. The acquisition of this information allows evacuation routes and even a preliminary evaluation of general losses due to volcanic hazards such as lava flows to be calculated.

### 3.2. Preparation phase

Entry into the preparation or unrest phase means that the volcanic system has reawakened. During this phase, monitoring data plays an important role and is essential as a support for decision making and, a short-term hazard assessment becomes necessary. For this reason, VERDI database contains monitoring information distributed in different groups and tables. GroupHazard contains precursor data such as deformation, seismic activity and groundwater monitoring for short-term hazard assessment; the MONITORING table summarizes all the monitoring networks within a volcanic area. Furthermore, in this phase the communication, alert, and evacuation play an important role in the disaster management.

The 2011–2012 eruption on El Hierro was preceded by three months of unrest. From July 2011 onwards a dense multi-parametric monitoring network including seismic and magnetic stations and GPS recorders were deployed throughout the island by the Instituto Geográfico Nacional (IGN). Data recorded during this unrest episode contributed to the understanding of the reawakening of the volcanic activity on the island. In general, this monitoring network assisted authorities in emergency...
management (López et al., 2012) and prepared them for the eruption that finally started on 10 October 2011, 2 km off the southern coast.

During an unrest phase, the updating of the possible eruptive scenarios computed during the emergency planning is necessary, mainly because the arrival of new data such as seismic information can change previous susceptibility analysis and, consequently, eruption forecasts. This may involve a change in the direction taken by the crisis management. For better understanding how the real-time monitoring interact with the VERDI database and with the different GIS tools, we give an example using the seismic information obtained during the 2011 unrest in El Hierro Island, and the QVAST tool to evaluate the volcanic susceptibility. During the unrest phase, starting on July 2011, seven new seismic stations were installed in different parts of the island and data was transmitted on real time to the IGN National Seismic Network, where earthquake locations and local magnitudes were calculated (López et al., 2012; Domínguez Cerdeña et al., 2014). The information about the seismic activity can be downloaded from the website of the Instituto Geográfico Nacional (IGN, http://www.ign.es/ign/layoutIn/sismoFormularioCatalogo.do).

During the unrest phase, the volcanic susceptibility can change considerably depending on the variation of the seismic activity. Therefore, if we consider from the first moments of the seismic unrest, we can see how this information conditions changes in the susceptibility map. For simplicity, we consider the beginning of the unrest on 19 July which was accompanied by an important increase in seismicity, mostly located on the north of the island. Seismic activity alternated relatively calm periods with high energy periods and most of the earthquakes were located in the El Golfo area (Fig. 9) at 10–15 km depth (see López et al., 2012 for further details).

Firstly, the information of the seismic activity needs to be stored in the SEISMICITY table located in the GroupHazard in the SHORT-TERM hazard subgroup (Fig. 4), containing monitoring data. In this case, the SEISMICITY table needs to be linked to the IGN database to obtain data in real-time. Once we have obtained this information, we need to visualize the information of the seismic activity in our GIS as point shapefiles and add this information in the QVAST tool to update the susceptibility map. In Fig. 9 it is shown how the seismic information is added to the Quantum GIS software (http://www.qgis.org) and the corresponding structure of the SEISMICITY table. The new susceptibility map elaborated through QVAST tool is shown in Fig. 7b. We can see how the susceptibility map changes compared to the previous one (Fig. 7a), adding a probability of new vent opening also in the north of the island. This determines that the product extent of the eruptive scenario simulations will change and, consequently, this should be taken into account to determine new emergency evacuation plans.

During an unrest phase economic losses may be estimated by using information derived from spatial and temporal analysis. It is imperative that data regarding possible costs, along with an a priori analysis of

![Lava Flow Probability Map](http://www.ign.es/ign/layoutIn/sismoFormularioCatalogo.do)
losses, are stored right from the beginning of the process (Baxter et al., 2005). In VERDI, we have added a support table (Table 1) for cost evaluation when a hazard volcanic scenario is computed. In fact, eruption models are able to provide, for an assumed eruption scenario, a detailed map of the possible geographical distribution of the eruption products, with point by point estimates of the key parameters. Where these parameters are known, it becomes possible to develop estimates of the eruption impact on buildings and infrastructure, and also on their occupants (Spence et al., 2009).

At the end of this phase, subsequently to whether or not the volcanic event has occurred, there are two phases in the disaster management cycle: the response and the recovery. During these phases, it is fundamental to upload all the data obtained to the database (see GroupResult) in order to facilitate future risk evaluations.

4. Conclusions and final remarks

VERDI is a new design for a database for risk assessment. Its logical structure has been conceived in order to facilitate the interaction between data sets and to guarantee the maintenance and evolution of the system. It is essential that the database structure permits the exchange of standardized information and the updating of data in order to prevent redundancy and repetitiveness. The VERDI database design aims to make scientific research easier and to promote information-sharing for volcanic surveillance, susceptibility, hazard and vulnerability. Its structure is linked to a spatial database in a GIS environment, which is used to create susceptibility, hazard, vulnerability, and risk maps.

VERDI has been conceived to be used as a source for modeling software packages such as QVAST (Bartolini et al., 2013), HASSET (Sobradelo et al., 2014) and VORIS (Felpeito et al., 2007). New geological hazard models related to volcanic systems such as landslides, lahars and tsunamis could be included in order to complete geo-risk databases. VERDI also helps to identify the basic information required to conduct hazard and risk assessment. We thus suggest that all the information included in VERDI should be available for each volcanic area. We also believe that it is important that information is stored in the same structure and format.

A future role for VERDI will be the publication of an interactive website that will enable registered users to access and share the information in the database, thereby allowing VERDI to become more dynamic and to continue developing. However, we cannot ignore the inherent limitations of available data and the effect that this may have on the interpretation of the compiled information. It is therefore vital to acknowledge that both data and interpretations are dynamic, that is, they have to be subject to continuous revision and updating. For this reason, VERDI needs to be freely available to all scientists interested in volcanic risk assessment since only contributions from all will allow VERDI growing and evolving into the useful tool we envisage.

Table 1
GroupCosts: SCENARIO_IMPACT table.

<table>
<thead>
<tr>
<th>Table</th>
<th>Field</th>
<th>Info</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCENARIO_IMPACT</td>
<td>scenarioImpact_id</td>
<td>Primary key</td>
<td>AutoNumber</td>
</tr>
<tr>
<td></td>
<td>scenarioImpact_type</td>
<td>Type of scenario simulation (lava, pdc, ashfall, …)</td>
<td>Text</td>
</tr>
<tr>
<td></td>
<td>scenarioImpact_pop</td>
<td>Population affected by eruptive scenario</td>
<td>Integer</td>
</tr>
<tr>
<td></td>
<td>scenarioImpact_facility</td>
<td>Facility affected by eruptive scenario</td>
<td>Integer</td>
</tr>
<tr>
<td></td>
<td>scenarioImpact_building</td>
<td>Building affected by eruptive scenario</td>
<td>Integer</td>
</tr>
<tr>
<td></td>
<td>scenarioImpact_landUse</td>
<td>Land use affected by eruptive scenario</td>
<td>Integer</td>
</tr>
<tr>
<td></td>
<td>scenarioImpact_transport</td>
<td>Transport affected by eruptive scenario</td>
<td>Integer</td>
</tr>
<tr>
<td></td>
<td>scenarioImpact_electricity</td>
<td>Electricity network affected by eruptive scenario</td>
<td>Integer</td>
</tr>
<tr>
<td></td>
<td>scenarioImpact_waterSystem</td>
<td>Water system affected by eruptive scenario</td>
<td>Integer</td>
</tr>
<tr>
<td></td>
<td>population_cd</td>
<td>Foreign key POPULATION table</td>
<td>Integer</td>
</tr>
<tr>
<td></td>
<td>volcano_cd</td>
<td>Foreign key VOLCANO table</td>
<td>Integer</td>
</tr>
</tbody>
</table>
Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.jvolgeores.2014.10.009.