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4 **Volcanic hazard vulnerability on São Miguel Island, Azores**  
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6 Wallenstein, Nicolau

7 Centro de Vulcanologia e Avaliação de Riscos Geológicos, Universidade dos Açores, Rua Mãe de  
8 Deus, 9501-801, Ponta Delgada, Portugal. E-mail: Nicolau.MB.Wallenstein@azores.gov.pt  
9

10  
11 \*Chester, David

12 School of Environmental Sciences (Geography), University of Liverpool, Liverpool, L69 3BX, U.K.  
13 E-mail: jg54@liv.ac.uk  
14

15 Coutinho, Rui

16 Centro de Vulcanologia e Avaliação de Riscos Geológicos, Universidade dos Açores, Rua Mãe de  
17 Deus, 9501-801, Ponta Delgada, Portugal. E-mail: Rui.MS.Coutinho@azores.gov.pt  
18

19 Duncan, Angus

20 Research Institute for Applied Natural Sciences, University of Bedfordshire, Park Square, Luton,  
21 LU1 3JU. E-mail: Angus.Duncan@beds.ac.uk  
22

23 Dibben, Christopher

24 School of Geography and Geosciences, University of St. Andrews, Fife, KY16 9AL, UK: E-mail:  
25 cjld@st-andrews.ac.uk  
26

27  
28 \*Corresponding author (e-mail: [jg54@liv.ac.uk](mailto:jg54@liv.ac.uk))  
29

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35 **Abbreviated title:** Hazard vulnerability  
36

37 **Abstract**  
38

39 In recent years much progress has been made in researching a wide variety of extreme events on  
40 São Miguel. In addition there are a number of volcano-related risks which impact upon the people  
41 of São Miguel. Some of these may occur both before and during volcanic emergencies (e.g.  
42 earthquakes), whilst others render São Miguel dangerous even when its volcanoes are not erupting  
43 (e.g. flooding, landslides, tsunamis and health impacts, especially the effects of CO<sub>2</sub> seepage into  
44 dwellings). In this chapter we first define what vulnerability means to the people of São Miguel, and

45 relate this to the cultural and economic characteristics of the island. The following  
46 aspects of vulnerability are discussed: a. physical (i.e. housing, settlement and the characteristics of  
47 evacuation routes and plans); b. demographic and economic;  
48 c. social and cultural and perceptual (i.e. do people have an accurate cognition of risk). Particular  
49 areas of concern relate to housing; the identification of isolated dwellings which would be difficult to  
50 evacuate; the vulnerability/resilience of evacuation routes following recent infrastructure  
51 improvements; characteristics of the island's transient population; management of livestock under  
52 emergency conditions; local leadership roles and educational outreach.

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56 Volcanic hazard may be defined as the probabilities of occurrence of eruptions and volcano-  
57 related phenomena. Risk is the interaction between the probability of an extreme physical event  
58 and its impact on a vulnerable human population (Susman et al. 1983, p. 264, see also Bankoff  
59 2001, p. 24-27; Wisner *et al.* 2004, p. 3-16). In recent years considerable progress has been made  
60 in researching a wide variety of extreme events on São Miguel. Particular attention has been paid  
61 to reconstructing past eruptions, drawing up future eruption scenarios and assessing the probable  
62 effects of such eruptions on people living on the island. These are discussed on other chapter in  
63 this volume (Ferreira *et al.* 2014; Gaspar *et al.* 2014 - Eruptive frequency and volcanic hazard  
64 zonation; Gaspar *et al.* - Earthquakes and volcanic eruptions in the Azores region; Queiroz *et al.*  
65 2014; Wallenstein et al. 2014). Future eruption scenarios for the three active central volcanoes of  
66 São Miguel (i.e. Sete Cidades, Fogo and Furnas - Fig. 1) are summarised in Table 1 and, in  
67 addition to the direct effects of future volcanic eruptions, there are a number of volcano-related risks  
68 which impact upon the people of São Miguel. Some of these, such as earthquakes generated by  
69 magma movement (Silveira *et al.* 2003; Wallenstein *et al.* 2005, 2007; Gomes *et al.* 2006), may

70 occur both before and during volcanic emergencies, whilst others render São Miguel  
71 dangerous even when its volcanoes are not erupting (Malheiro 2006; Wallenstein *et al.* 2007). Such  
72 phenomena have been studied by a number of authors and include:  
73 a. climatic and geomorphological hazards, particularly flooding and landslides, triggered by both  
74 rainfall and seismic activity (Louvat & Alleger 1998; Chester *et al.* 1999; Duncan *et al.* 1999;  
75 Valadão *et al.* 2002; Gomes *et al.* 2005; Marques *et al.* 2005, 2006, 2007, 2008; Wallenstein *et al.*  
76 2005, 2007);  
77 b. the exposure of coastal areas to tsunamis generated by either near or distant earthquakes and/or  
78 collapses into the Atlantic ocean from its many islands (Andrade *et al.* 2006); and  
79 c. the health impacts on the population, especially the effects of CO<sub>2</sub> seepage into dwellings (Baxter  
80 *et al.* 1999, 2005; Hansell *et al.* 2006; Viveiros *et al.* 2009, 2010).  
81 CO<sub>2</sub> acts as a carrier for radon and Baxter (2005, p. 280-282) argues that smokers are particularly  
82 at risk of developing lung cancer.

83 Human vulnerability has also been studied and research has concentrated not only on  
84 detailing the threats faced by the population of São Miguel, but also on how people would cope in  
85 the event of a future eruption or volcano-related emergency. *Vulnerability*, or the susceptibility to  
86 damage, is defined as "the characteristics of a person or group ..... that influence their capacity to  
87 anticipate, cope with, resist and recover from the impact of a natural hazard... . It involves a  
88 combination of factors that determine the degree to which someone's life, livelihood, property and  
89 other assets are put at risk" (Wisner *et al.* 2004 p.11). Whereas hazard assessment focuses on the  
90 physical processes that produce extreme and potentially damaging occurrences, *vulnerability*  
91 analysis concerns the ways in which these - often in combination with pre-existing social and  
92 economic circumstances - produce unsafe conditions for groups within a population. Traditionally  
93 hazard analysis has stressed the physical processes that produce disasters, but more recently a  
94 number of authors have emphasised that hazards may act as 'triggers' that bring to the surface

95 more deep-seated economic, political and cultural issues that are already present within a  
96 society (Hewitt 1997; Pelling 2001), a disaster being viewed as a "highlighter or amplifier of daily  
97 hardship and everyday emergencies rather than as an extreme and rare phenonema" (Gaillard &  
98 Texier 2008, p. 347). In order to reduce disaster susceptibility and increase what is termed,  
99 *resilience* or *capacity*, these deep-rooted causes of vulnerability have also to be addressed (Degg &  
100 Homan 2005; Gaillard 2007).

101 Over the past decades several scholars have devised typologies, whereby the  
102 characteristics that produce human vulnerability in different societies may be classified (e.g.  
103 Alexander 1997; Zaman, 1999; Degg and Homan, 2005). We propose a similar scheme that is  
104 tailored to the situation in the Azores and which we will use to study human vulnerability on São  
105 Miguel (Table 2).

## 106 **Physical vulnerability**

107 On São Miguel physical vulnerability is expressed in its housing stock; the distribution of its  
108 population and settlement and the characteristics of its evacuation plans.  
109

### 110 **Housing**

111 The housing stock of São Miguel is highly vulnerable to losses in the event of seismic  
112 events and tephra-fall. During historic times the island has been affected by ten major earthquakes  
113 (1522, 1638, 1713, 1810, 1811, 1848, 1852, 1932, 1935 and 1952), together with several episodes  
114 of seismic swarms associated with volcanic activity. In a study of the *freguesias* (i.e. parishes)  
115 within the *concelho* (i.e. county or municipality) of Ponta Delgada, that lie either on the flanks of  
116 Sete Cidades volcano or within its caldera (Fig. 2), Gomes *et al.* (2006) have classified housing  
117 according to its vulnerability using a scheme developed in connection with the European  
118 Macroseismic Scale 1998 (Grünthal 1998). In this classification the buildings most at risk from  
119 earthquakes (Classes A and B) are constructed from *rubble-stone* and *simple-stone*. *Rubble-stone*

120 is defined as traditional construction "in which undressed stones are used as the basic  
121 building material, usually with poor quality mortar, leading to buildings which are heavy and  
122 have little resistance to lateral stress. Floors are typically of wood, and provide no horizontal  
123 stiffening. *Simple-stone* differs from *rubble-stone* construction "in that the building stones have  
124 undergone some dressing prior to use. These hewn stones are arranged in the construction of  
125 the building according to some techniques to improve the strength of the structure, e.g. using  
126 larger stones to tie in the walls at the corners. In the normal case, such buildings are treated as  
127 vulnerability class B, and only as class A when in poor condition or put together with particularly  
128 poor workmanship" (Grünthall 1998, p. 34-5).

129  
130 Before the 1970s most dwellings were up to two storeys in height and of *rubble-stone*  
131 construction, though some have subsequently been improved by the addition of reinforced slabs  
132 and columns. From the 1970s buildings have usually been constructed using reinforced concrete  
133 frames and/or un-reinforced concrete blocks. Official data show that in Povoação and Lagoa  
134 *concelhos*, 41% of houses were built before 1971 and ca.40% in Ponta Delgada *concelho* (INEP  
135 2002, p.18). In their field area Gomes *et al.* (2006) concluded that some 76% and 17% of houses  
136 belonged, respectively, to vulnerability Classes A and B. On Faial some 508 rubble-stone buildings  
137 were damaged and 273 destroyed in the two-day volcano-tectonic swarm in May 1958 which was  
138 associated with the Capelinhos volcanic eruption (Coutinho *et al.* 2008, 2010), while on July 9 1998  
139 an earthquake, with an epicentre located off the coast of the island and having a Mercalli  
140 Magnitude of 5-6, killed 8 people, injured 150, rendered 1,500 people homeless and damaged  
141 many buildings (Coutinho *et al.* 2008). Using the *European Macroseismic Scale (EMS)*, Gomes *et*  
142 *al.* (2006) demonstrate that the maximum historic intensity reached on Sete Cidades volcano on  
143 São Miguel was IX and that this took place during the seismic crisis associated with the offshore  
144 volcanic eruptions of 1713 and 1811. Traditional housing is so vulnerable that an earthquake with

145 an *EMS* intensity of IX would cause between 57% and 77% of dwellings in Sete Cidades area  
146 (Fig. 2) to be either destroyed or badly damaged, representing between 2,480 and 3,350 homes.

147 An estimated 80% of buildings on Furnas volcano are constructed from rubble-stone and, in  
148 a survey that also covered part of Fogo volcano, Pomonis *et al.* (1999) identified an additional  
149 feature of physical vulnerability. Even a small eruption would produce extensive tephra deposition  
150 and could affect towns and villages downwind of eruption sites especially if hydromagmatism  
151 featured in such an event (Table 1). Higher magnitude eruptions would cause more extensive  
152 damage. In the villages examined by Pomonis and his colleagues (i.e. Furnas, Ribeira Quente,  
153 Povoação and Ponta Garça - see Fig. 2), they found that ca.18% of buildings had roofs that were in  
154 poor condition and, hence, highly vulnerable to collapse. More recently important research has  
155 been published on strengthening traditional Portuguese buildings generally (Oliveira 2003; Murphy-  
156 Corella 2009, see also Spence 2007, page 187, Table 7) and Azorean housing in particular (Costa  
157 2002). Costa and Arede (2006) point out that resilience could be greatly improved by relatively  
158 simple measures including, *inter alia*: reinforcing walls and roofs by connecting structural  
159 elements together so as to improve rigidity; and ensuring that roofs are not only in good  
160 condition but also firmly connected to walls.

161

#### 162 Distribution of population and settlement

163 In 2001, the date of the most recently published census, the resident population of São  
164 Miguel was recorded as 131,530 (INEP 2002) and by early 2011 had risen to an estimated 134,000  
165 (INEP 2011b). The most recent census was held in March 2011. At the time of writing no results  
166 are available. The *Serviço Regional de Estatística dos Açores*, provide estimates of the population  
167 resident in each *concelho*, for various years since 2001, the latest data being for December 2008  
168 (SREA 2011).

169 About 9% of the population lives in the *Sete Cidades area*, 43% in the *Fogo area* and 19%

170 in the *Furnas area*, some 71% of the total (Fig. 2). The overall distribution shows two general  
171 characteristics:-  
172 i. The interior of São Miguel is mountainous and population is concentrated near to the coast, with  
173 Sete Cidades, Covoada, Arrifes, Fajã de Cima, Fajã de Baixo, Pico da Pedra (Ribeira Grande  
174 *concelho*), Cabouco, Santa Bárbara (Ribeira Grande *concelho*), Furnas and Nossa Senhora dos  
175 Remédios, being the only inland settlements of importance, though it should be noted that Covoada,  
176 , Fajã de Cima and Fajã de Baixo are suburbs of Ponta Delgada (Fig. 2).  
177 ii. A marked population focus around Ponta Delgada, the island's capital and principal settlement,  
178 which contains 15% of the island's inhabitants in the four *freguesias* which comprise the capital in  
179 official statistics, double this figure if adjacent commuter settlements are included and some 48% if  
180 the whole *concelho* is taken into account (INEP 2002; SREA 2008).

181 In one respect the overall distribution of settlement is highly fortuitous because much of the  
182 land in the three volcanic *areas* is rural and many *freguesias* show low population densities; figures  
183 of less than 100 people per km<sup>2</sup>, for example, are commonplace in the northeast and east of Furnas  
184 and Fogo *areas*. In the Sete Cidades *area* (Fig. 2) figures are only slightly higher and range from  
185 ca.72 to ca.171 people per km<sup>2</sup>. Although in many volcanic regions low population densities  
186 represent a major impediment to successful evacuation, since it is may be difficult to locate people,  
187 in the case of São Miguel this is not a serious problem because population is highly concentrated  
188 within the principal settlement (*povoação sede de freguesia*) of each parish. Study of detailed maps  
189 (1: 25,000 scale) and aerial photographs, together with information collected in the field, shows  
190 some isolated farms and houses that would require special attention in the event of a planned  
191 evacuation. Another issue concerns people who live in settlements with poor communications, a  
192 factor that is reviewed in section 2.3.

193 Eruptions on São Miguel are rare (Table 1), yet certain villages are at considerable risk of  
194 being damaged each year by volcano-related events. As a result of its volcanic character the island

195 has considerable relief amplitude and plentiful, often intense, rainfall has produced a high  
196 drainage density. Storms are particularly prevalent between September and April and in April 1996  
197 slope failure occurred on the inner slopes of Furnas caldera and a landslide reached the western  
198 margin of Furnas village. On October 31 1997 and following a long period of heavy rainfall, around  
199 1000 small landslides occurred in Povoação *concelho* and two of these were responsible for 29  
200 fatalities, 114 residents being left homeless mainly in the village of Ribeira Quente (Fig. 2 - Gaspar  
201 *et al.* 1997; Cole *et al.* 1999; Wallenstein *et al.* 2005; Marques *et al.* 2008). Ribeira Quente was cut  
202 off from the rest of the island for more than 12 hours and total economic losses were estimated at  
203 more than €20 million (Cunha 2003). Research in Povoação *concelho* by Marques *et al.* (2008, p.  
204 486), involved historical records of rainfall intensity (mm/day) being plotted against rainfall  
205 duration (D days) and showed that intensity increases exponentially as duration decreases,  
206 according to the regression equation  $I = 144.06 D^{-0.5551}$ . As Figure 3 shows, the regression curve  
207 may be used to define thresholds above which landslides may occur. Historical data indicate  
208 that landslides are related to both: short duration (1-3 days) precipitation events, with high mean  
209 intensities of 78 - 144 mm/day; and longer (1-5 month) rainfall episodes, with lower mean  
210 intensities of between 9 and 22 mm/days. On São Miguel rainfall regimes with these  
211 characteristics are common between October and March and landslides occur in São Miguel  
212 during most winters. Mean rainfall of 911 mm at Ponta Delgada is enhanced by topographic  
213 effects (Moreira 1987), rising to 1992 mm at Furnas (height 290 m), being characterised by both  
214 high inter-annual and inter-seasonal variations. In Povoação *concelho* some 85% of historic  
215 landslides have occurred between October and March and, between 1918 and 2002, some 40  
216 instances of landslides were recorded with only 1/4 being classified as 'minor' (Marques *et al.*  
217 2008, p. 484).

218 Landslides may also be triggered by seismic activity. For example more than 46,000  
219 earthquakes occurred in the Fogo area between May and December 2005, some 180 being felt



220 by residents in near to the epicentre. The strongest shocks occurred on September 20  
221 and 21 and had magnitudes ( $M_L$ ) 4.1 and 4.3, respectively, and caused extensive slope failure  
222 in the central part of the island. During this episode more than 250 landslides were triggered  
223 (Marques *et al.* 2007).

224

## 225 Evacuation plans

226 Most settlements on São Miguel are linked by roads located near to the coast (Fig. 4), but  
227 this does not apply either to the, albeit few, inland settlements or other villages that are linked to  
228 coastal routes by highly vulnerable subsidiary roads. Furnas and Sete Cidades villages are, for  
229 instance, located within active calderas and would require early evacuation if an eruption were  
230 threatened, whereas an isolated coastal settlement – such as Ribeira Quente (Fig. 2 and Table 3) -  
231 is particularly at risk. The road linking the village to the island's network utilizes the valley of the  
232 Ribeira Amarela, which drains Furnas crater lake before passing through Furnas village and  
233 reaching Ribeira Quente by means of a very steep-sided and narrow valley. Any flooding, produced  
234 by draining of the crater lake and/or temporary damming of the valley, would destroy the road,  
235 making early evacuation essential if major loss of life were to be avoided (Chester *et al.* 1995).  
236 Similar comments apply to the small village of Praia, located 1 km to the west of Água de Alto (Fig.  
237 2), where the draining of the Lagoa do Fogo through the south flowing Ribeira da Praia would  
238 produce similar widespread destruction.

239 In research carried out on Furnas volcano (Chester *et al.* 1995; 1999; Duncan *et al.* 1999),  
240 detailed studies were made of roads that could be used should an evacuation of the *area* be  
241 required, later this approach was extended to Fogo (Wallenstein 1999; Wallenstein *et al.* 2005,  
242 2007; Table 3 and Fig. 4) and these studies highlighted three further areas of human vulnerability  
243 many of which also apply to Sete Cidades.

244 First many roads that could be used as evacuation routes are highly exposed to landslides

245 and debris flows. At their most extreme these phenomena could destroy whole stretches of  
246 road, while less serious events would seriously restrict capacity. On Fogo there are particular  
247 problems with the northern and southern coast roads (EN1-1<sup>a</sup>) and at certain points on EN2-1<sup>a</sup>,  
248 which links Furnas village to the north coast (Fig. 4). A second feature of vulnerability concerns  
249 masonry bridges that are present on many roads, together with the occurrence of rubble-stone  
250 buildings in virtually every town, both of which are highly susceptible to earthquake damage. Such  
251 damage would block roads and seriously impede evacuation. A third issue is strategic. Fogo is  
252 located in the centre of São Miguel (Fig. 1) and both the northern and southern coastal routes  
253 would be cut by even a small eruption, a landslide, an episode of heavy rainfall or an earthquake,  
254 so isolating the population living in much of the *Fogo area* (in excess of 45,000 people), together  
255 with those to the east in the *concelhos* of Povoação and Nordeste (ca.10, 000 people). In order to  
256 avoid this eventuality, evacuation would have to begin before the main phase of eruption. As will be  
257 discussed later when social/cultural and perceptual/informational vulnerability are reviewed,  
258 persuading people to evacuate before there are any clear signs of eruption would be problematic.  
259 Similar problems may also be encountered in trying to encourage people to leave Sete Cidades  
260 and Furnas villages, because both settlements would be devastated by even small scale intra-  
261 caldera eruptions and roads linking these settlements to the main coastal roads could easily be  
262 damaged and rendered unusable. In the *Furnas* and *Sete Cidades areas*, any disruption of the  
263 northern and southern coastal roads would isolated many communities. On Sete Cidades, the  
264 *freguesias* of Bretanha, Mosteiros and Ginetes are particularly vulnerable and involve a possible ca.  
265 4000 people, whereas in the *Furnas area* and to its east affected *freguesias* could include Salga,  
266 Achadinha, Achada, Santana, Nordestinho, Lomba da Fazenda, Nordeste, Água Retorta, Faial da  
267 Terra, Nossa Senhora dos Remédios and Povoação and ca. 9, 600 people would be affected (Figs.  
268 2 and 4).

269 Announced in 2002 (Anon 2002), in 2007 work began on a new programme of high speed

270 roads on São Miguel (Fig. 4). Put Known by the acronym SCUTS (*Estradas sem custos*  
271 *para utilizador*, or roads without charge to the user), this programme involves private finance of  
272 325 million Euros and is be funded from general taxation over a 30 year period. The new roads  
273 were all fully open by the end of 2011. Although promoted primarily for reasons of economic  
274 development, especially of the eastern extremities of the island, the impacts on Civil Protection  
275 and evacuation planning in the *Fogo* and *Furnas areas* are likely to be both profound and in  
276 some respects uncertain. As Figure 4 shows, the new roads do not impact upon the *Sete*  
277 *Cidades area*.

278 The principal positive impact on the vulnerability of the *Fogo* and *Furnas areas* is that  
279 the towns of *Água de Pau*, *Água de Alto*, *Vila Franca do Campo*, are now bypassed as was  
280 *Ribeira Grande* a few years earlier. With regards to the latter, this has removed a major 'bottle  
281 neck' which could have inhibited evacuation, while the stream flowing through the town - the  
282 dangers of which are discussed in Table 3 - has been more effectively bridged. The *Ribeira*  
283 *Grande* to *São Brás* and the *São Brás* to *Lomba da Fazenda* roads on the north of the island,  
284 and the *Lagoa* to *Vila Franca do Campo* road in the south only opened towards the close of the  
285 construction period and it is only with time that major changes in the balance between  
286 vulnerability and resilience of communities in the event of an eruption and a planned evacuation  
287 will be able to be assessed. On the one hand the new roads are, not only of a higher standard  
288 and much faster - travel times from *Ribeira Grande* to *Nordeste* being cut by some 45 minutes -  
289 but they are also constructed further inland, at a greater height and, consequently bridge many  
290 rivers and streams in a far more satisfactory manner than was the case hitherto using existing  
291 roads (Fig. 5). Indeed severe flooding, landsliding and even laharic activity could be  
292 accommodated without severely damaging these new bridges. On the other hand the new  
293 roads, that from *São Brás* to *Nordeste* (Fig. 5), do not replace but rather supplement existing  
294 routes with their many vulnerable sites (Table 3). New features of vulnerability could be created

295 and may include:-

296 a. Poor weather, particularly fog, higher rainfall and strong winds at high altitudes particularly in  
297 winter.

298 b. The new routes are closer to the Furnas and Fogo calderas and during eruption could carry a  
299 higher ash loading than may be the case with existing roads.

300 c. The vulnerability of access points from the existing road system to the new roads is not clear.

301 In time a new road survey will be required and revised evacuation plans will have to be  
302 published.

303

#### 304 **Demographic and economic vulnerability**

305 Demographic vulnerability

306 Over the past fifty years the principal demographic characteristics of São Miguel have been  
307 out-migration to mainland Portugal and abroad, together with internal migration and commuting to  
308 the principal settlements of the island, particularly Ponta Delgada (Trindade 1976; Williams 1982;  
309 Silva 1988/9; Fortuna 1988; Rocha 1988/9, 1990). In recent years out-migration has been less  
310 significant and the island's population increased by ca.4% between 1991 and 2001 (INEP 2002)  
311 and ca. 2% between 2001 and 2011, showing an annual rate of natural increase of 0.33% in 2009  
312 compared to an average for the Azores of 0.24% (SREA 2007, 2010, 2011b). Long-term features  
313 of out-migration and an historic lack of full employment are still present within the island's  
314 demographic profile while internal migration and commuting continue apace. In recent years  
315 employment opportunities in the Azores have been better than in Portugal as a whole. Data for  
316 2009 show 9.5 % unemployment in Portugal and 6.7% in the islands (SREA 2010b). For the third  
317 quarter of 2011 figures were 12.4% for Portugal and 11.6% for the Azores (SREA 2010d). This  
318 means that in the late 1990s (Chester *et al.* 1999) *dependency ratios* (i.e. % of the population  
319 under 15, plus % over 65) across the *Furnas area* ranged from 38-46%, and the proportion of the

320 population classified as economically active was never greater than 36% in any *freguesia*. In  
321 addition many older people were illiterate and rates exceeding 15% of the population occurred in 11  
322 of the 15 *freguesias* that comprise the *Furnas area*. As mentioned in the introduction, the study of  
323 natural hazards often highlights deep-seated issues that normally lie dormant within a society. It  
324 was concluded by Chester *et al.* (1995) that, as a result of these long-standing demographic  
325 characteristics, a high proportion of the population would require assistance, especially in following  
326 instructions should an eruption-related emergency be declared. More recent data show that high  
327 dependency, low levels of economic activity and poor educational attainment remain features of the  
328 island's demography. For instance in 2001 *dependency ratios* for the *concelhos* that comprise São  
329 Miguel ranged from 33% in Ponta Delgada to 43% in Ribeira Grande, the economically active  
330 population varied from 36% in Povoação to 44% in Ponta Delgada, while illiteracy was still 16% in  
331 Vila Franca do Campo and 7% in Ponta Delgada (INEP 2002).

332 One feature of the population statistics for the Azores is that data at the most detailed level  
333 of sub-division (i.e. the *freguesia*) and which are so important in assessing demographic  
334 vulnerability are derived from the census, the latest figures available being from 2001. Figures from  
335 the 2011 census have not yet been published (SREA 2011b). Although the Regional Statistical  
336 Service (*Serviço Regional de Estatística dos Açores*) has a policy of updating some sets of data  
337 and estimating others between censuses (see SREA 2006b, 2007, 2010, 2011a, 2011b), statistics  
338 are only available for *concelhos* and in some cases for whole of São Miguel. Another feature of  
339 demographic vulnerability, which is not captured by official statistics, is the transient nature of much  
340 of São Miguel's population. A census can only give a snapshot of population on a specific date,  
341 traditionally in Portugal in March or April in the first year of the decade and, as field surveys have  
342 shown in rural areas especially, many houses are often only occupied at weekends and/or in  
343 summer. The number of people who would have to be evacuated on, say, a Saturday in August  
344 would be far greater than on a weekday in January. Tourist numbers also vary over the year and

345 recently the number arriving in São Miguel has shown a rapid increase. The numbers of nights  
346 spent on the island by tourists more than tripled between 1993 and 2003 and reached a figure of  
347 over 700,000 in 2010 of whom ca.40% were ordinarily resident of other areas of Portugal, with  
348 some 39% visiting in July, August and September (SREA 2005a, 2005b, 2007, 2010, 2011c). In  
349 2009 just over 5,200 people could be accommodated in hotels and other lodgings on any given  
350 night suggesting a total annual capacity of ca. nearly 2 million rooms, assuming each visitor only  
351 stayed one night. The average stay was, however, 3.5 nights and average occupancy only 37.5%,  
352 implying that there are many visitors to the island who are effectively 'lost' from the official record  
353 (SREA 2010a). From a hazards management perspective it is important to know:

- 354 a. where the excess population is accommodated; and  
355 b. how many visitors are true tourists and, conversely, how many are expatriates returning to family  
356 homes that are either vacant or under-occupied for most of the year.

357 If civil protection and evacuation planning are to be effective, then a detailed study of this transient  
358 population is required.

359

#### 360 Economic vulnerability

361 Some hazards, such as landslides, flooding and even low intensity seismic activity, will have  
362 economic impacts that are spatially limited to a small number of *freguesias*. It is widely recognised,  
363 however, that if any of the future eruption scenarios listed in Table 1 were to occur then the effects  
364 on the economy of São Miguel would be severe, necessitating the closure of many enterprises and  
365 a period of widespread unemployment. Outside assistance from the Portuguese government and/or  
366 the European Union would be required. There is one major change, nevertheless, that has  
367 occurred in the economy of São Miguel in recent decades which has produced an important new  
368 area of vulnerability.

369 In the late 1970s agriculture and fishing accounted for nearly 40% of total employment, but

370 by 2009 this had fallen to just under 13% (SREA 2010b). Over the past few decades the  
371 major economic changes have been declines in both subsistence agriculture and the production of  
372 export crops and a rapid increase in cattle rearing. In 1980 there were just over 36,000 cattle in the  
373 whole of São Miguel (Langworthy 1987), whereas in the 1999 agricultural census this figure had  
374 risen to over 108,000 around 45% of the total for the Azores (INEP 2001). Although cattle numbers  
375 have declined slightly in the Azores in recent years, assuming a similar proportion to 1999, this still  
376 implies that just over 110,000 cattle were reared on São Miguel in 2009 (SREA 2010b). All three  
377 volcanic *areas* have large numbers of cattle, mostly located above heights of 300 m in summer and  
378 at lower altitudes in winter, and with some *freguesias* providing a home for more cattle than people.  
379 Such large numbers of livestock have major implications for contingency planning. In a volcanic  
380 emergency, animals - both living and dead - could block many of the roads that would have to be  
381 used for evacuation, and this is an issue that needs to be addressed by Civil Defence planners.

382

### 383 **Social and cultural vulnerability**

384 In studies of hazard exposure on Furnas and Fogo volcanoes (Chester *et al.* 1995, 1999,  
385 2002; Wallenstein *et al.* 2005), aspects of social and cultural vulnerability are highlighted which  
386 apply with equal measure, not only to the Sete Cidades, but also more generally to São Miguel as a  
387 whole. Through processes of mobility, especially as a result of more comprehensive programmes of  
388 education that have been put in place since the 1974 revolution and inter-marriage, social  
389 stratification is not so prominent a feature of island life as it was a few decades ago, but is still  
390 recognisable. According to pioneer sociological research carried out in the 1980s by Francis Chapin  
391 (Chapin 1989), the people of São Miguel usually belong to one of five social groups (Table 4), but  
392 since Chapin carried out his research several changes have occurred and Table 4 has been up-  
393 dated to reflect more recent conditions.

394 As far as planning for a hazard-based emergency is concerned, two points emerge. First,

395 the social structure shown in Table 4 has important implications for the management of  
396 any emergency. Within rural villages *proprietários* and members of the *established educated*  
397 groups (especially government officials, local doctors and school teachers) already possess  
398 established leadership roles within their communities. It is upon these two groups, plus local political  
399 leaders who are also usually drawn from these cohorts, that civil defence planners would have to  
400 rely in the event of a volcano-related crisis. A second issue concerns the high concentrations of  
401 *trabalhadores* found within rural areas of which the three volcanic *areas* are typical. Illiteracy  
402 although falling as older people die is an issue, but more important is strong attachments to land,  
403 community and livestock which could mean that orders to evacuate would at best ignored and at  
404 worst resisted. This feature, which is perceptual as well as social and cultural, is more fully  
405 discussed below and re-enforces an issue already aired regarding the problems caused by the  
406 presence of large populations of livestock, particularly cattle.

407

#### 408 **Perceptual and informational vulnerability**

409 An individual's susceptibility to risk depends on many factors. Location of a person's home  
410 and the characteristics of his or her livelihood, activities and resources have already been  
411 discussed. Susceptibility is also determined by a person's ability for self-protection (Cannon 1994)  
412 and their physiological resilience, which itself may depend on factors such as age, psychological  
413 make-up and the accuracy with which a person may perceive the threat of being affected by a  
414 natural calamity (Dibben & Chester 1999). In order to investigate these factors in the context of  
415 Furnas volcano, an in-depth interview-based study of 50 respondents within the village of Furnas  
416 was carried out by one of us (Dibben 1999). In addition interviews were conducted with the Civil  
417 Defence authorities, local government officials and people affected by previous earthquakes. Five  
418 themes were covered by the interviews:

419 1. length of residence and reasons for moving to the village;



420 2. the respondent's attitude to the social and physical character of the village;

421 3. perceptions of volcanic and others hazards;

422 4. disaster preparation and

423 5. attitudes to measures for the mitigation of risks.

424 As far as vulnerability between eruptions is concerned and despite the fact that a number of  
425 people (e.g. civil defence workers and medical staff) in Furnas village knew of the risk of CO<sub>2</sub>  
426 seepage into buildings, not one interviewee at that time realised that gases posed a hazard to  
427 health. This suggests that at the time of the survey comprehensive information on civil protection  
428 had not been diffused throughout the village. There is a significant lung cancer risk to those who  
429 live in CO<sub>2</sub> exposed buildings, or whose employment involves working in hollows or cellars and this  
430 is a serious omission.

431 Responses to the interviews illustrated further aspects of vulnerability. Of the residents  
432 surveyed by Dibben (1999), none had prepared themselves for a future eruption, either mentally or  
433 physically, even though they generally knew that the volcano was active. Indeed Dibben & Chester  
434 (1999, p.10) record that respondents were shocked by the question, adding that either they did not  
435 know what they would do, or else they would simply run away. Even more worrying was that many  
436 people felt they would have no warning and did not know to whom to turn for advice, often citing  
437 television or scientists from the University of the Açores as their only sources of information. Some  
438 interviewees even thought that the presence of fumaroles in the village meant that eruptions were  
439 less likely and that earthquakes would be weaker. At a deeper psychological level, 28% of  
440 respondents believed they had little control over future events, some being very fatalistic and others  
441 placing their fate in the hands of God. Responses to the questions asked in the interviews,  
442 however, did not reveal any evidence of economic or social marginalisation (Susman *et al.* 1983),  
443 with all socio/economic groups being equally ill-informed. Surprisingly since felt earthquakes on São  
444 Miguel occur frequently, interviewees had little idea about how to respond to seismic events.

445 Behaviours amongst the respondents ranged from 'staying in bed' to 'curling up in a corner';  
446 with not one interviewee indicating that he or she had tried to remove him or herself from their home  
447 and/or village.

448 Attachment to place, mentioned when economic, social and cultural vulnerabilities were  
449 being discussed, comes out very strongly in the interviews. Attachment often reflects stable long-  
450 term bonds between, people their homes and communities (Rivlin 1987; Dibben and Chester  
451 1999), with a majority of respondents being very positive about their home village, but showing  
452 some negativity towards outsiders. Accepting two mutually incompatible explanations, or holding  
453 one view but acting in opposition to it is often termed *parallel practice* (Coutinho *et al.* 2010) and at  
454 Furnas people recognised that the village was both a fine place to live and a potentially very  
455 dangerous one. It should be noted that *parallel practice* is sometimes termed *cognitive*  
456 *dissonance* in hazard studies. However in psychology where the term was first used it has a  
457 more restrictive definition (Carroll 1990, p. 123-4) and, hence, the term *parallel practice* is used  
458 in the present paper.

459 The Furnas attitude survey was carried out more than a decade ago and ideally needs, not  
460 only to be repeated, but also undertaken in other villages representative of the situation of the Fogo  
461 and Sete Cidades *areas*. The present authors see no reason to believe, however, that its findings  
462 are atypical of the attitudes of rural dwellers in other areas of São Miguel. Providing clear  
463 leadership, reliable information and instilling confidence amongst the people living on the three  
464 volcanoes is clearly an educational and policy priority. In recent years an important start has been  
465 made. For instance: the *Centro de Vulcanologia e Avaliação de Riscos Geológicos (CVARG)*  
466 and its seismic network in particular is viewed by hundred of school children every year in pre-  
467 arranged visits; information provided by the Civil Protection Authorities (*Serviço Regional de*  
468 *Protecção Civil e Bombeiros dos Açores - SRPCBA*) for *concelhos* and *freguesias* has been  
469 greatly improved; and the *CVARG* has enhanced its capacity to provide dynamic hazard

470 scenarios and scientific support for the *SRPCBA*.

471  
472 **Conclusion: Moving Forward**

473  
474 The 1990s were designated by the United Nations the *International Decade for Natural*  
475 *Disaster Reduction (IDNDR)*, being superseded from the end of the millennium by the  
476 *International Strategy for Disaster Reduction (ISDR)*. In recent years research carried out under  
477 the influence of these initiatives has increasingly stressed the uniqueness of human vulnerability  
478 in volcanic regions and the need to construct plans for hazard reduction, which are more fully  
479 aware of the complexities of local society and culture (United Nations 1999, 2002, 2005). As  
480 argued elsewhere (Chester 2005, p.427-428), an approach to hazard reduction has developed  
481 that draws heavily on the methodology used in *Environmental Impact Analysis (EIA)* (Fig. 6),  
482 *EIA* being developed from the 1960s to evaluate the impact of large, potentially environmentally  
483 damaging, projects. In terms of their impacts on society, volcanoes are similar to such projects  
484 and there are close parallels between the methodology used in *EIA* and approaches currently  
485 being developed to study volcanoes, society and culture in many volcanic regions including the  
486 Azores. As in *EIA*, so in recent more 'incultured' approaches to hazard assessment, the large  
487 number of social and physical factors which need to be studied may be expressed as *checklists*,  
488 whilst the *overlay* approach may be used to compare spatial (i.e. geo-referenced) data.

489 On São Miguel a start has been made in introducing such an approach with the  
490 development of AZORIS by CVARG, a spatial data-base for risk analysis which has the aim of  
491 improving land-use planning and emergency responses to hazardous events (Gaspar *et al.*,  
492 2004). Using a *Geographical Information System (GIS)*, AZORIS, an acronym for AZOes RiSk,  
493 employs nine geo-referenced sets of data which range, on the one hand, from those concerned  
494 with volcanological and geophysical factors producing hazard exposure, to geographical and  
495 socio-economic aspects of risk and vulnerability on the other. In 2004 the data sets used in

496 AZORIS comprised information on the following factors: geographical and socio-  
497 economic; civil protection; geological and geomorphological; landslides; volcanological;  
498 seismological; geodetic; fluid geochemistry and meteorological.

499 Whilst recognizing that some important sets of data cannot be expressed in geo-  
500 referenced formats, AZORIS provides a facility for such documents to be viewed alongside  
501 spatial data so maximizing the advantages of *checklist* and *overlay* methodologies. Research  
502 on improving the database is ongoing and information acquired by geophysical field monitoring  
503 is, for instance, routinely transmitted to CVARG and CIVISA (*Centro de Informação de*  
504 *Vigilância Sismovulcânica dos Açores* or Centre for Information and Seismovolcanic  
505 Surveillance of the Azores) for storage in AZORIS (Gaspar *et al.* 2011). Once published and  
506 analysed, relevant information from the 2011 census will be entered.

507 Another example is exemplified by a recent study of seismic risk and vulnerability at the  
508 village scale (Martins *et al.*, 2012). Detailed data on geo-referenced features of the demography,  
509 socio-economic conditions and the building characteristics of Vila Franco do Campo (Fig. 1) were  
510 first weighted and then modelled by means of a quantitative multi-criteria analysis (MCA). Results  
511 show how the historic core of the village is particularly at risk because of strong spatial correlation  
512 between seismically 'unfit' buildings buildings and vulnerable economically and socially  
513 disadvantaged people. This approach could be applied to other settlements in São Miguel.

514 The vulnerability of buildings on São Miguel to seismic activity and volcanic ash fall is  
515 now known in some detail. In order to mark the 200<sup>th</sup> anniversary of the Lisbon earthquake a  
516 symposium was held in 1955 and found that Portuguese buildings were highly vulnerable to  
517 earthquake losses and that a more comprehensive building code was urgently needed (Ordem  
518 dos Engenheiros, 1955). A code was published in 1958, the impact of which was generally  
519 viewed to have been ineffective (Azevedo *et. al.* 2009, p.561-562) and a new code was  
520 introduced in 1983 (RSA 1983). Only time and another earthquake will allow the effectiveness of

521 the 1983 code to be tested. As argued above, in the Azores the principal cause for concern  
 522 is not relatively newly constructed structures, but houses and other heritage buildings which  
 523 were erected before there were effective codes.

524 Other aspects of vulnerability require further research so that emergency planning may  
 525 be improved and the AZORIS methodology made more comprehensive. In particular these  
 526 areas relate to: identifying isolated housing; the more detailed investigation of the degree to  
 527 which evacuation routes would be robust in the event of an eruption; the annual variability in the  
 528 island's transient population and its location at different times of the year; the location of São  
 529 Miguel's livestock; issues of local leadership; devising policies of educational outreach to the  
 530 community so that risk perception more accurately reflects the actual risk.

531  
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## 872 **Figures caption**

873  
 874 Figure 1. Map showing the location of the Azores and the island of São Miguel.

875  
 876 Figure 2 The limits of the Sete Cidades, Fogo and Furnas Areas. The figures also show population  
 877 numbers for each *freguesia*. Areas comprise those locales likely to be affected by the most  
 878 probable future volcanic eruptions/volcano-related events occurring at the three volcanoes. The  
 879 three maps are based on: Gomes *et al.*, 2006 - Sete Cidades; Wallenstein *et al.*, 2005 – Fogo and  
 880 Chester *et al.*, 1999 - Furnas. It should be noted that in July 2002 Bretanha *freguesia* was sub-  
 881 divided into two new parishes: Ajuda da Bratanha and Pilar da Bretanha. Because most statistical  
 882 data relate to the pre-2002 boundaries, the sub-division is not recognised in this figure. The  
 883 population total for Ponta Delgada includes the four *freguesias* (i.e. Matriz, São José, São Pedro  
 884 and Santa Clara) which are recognised in official statistics (INEP 2002), together with adjacent  
 885 commuter settlements.

886  
 887 Figure 3 Regression line of rainfall intensity (mm/day) and event duration (days) for Povoação  
 888 *concelho*, 1918-2002. The line defines thresholds between land stability and instability. The inset  
 889 maps shows the same plot using a log-log scale. Triangles are used to denote disastrous  
 890 landslides, squares severe landslides and circles minor landslides (Based on Marques et al. 2008,  
 891 p. 491, figure 11, and used with the permission of the author).

892  
 893  
 894 Figure 4 The principal roads of São Miguel: A. Before the improvements carried out under the

895 SCUTS Programme 2007-12; and B. Roads constructed under the SCUTS Programme.

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897 Figure 5 Photograph of high level bridge on the new road between São Brás to Lomba da Fazenda  
898 (Photograph Nicolau Wallenstein).

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900 Figure 6. An evolving framework for the study of volcanoes and human vulnerability. Parallels  
901 with *Environmental Impact Assessment (EIA)* should be noted. Modified from Chester 2005, .  
902 428, fig. 14.8.

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922 **Table 1. Scenarios of future eruption. Based on: Moore, 1990; Cole et al., 1999, 2008; Guest et al.,**  
923 **1999; Queiroz et al., 2008 and Wallenstein et al., 2005, 2009.**

| Sete Cidades  | Fogo   | Furnas   |
|---|--|--|
| At least three major caldera forming events have occurred in the last c. 36,000 years. Around 5,000 ago, intra-caldera volcanic activity changed from magmatic to predominantly hydromagmatic. At least 17 intra-caldera eruptions are recognised. Offshore vents have also erupted in 1638, 1682, 1713, 1811 and 1880. | Trachytic plinian and sub-plinian explosive eruptions have occurred on Fogo, together with less violent basaltic events. The most recent event occurred in 1536, was sub-plinian and comprised pronounced seismic activity, deposition of extensive ash-fall (partially generated hydromagmatically) and the production of debris flows. | The most recent eruption took place in 1630. Damaging precursory earthquakes caused considerable damage to settlements, and this was followed by explosive sub-plinian activity that produced widespread air-fall, pyroclastic flows/surges, floods and landslides. The intra-caldera area was devastated, as were several valleys draining the volcano. |
| In terms of hazard, a future intra-caldera event will probably have a hydromagmatic element and   | A plinian event is considered the most extreme future scenario, the most likely being  | A 1630 type event is considered to be the most likely future eruption scenario.  |

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affect both the caldera and volcano's flanks. a sub-plinian event such that which occurred as 1536.

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**Table 2.** *Typology of human vulnerability to volcano and volcano-related hazards on São Miguel (based on: Alexander, 1997; Zaman, 1999; Degg and Homan, 2005).*

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| Type of Vulnerability        | Characteristics on São Miguel  |
|------------------------------|--|
| Physical                     | Housing quality, population distribution/ settlement and the characteristics of evacuation plans   |
| Demographic and economic     | Detailed demographic characteristics of the population at risk: their economic status; demographic structure and dependent cohorts within the population. Implication for emergency planning and leadership. |
| Social and cultural          | The social structure and cultural <i>milieu</i> of the people at risk  |
| Perceptual and informational | Accurate and inaccurate perceptions of risk. The lack of accurate information  |

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**Table 3.** *Site characteristics of the principal settlements of the Fogo Area, and issues raised by the survey of roads (after Wallenstein et al., 2005 and updated by data collected in the field). Areas are defined by freguesia (see Fig. 2) and population data are taken from the 2001 census (INEP 2002), updated where possible by the estimates provided by Serviço Regional de Estatística dos Açores (SREA 2011a).*

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#### Major Constraints by Area

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**Area 1. South Flank (Lagoa, Água de Pau, Ribeira Chã, Água de Alto, Vila Franca do Campo and Ribeira das Tainhas).** Nearly 22,000 people (~39% of the population of the *Fogo Areas*) live immediately to the south of the volcano within an 8km radius of the centre of the Lagoa do Fogo. Parts of the villages of Água de Pau and Ribeira Chã are less than 5km distant. People in this sector are highly vulnerable, not only because of their proximity to the summit, but also because the main coast road (route En 1-1a) would be blocked by tephra fall in even a small eruption. Further constraints include:-

- a. River valleys that drain the summit region, would be flooded if the walls of the Lagoa do Fogo were breached. Valleys would also be routes for *lahars* and *pyroclastic flows*.
- b. Landslides would choke valleys with sediment and up-rooted trees would create temporary dams, so exacerbating the risk of flooding.

It is because of the dangers faced by people living in this sector and the fact that communications are far from secure, that pre-eruption evacuation is essential. Early evacuation of Ribeira das Tainhas and Ribeira Chã *freguesias* is particularly important

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because some of their population can only be reached by minor roads.

**Area 2. North Flank (Ribeira Seca, Ribeira Grande, Ribeirinha, Porto Formoso, São Brás and Maia) and Inland (Santa Bárbara),** Over 15,000 people (~27% of the *Fogo Area*) live in these *freguesia*. Although not so close to the summit as the towns to the south and possessing much better road access to Ponta Delgada and the west (roads En 1-1<sup>a</sup> and En 3-1<sup>a</sup>), a sub-plinian or even a basaltic eruption would cause major difficulties. Specific concerns include:-

- a. The main road passes near to Ribeira Grande and the stream with the same name has a large catchment reaching almost to the caldera rim. In an eruption it would be filled with volcanic products.
- b. The settlement of Caldeiras da Ribeira Grande (Fig. 2), just over 3km from the caldera, is an isolated and highly exposed settlement.

Early evacuation of this area of the north coast is essential.

**Area 3. North Coast (Calhetas and Rabo de Peixe) and Inland (Pico da Pedra)** These settlements would only be affected by tephra, if winds were from the east and/or if an eruption was sub-plinian. Good road links to the west of the island and to Ponta Delgada, suggest that evacuation would be relatively straightforward.

**Area 4. North coast (Lomba da Maia, Fenais da Ajuda and Lomba da São Pedro).** These villages would only be affected if winds were from the west and/or a sub-plinian event occurred. A major issue is that, if the roads in areas 1 and 2 were closed, then the population in this area would be isolated from Ponta Delgada and the west of the island.

**Area 5. South Coast (Ponta Garça and Ribeira Quente) and Inland (Furnas)** If Lagoa das Furnas would be affected by an eruption of Fogo, then evacuation would involve removing people quickly from the caldera region. There are major flood risks on the road running by the side of the Lagoa das Furnas (i.e. En 1-1<sup>a</sup>). The best overall route for evacuation is the EN2-1<sup>a</sup>, which runs to the west and north west of Furnas.

Ribeira Quente is a very dangerous settlement. Not only would floodwaters be concentrated within the valley leading to the village but, the road also has several major constraints on its use during an eruption. These include hazards from: falling trees; landslides; flooding and roadway instability. It is likely that once an eruption started this route would be unusable as was case during the 1997 landslides.

Ponta Garça is located some distance to the south of the main southern road (En1-1a) and early evacuation would be called for.

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**Table 4.** *The principal social groupings on São Miguel. Based on Chapin (1989) and updated using the references cited.*

| SOCIAL GROUPS                         | CHARACTERISTICS  |
|---------------------------------------|--|
| <i>Trabalhadores</i><br>(workers)     | In 2009, ca.13% of the population is employed in the <i>primary</i> economic sector (i.e. agriculture, fishing and extraction) and ca.24% in the <i>secondary</i> (i.e. manufacturing, energy and construction) sector (SREA 2010b). Many of these were manual workers. Since 1950 many emigrants have been drawn from this group. <i>Trabalhadores</i> work for themselves on small holdings (either family owned or rented) and as labourers for others. Mostly they live in towns and villages, commuting to work. In rural areas - like the <i>Furnas, Fogo and Sete Cidades areas</i> - <i>trabalhadores</i> are predominantly agricultural labourers - raising crops, keeping cattle, and fishing. Illiteracy is common (16% in Vila Franca do Campo and 7% in Ponta Delgada <i>concelhos</i> INEP 2002), but has declined during the past decade as older people die. |
| <i>Proprietários</i><br>(proprietors) | <i>Proprietários</i> own property and do not work for others. In rural areas, such as those that comprise the three volcanic <i>areas</i> , <i>proprietários</i> are small-scale village entrepreneurs (e.g. shop keepers, bar owners) and own their own farms. Most members of this group have at least a primary education, but a minority of older people are illiterate. Many  |

local leaders are drawn from this group. Often younger *proprietários* have left home, gained higher qualifications and live outside the community, or even abroad. There are often known as educated *proprietary*. *Proprietários* have contacts with many social spheres, both external and internal.

Established educated

The educated 'middle class'. With the exception of doctors and local government officials, few members of this group live in rural areas, but some own summer homes.

Heavily concentrated in the Ponta Delgada *area* and surrounding villages from which they commute, relatively few families reside in rural areas like the such as those on the flanks of the three active volcanoes.

A numerically small sub-group is the *Nobreza* (nobility), whose ancestors colonised the island and still own much land.

New entrepreneurs

Heavily concentrated in the Ponta Delgada and relatively few families reside in the three 'volcanic' *areas*.

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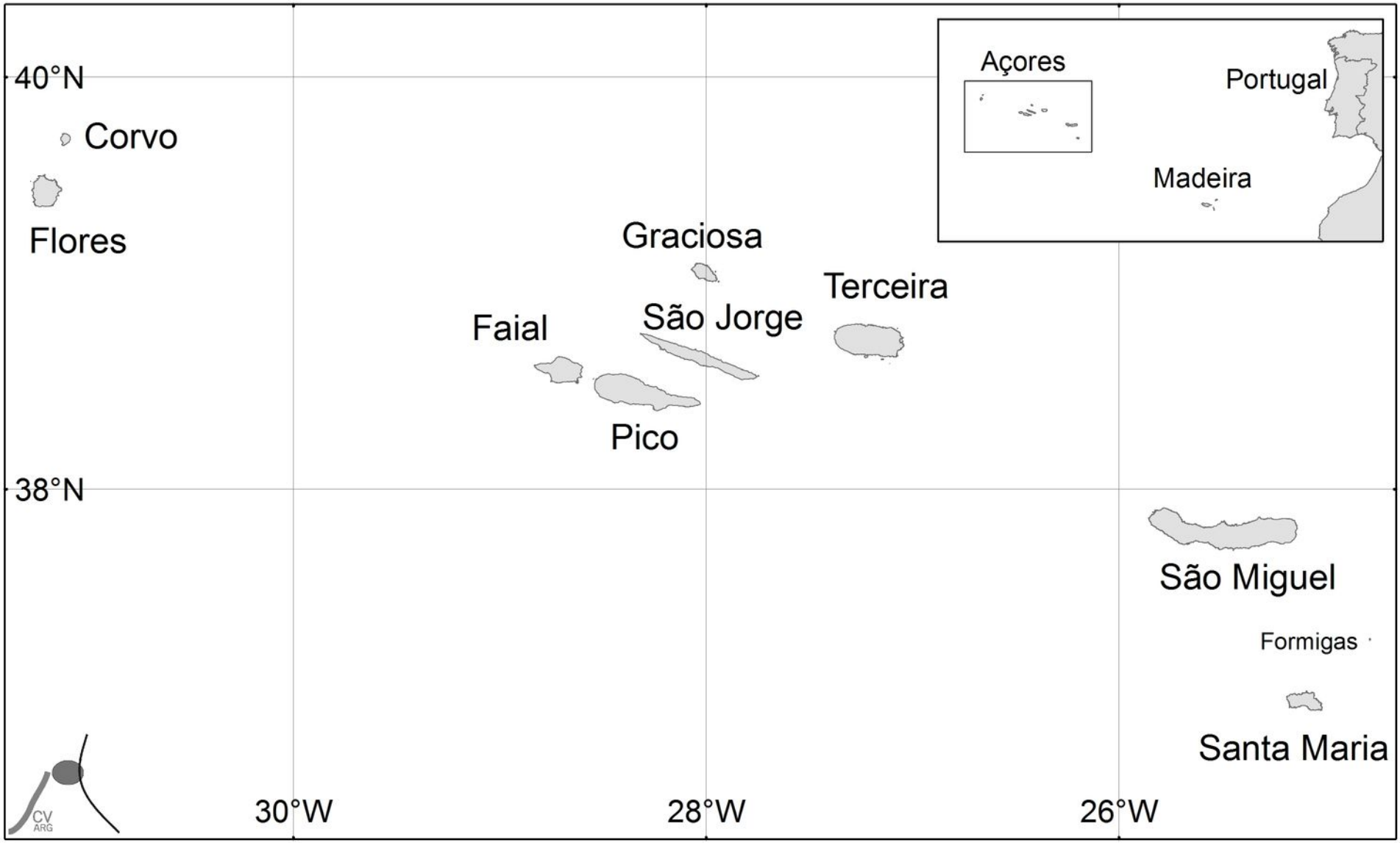
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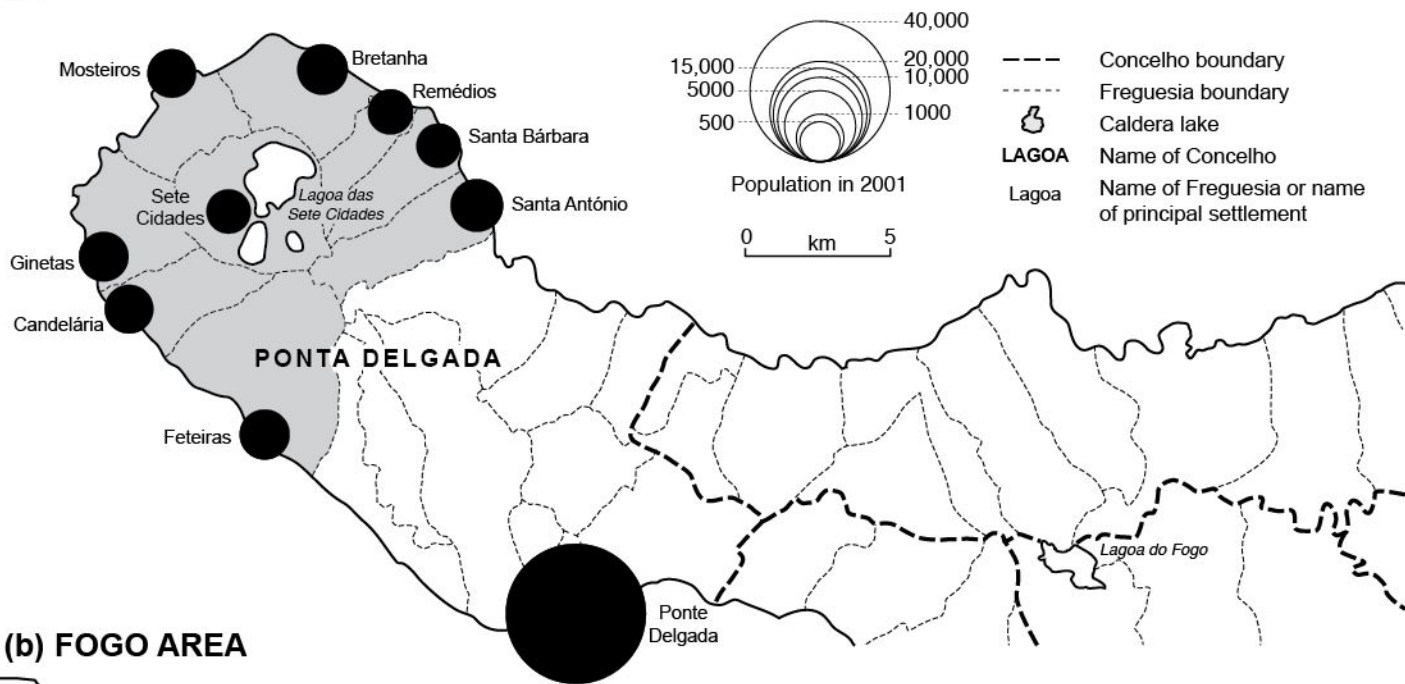
1026 Fig. 6

| <i>Increasing complexity</i> | Technique | Features  | Comments on and examples of applications in volcanic regions  |
|------------------------------|-----------|---|---|
|                              |           | Checklist   | Lists all the factors - physical, economic, cultural and societal - which need to be considered. Cause/effect relationships are implied but not specified in detail.  |
|                              | Overlays  | Traditionally this has relied on overlay maps showing physical, social, historical aspects of the region. Today Geographical Information Systems (GIS) are increasingly being used. | There is much scope for this approach to be used in volcanic regions, because many of the variables are spatial and capable of being either mapped or incorporated into a GIS. The impact of satellite-based systems, significant at present, is likely to be much more prominent in the future (Wadge 1994). GIS based studies have been used in the Azores (see text) |
|                              | Matrices  | Matrices are used to identify first-order cause/effect relationships.   | At the present time variables are not sufficiently well specified to enable matrices and network based studies to be carried out. There may be much scope in the future.  |
|                              | Networks  | Used to identify 'chains' of complex interactions. Ideally this approach requires mathematical modelling.   |   |

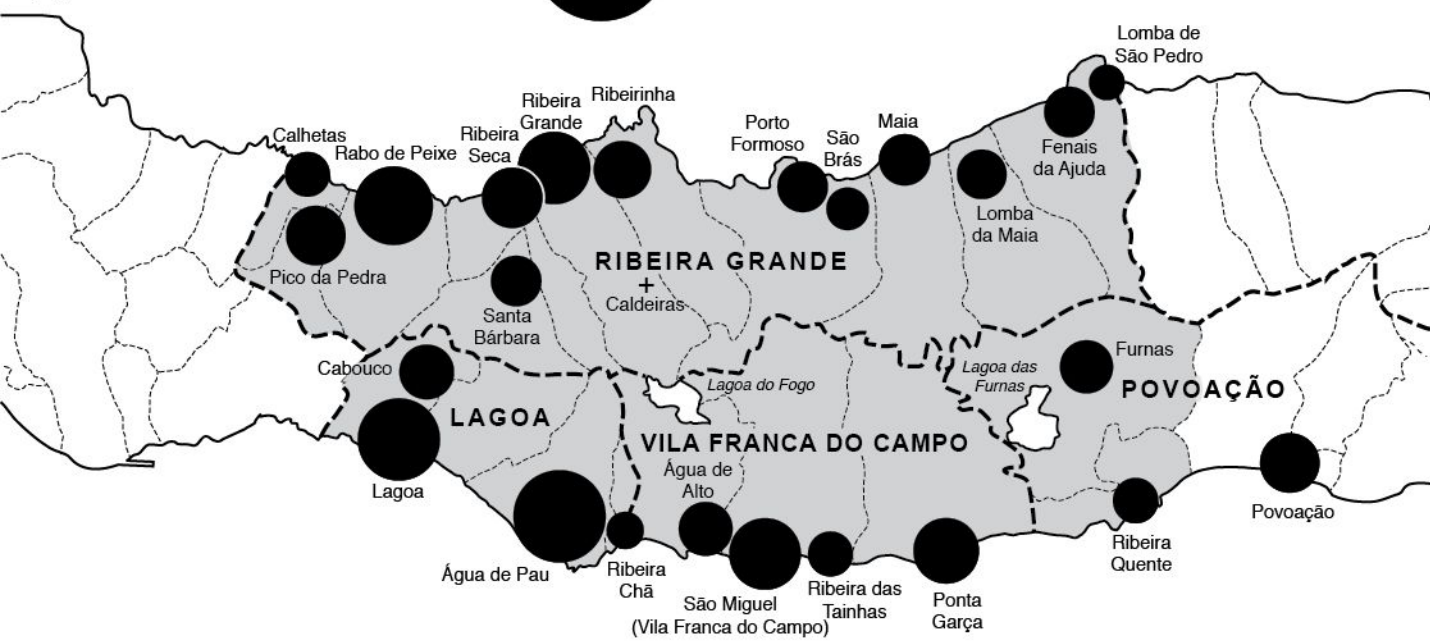
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**(a) SETE CIDADES AREA**

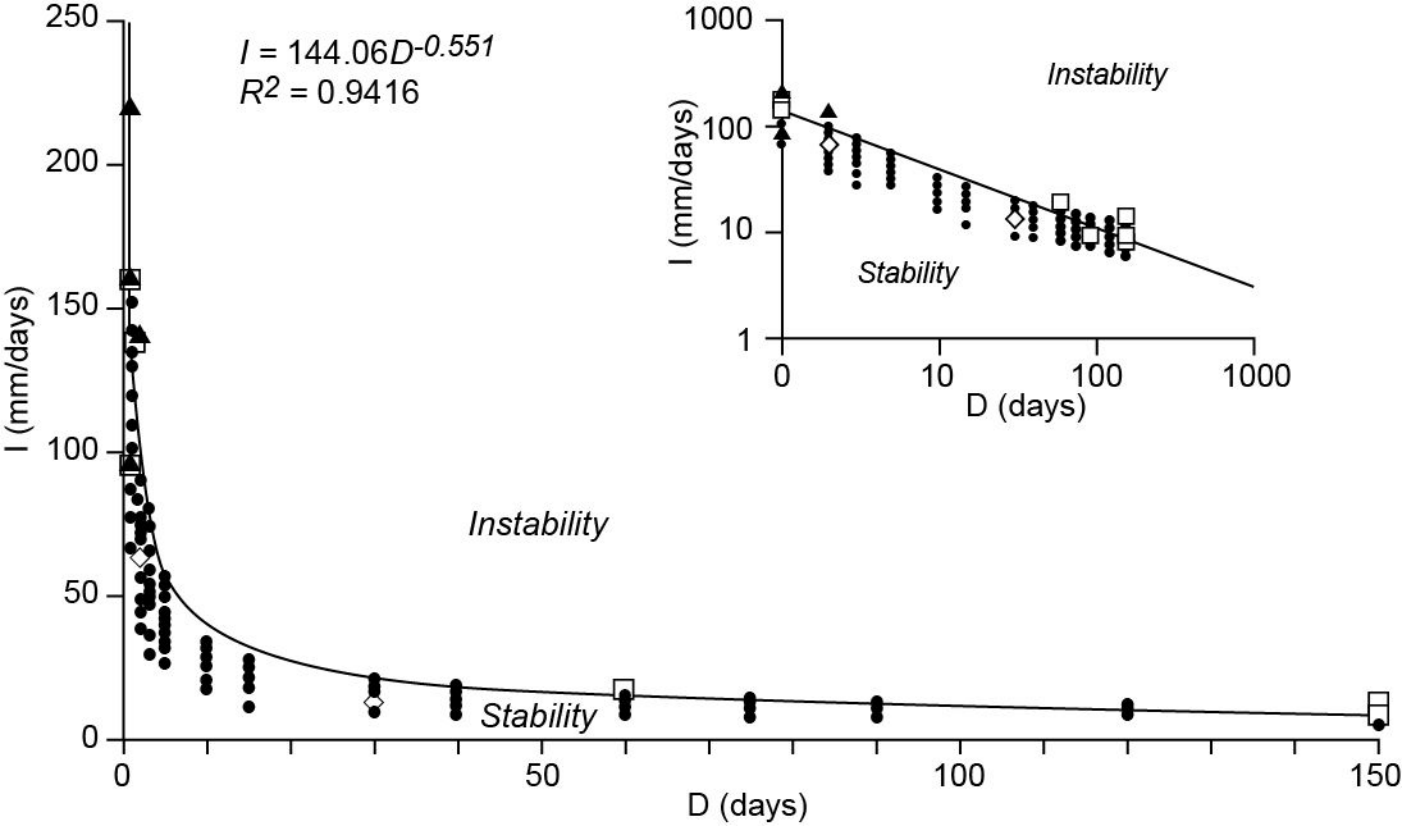


**(b) FOGO AREA**



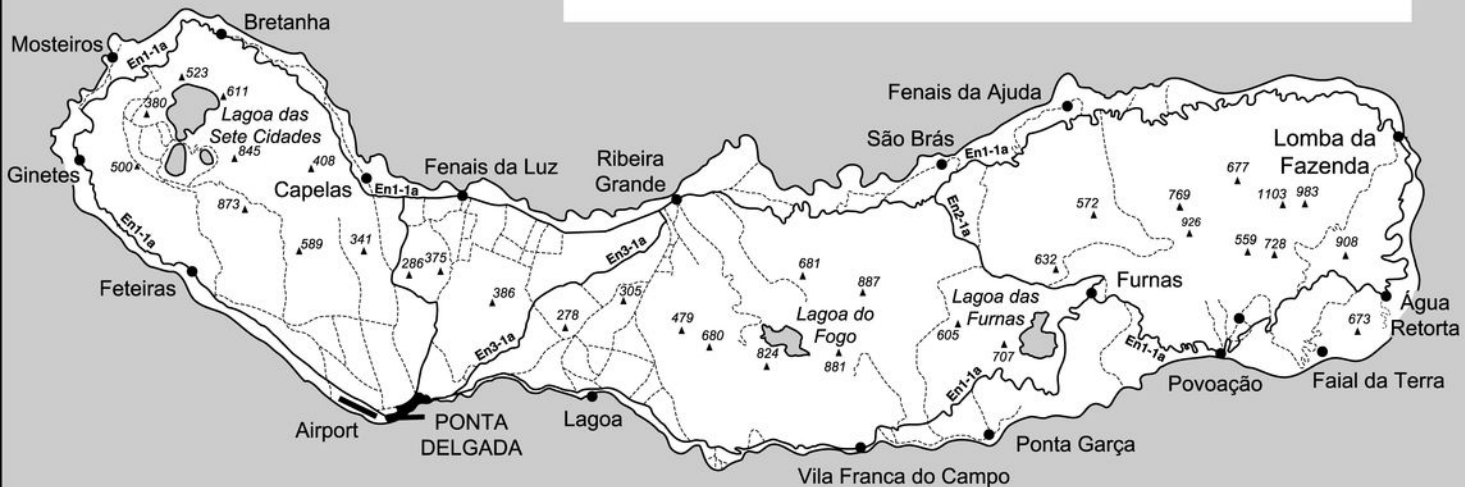
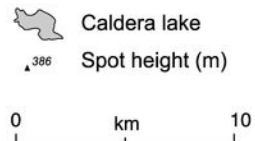
**(c) FURNAS AREA**





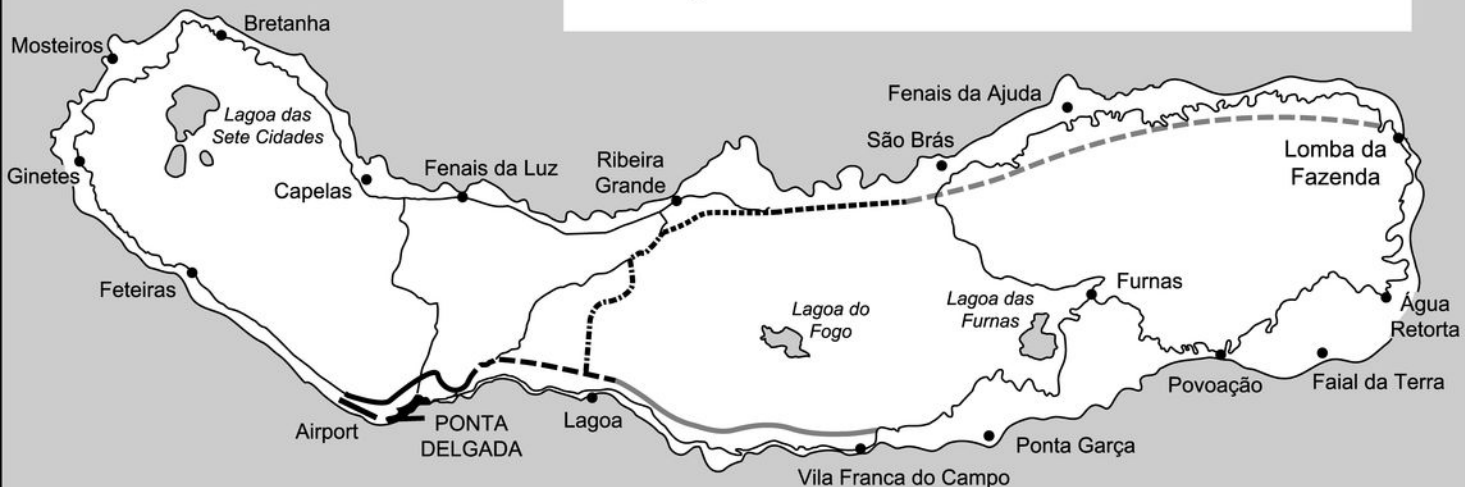
North Atlantic Ocean

- (En-1a) Major road
- Secondary road
- Major town



North Atlantic Ocean

- Airport to Ponte Delgada
- Ponte Delgada to Lagoa
- Lagoa to Ribeira Grande
- Bypass around Ribeira Grande
- Ribeira Grande to São Brás
- São Brás to Lomba da Fazenda
- Lagoa to Vila Franca do Campo
- Older road









|   | Technique | Features  | Comments on and examples of applications in volcanic regions  |
|---|-----------|---|---|
| <p style="text-align: center;">↑</p> <p style="text-align: center;"><i>Increasing complexity</i></p> <p style="text-align: center;">↓</p> | Checklist | Lists all the factors - physical, economic, cultural and societal - which need to be considered. Cause/effect relationships are implied but not specified in detail.                | The US Geological Survey's programme, Living with Volcanoes (Wright and Pierson 1992: 6) and many initiatives in other countries involve, either implicitly or explicitly, a checklist approach. It is the evolving norm of the IDNDR/ISDR  |
|   | Overlays  | Traditionally this has relied on overlay maps showing physical, social, historical aspects of the region. Today Geographical Information Systems (GIS) are increasingly being used. | There is much scope for this approach to be used in volcanic regions, because many of the variables are spatial and capable of being either mapped or incorporated into a GIS. The impact of satellite-based systems, significant at present, is likely to be much more prominent in the future (Wadge 1994). GIS based studies have been used in the Azores (see text) |
|   | Matrices  | Matrices are used to identify first-order cause/effect relationships.   | At the present time variables are not sufficiently well specified to enable matrices and network based studies to be carried out. There may be much scope in the future.  |
|   | Networks  | Used to identify 'chains' of complex interactions. Ideally this approach requires mathematical modelling.   |   |