Application of GIS in Mapping Lava Flows

1.0 Introduction
The constant growth of the human population and the migration of these people into hazardous areas has given rise to an apparent increase in natural disasters. Effective mitigation is required to reduce the loss of life and damage to infrastructure. Geographic Information Systems (GIS) have been extensively used in natural hazard mitigation (e.g., Pareschi et al., 2000; Lirer et al., 2001; Temesgen et al., 2001) and have proven a functional tool in risk management in general. Further confirmation of the value of GIS in managing risk has come with the application of this technology to specific areas of geological phenomena. For example, Bisson et al. (2002) used GIS in the assessment of debris flow hazards, and Cubellis et al. (2004) used GIS to manage historical seismic data from southern Italy.

The slow moving nature of most lava flows allows for mitigation, including barrier erection, flow diversion, the use of explosives in changing the feeder system and/or flow path, and the chilling the flow front using water (Wadge et al., 1994). Information regarding the likely flow path and the rate of advancement is required for short term planning. Longer term mitigation requires information on the probability of a site being overrun by lava and forms the basis for studies by Kauahikaua et al. (1995) and Wadge et al. (1994). In these case examples there is a strong application of GIS in mapping lava flows.

2.0 Case examples
Kauahikaua et al. (1995) used digital geologic maps of Mauna Loa, Hawaii, combined with vector based GIS, to assess the probability that lava flows would overrun certain vicinities more than others. This probability can be assessed using an estimate of the reoccurrence interval of flows in a specific area. Lava flows within a certain distance of a feature (i.e., well (point), road (line) or region (polygon)) can be selected and data such as, age, morphology, chemistry or mineralogy can be tabulated. Risk maps can be produced based on this data.
Wadge et al. (1994) explored computer simulation techniques to assess lava flow hazards at Lonquimay volcano, Chile, and Mt Etna, Sicily. The advance of lava flows was predicted using a deterministic method, and the prospect of flow inundation was determined using a probability method (multivariate statistical analysis). The Mt Etna hazard map produced shows the main areas at risk are to the east, south and west of the summit (Fig. 1).

Gomez-Fernandez (2000) employed GIS algorithms to identify areas protected from lava flows invasion on Tenerife Island. The algorithm uses spatial analysis functions called “neighborhood operators” to evaluate the characteristics of an area surrounding a specific location. The output is the maximum extent to which lava might reach based on simple behavioral rules. The maps generated are not useful in identifying areas which could be affected by lava flows, but rather, areas not affected by lava flows.

3.0 GIS data layers
Effective risk mitigation using GIS requires specific spatial information (used as data layers) in order to generate reliable, reproducible answers to spatial queries. Spatial information can be in vector or raster form. GIS data layers required for mitigation include, but are not limited to; digital elevation models (DEM), satellite imagery, existing hazard maps (both paper and digital forms), vector data on natural and artificial features (e.g., roads, railways, streams, ponds), and existing geology maps (both paper and digital forms).

4.0 Conclusions
The application of GIS to specific sectors of geology has proven a useful tool in hazard mitigation. A GIS can efficiently store and analyze large amounts of geo-referenced data. The combination of existing maps and probability modeling facilitates the production of precise hazard and risk maps, plans for mitigation to minimize risk, and evacuation plans.

5.0 References

Figure. 1 The probability map for lava flow inundation at Mt Etna. The numbers of times an area has been covered by lava is represented by the colors (red to yellow, 1-10). The black areas had been inundated more than 10 times. From Wadge et al. (1994).


Pareschi et al. (2000) highlights the use of Geographic Information Systems (GIS) (linked with remote sensing) in the decision making process when mitigating for volcanic hazards. The paper covers two contrasting styles of volcanism (i.e., effusive volcanism produced by Mt. Etna and explosive volcanism from Mt. Vesuvius) in Italy and the developed areas which may be affected by them.

At Mt. Etna GIS has been used to map lava flows, record the time-scales of flows and identify areas of viable modification that are in the paths of flows.

Explosive volcanism from Mt. Vesuvius has the potential to affect hundreds of thousands of people in the surrounding area. GIS has been used to map the deposits of historic pyroclastic flows, surges, ash-falls and lahars. Using this historic information, hazard maps could be generated identifying areas most likely to suffer from these phenomena. The maps and thematic layers necessary for a GIS-based management include digital elevation maps (DEMs), existing hazard maps, satellite images, and raster and vector data on natural and artificial features.


Lirer & Vitelli (1998) have used GIS to assess the risk to people and property from lava flows in the Vesuvian area. The authors used an existing lava flow hazard map from Vesuvius and created a land use map covering the same area. Demographic and urban data from the area were collected and entered into a GIS database. The lava flow map was overlain on the land use map and they delineated risk maps by land use (e.g., agricultural, forest, and natural land areas). A building density risk map was created for the more highly populated areas. Five risk classes were then derived by comparison to the hazard maps and which communities were in the highest hazard zones, and which undeveloped regions in the higher hazard zones should be shielded from over-development by strategic land use planning in the future were identified.


The Soule et al. (2004) paper identified lava flows at mid-ocean ridges (MORs) using high-resolution bathymetry, sonar backscatter maps and seafloor images contained within a GIS database. The GIS was used to create detailed maps of flows with similar features to subaerial lava channels, which can be distinguished by their low back scatter intensities. Using numerical and physical models of submarine lava flows, the authors constrained the velocity and shear rates across flow channels. From this they can infer flow rates and ultimately magma supply rates at MORs.

Kauahikaua *et al.* (1995) used GIS combined with digital geological maps to assess lava flow probability on Mauna Loa volcano, Hawaii. To do this, detailed information on the spatial and chronological distribution of lava flows was required, and ARC/INFO was used to digitize preexisting geologic maps. Each individual lava flow was assigned a flow ID, morphology code, and an age category. All lava flows within a certain distance (buffer) of any point, line, or region of interest can be selected and details of the flow can be assessed. Each lava flow is represented by multiple polygons and can be combined with other layers such as geology, topography, roads and infrastructure.

The authors used two parameters: A) probability of lava flow occurrence, the probability that one lava flow will enter the target region within a target time period; and B) probability of coverage, the probability that a particular point will be covered by one or more lava flows within the target time period. I have to question the use of “one or more” lava flows in parameter B on the rationale that one lava flow is all you need to destroy infrastructure and possibly the size of the lava flow is more important than the number of flows.


A GIS algorithm was used by Gomez-Fernandez (2000) to analyze potential lava flow extent on Tenerife Island. The spatial analysis functions known as “neighborhood operators” were used in the algorithm. The interesting part about this article is the author identified areas which are potentially safe from lava flows instead of identifying areas at highest risk. Three main tasks were used to complete the task: A) development of an appropriate algorithm; B) identification of potential source areas where future effusive eruptions could occur; and C) the application of the algorithm to identify areas safe from lava invasion. The GIS databases used included DEMs and the source maps. Essentially Gomez-Fernandez was mapping potential lava flows (in the background of his algorithm) to identify areas safe from lava invasion. The algorithm is strongly dependent on the resolution of the DEM data used.

This paper covers the application of Answer Set Programming (ASP) (e.g., Lava Motion and Lava Motion Linear Front) to the question “Can a lava flow cross the designated evacuation path under some circumstances (which we have no control on)?” The goals were for the results to be of use to emergency planners and geologists in order to improve evacuation plans for possible affected areas. Historical data sets and previously published lava flow models for Mt. Etna, Italy were used in the analysis. Each of the ASPs used introduced different variables for possible flow behavior during an eruption. Preliminary results indicate that the models and data sets are comparable to those in the published literature. Eventually, evacuation plans will be compiled for Mt. Etna and compared to ones already developed by the emergency management officials in this area. One of the final goals is to compare model generated evacuation plans with existing ones.