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RESEARCH ARTICLE

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Community preparedness for lava flows from Mauna Loa and Hualālai volcanoes, Kona, Hawai'i

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Abstract Lava flows from Mauna Loa and Hualālai volcanoes are a major volcanic hazard that could impact the western portion of the island of Hawai'i (e.g., Kona). The most recent eruptions of these two volcanoes to affect Kona occurred in A.D. 1950 and ca. 1800, respectively. In contrast, in eastern Hawai'i, eruptions of neighboring Kīlauea volcano have occurred frequently since 1955, and therefore have been the focus for hazard mitigation. Official preparedness and response measures are therefore modeled on typical eruptions of Kīlauea.

The combinations of short-lived precursory activity (e.g., volcanic tremor) at Mauna Loa, the potential for fast-moving lava flows, and the proximity of Kona communities to potential vents represent significant emergency management concerns in Kona. Less is known about past eruptions of Hualālai, but similar concerns exist. Future lava flows present an increased threat to personal safety because of the short times that may be available for responding.

Mitigation must address not only the specific characteristics of volcanic hazards in Kona, but also the manner in which the hazards relate to the communities likely to be affected. This paper describes the first steps in developing effective mitigation plans: measuring the current state of people's knowledge of eruption parameters and the implications for their safety. We present results of a questionnaire survey administered to 462 high school students and adults in Kona. The rationale for this study was the long lapsed time since the last Kona eruption, and the high population growth and expansion of infrastructure over this time interval. Anticipated future growth in social and economic infrastructure in this area provides additional justification for this work.

The residents of Kona have received little or no specific information about how to react to future volcanic eruptions or warnings, and short-term preparedness levels are low. Respondents appear uncertain about how to respond to threatening lava flows and overestimate the minimum time available to react, suggesting that personal risk levels are unnecessarily high. A successful volcanic warning plan in Kona must be tailored to meet the unique situation there.

Keywords Mauna Loa · Hualālai · Kīlauea · Kona · Warning · Lava flow hazard

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Introduction

Of five volcanoes on the island of Hawai'i (Kīlauea, Mauna Loa, Hualālai, Mauna Kea, and Kohala; Fig. 1a), the first three have erupted since about A.D. 1800, although with very different frequencies. Lava flows are a well-known hazard from Kīlauea volcano on the eastern side of the island, but are less frequent at Mauna Loa and even less so at Hualālai (Macdonald et al. 1983). This paper focuses on future lava flows from Mauna Loa and Hualālai volcanoes affecting the western portion of the island (i.e., Kona, Fig. 1b). We also describe the results of a survey of individual preparedness for responding to future lava flows from Mauna Loa and Hualālai. Findings of this survey are discussed in the context of the lava-flow

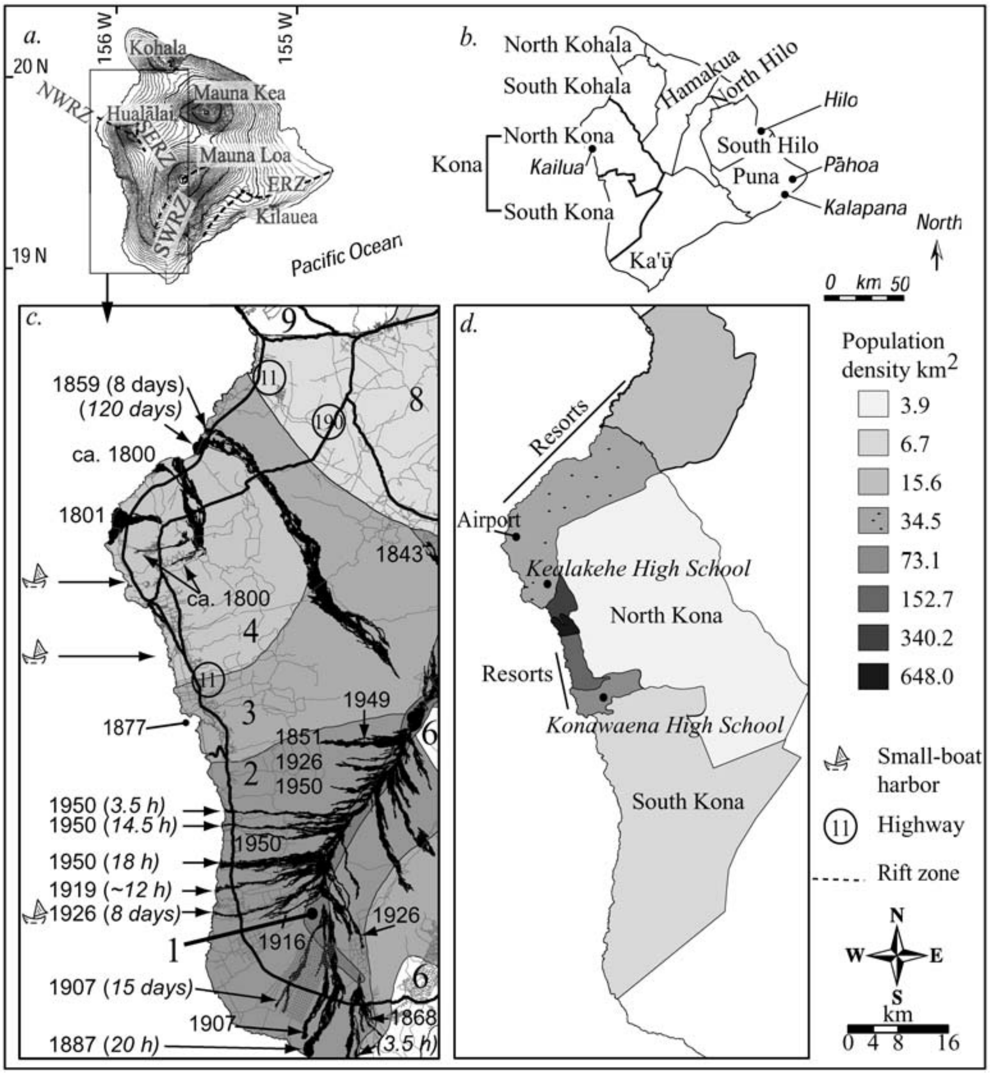

Fig. 1a–d **a** Island of Hawai'i, topography (contour interval=100 m), volcanoes and selected rift zones (*dashed lines*; SWRZ=southwest rift zone of Mauna Loa, ERZ= east rift zone of Kīlauea, NWRZ=northwest rift zone of Hualālai, SERZ=southeast rift zone of Hualālai). **b** District boundaries and place names. *Bold lines* outline our study area. **c** General study area. Lava flow hazard zones are *shaded* and numbered *1* (highest hazard) to *9* (lowest hazard) (excludes zones 5 and 7 of Kīlauea and Mauna Kea; after Wright et al. 1992). The area of Hualālai is defined by lava flow hazard zone 4; Mauna Loa by zones 1, 2, 3 and 6. Zones 8 and 9 represent areas of Mauna Kea and Kohala, respectively. Dates of selected recent lava flows (A.D.) and advance times (h=hours; after Hawai'i State Civil Defense 2002). Primary and secondary through roads (bold lines) are shown with all other roads, including four-wheel drive roads (*light lines*; after US Census Bureau 2000a). A boat marks the location of a small-boat harbor. **d** Population densities of 2000 Census Tract boundaries illustrating the distribution of people within the study area (County of Hawai'i 2000). Major resort areas and schools surveyed are shown.

hazards in Kona and volcano monitoring systems and warning plans.

Kona

Our study area lies in the political districts of North Kona and South Kona, collectively called Kona, which are located on Hualālai and the western portion of Mauna Loa shield volcanoes. These districts have populations of 28,543 and 8,589, respectively (County of Hawai'i 2000). North Kona includes the second largest city on the island (Kailua-Kona, also known simply as Kailua; population 9,870; Fig. 1b) and has a higher population density (58 persons per mile^2) than does South Kona (26 persons per mile^2, Fig. 1c, d; County of Hawai'i 2000). Risk to society in Kona (e.g., residents, tourists and the built environment) as a consequence of future volcanic activity at Mauna Loa and Hualālai has increased with rapid growth in population and tourism (Kona's principal economic resource) and expansion of infrastructure. In 1998, nearly 1.1 million people visited Kona (County of Hawai'i 2000). Many developed areas are within 15 km of vents at Hualālai's summit and northwest and southeast rift zones and along Mauna Loa's southwest rift zone (Fig. 1a). Radial vents could occur within developed areas on Mauna Loa's west flank in Kona or on Mauna Loa's north flank (Trusdell 1995). Few roads connect Kona to other parts of the island (Fig. 1c). Three of five 20th-century eruptions of Mauna Loa in South Kona produced lava flows that severed the main arterial highway (Highway 11). If repeated today the most recent lava flows of Hualālai would sever the two arterial highways in North Kona and thus separate Kailua and its international airport from the island's primary and growing resort industry further north (Fig. 1d).

Social and demographic characteristics of Kailua differ from the largest settlement on the east rift zone of Kīlauea (Pāhoa, Fig. 1a, b). For example, comparisons of US Census Bureau (2000b) data show that Kailua, in contrast to Pāhoa, differs with regard to language spoken at home, race and ethnicity, per capita income and level of education attained. However, the Census data also show, not unexpectedly, that housing occupancy in Kailua is more seasonal and recreational in use than in Pāhoa and that people in Kailua are more transient than those in Pāhoa. These differences between east and west Hawai'i may strongly influence preparedness for, and response to, volcanic eruptions. The last eruption of Mauna Loa in Kona was in 1950 (Macdonald 1954). The last eruption of Hualālai was A.D. 1801 (Kauahikaua et al. 2002).

Social science

Few systematic studies of human behavior in response to volcanic eruptions have been conducted in Hawai'i (Lachman and Bonk 1960; Murton and Shimabukuro 1974), and none at all in Kona (Gregg et al. 2004). Hazard education programs in Hawai'i have lacked the involvement of social science to measure potential changes in hazard awareness, risk perception and adjustment adoption (i.e., how people cope with, prepare for, respond to, or otherwise live with specific hazards) resulting from the programs. Consequently, the effectiveness of education programs is unknown. Particularly problematic has been the lack of systematic and theoretically rigorous research into how natural hazards in Kona interact with the social and economic characteristics of the community. In the absence of these data, it is difficult to formulate detailed risk-reduction and preparedness plans. Consequently, risk reduction planning in Kona requires an evaluation of two elements: (1) community members' knowledge of the different volcanic hazards that might affect them, and (2) the extent to which these people's understanding of mitigation actions is appropriate given the nature of the prevailing hazards.

Lava flow hazards at Mauna Loa and Hualālai in Kona

Lava flow hazard zones for the island of Hawai'i are ranked 1 (most hazardous) through 9 (least, Wright et al. 1992). South Kona includes zones 1, 2 and 3 of Mauna Loa, and North Kona mostly zones 3 and 4 of Mauna Loa and Hualālai, respectively. All of Hualālai is currently in zone 4 (Fig. 1a-c). Relatively steep slopes and high effusion rates at these volcanoes contribute to the higher flow velocities, thus posing a considerable threat to Kona because most commercial and residential development lies at the foot of these steep slopes (near the coast) and in the paths of future lava flows (Moore et al. 1987; Fig. 1c, d). Lava flow-front velocities in Hawai'i are generally less than walking speed (3–5 km hr^{-1}, Mullineaux et al. 1987). In Kona, however, flow-front velocities have sometimes been much faster (e.g., average over 24 km = 9.6 km hr^{-1} at Mauna Loa in 1950; Macdonald 1954). Similar velocities have been proposed for lava flows during the most recent eruptions of Hualālai (Kauahikaua et al. 2002). Flows often reach the ocean in Kona (Trusdell 1995). Figure 1c illustrates that times taken for selected recent lava flows from Mauna Loa to reach the ocean in Kona have ranged from less than 3.5 h to 120 days (Hawai'i State Civil Defense 2002). Moore et al. (1987) concluded that recurrence intervals for Hualālai during the Holocene are one eruption about every 50 years, although eruptions tend to cluster. At Mauna Loa the recurrence interval since 1832 is one eruption every 4.4 years (39 eruptions since 1832, Barnard 1995). Return periods of this nature suggest some urgency in regard to both understanding community risk attitudes and implementing risk reduction and readiness strategies.

Experience with lava flows

In Hawai'i, recent (i.e., since about A.D. 1955) human experience in adjusting and responding to lava flows in inhabited areas is greatest for Kīlauea (in the Puna District) and to a lesser extent in the area around Hilo (Fig. 1b), which was last threatened in 1984 by Mauna Loa lava flows (Lockwood et al. 1987). Several means of adjusting to lava flows are possible, but evacuation was found to be the standard response to lava flows in the Puna District (Murton and Shimabukuro 1974). Other means of adjustment in Hawai'i have included land-use zoning restrictions that prevent or limit development of vulnerable areas, fire insurance, tax incentives, resettlement, government loans, religious appeals to supernatural beings and simply the bearing of losses.

Murton and Shimabukuro (1974) found that residents of the Puna District on Kīlauea believed the quality of life in that area was so great that it outweighed the volcanic risk, and so the people were content to live in a zone of relatively high volcanic hazard, despite awareness of available land and jobs in safer areas of the island. This raises another potential problem for creating risk acceptance among community members. People who have made costly decisions about things that they value (e.g., purchasing a house or electing to live in a specific area) may seek to ignore information that casts their decision in a negative light, such as being told that they have chosen to live in an area capable of being destroyed by lava flows (a process called cognitive dissonance; Festinger 1980). Similar behavior can arise when the attitudes that underpin peoples' lifestyle choices (e.g., deciding to live in a particular place) are more salient than those for protection against infrequently occurring hazards (Ajzen 1985; Paton 2003). Thus, while people may acknowledge the relevance of protective actions, such actions are overridden by their lifestyle choices. Moreover, people may adopt a fatalistic attitude toward lava flow hazards. In Hawai‘i, this has involved religious appeals such as prayer and offerings to the volcano goddess, Pele (Lachman and Bonk 1960; Murton and Shimabukuro 1974). Promoting preparedness in this context will involve understanding these attitudes and developing ways of reconciling them with the emergency management objective of reducing risk, including maintaining trust in scientific and administrative agencies.

Evacuation and traffic control

Future large eruptions of Mauna Loa's southwest rift zone and Hualālai in Kona may progress quickly and produce lava flows that travel up to tens of kilometers in a few hours or less, generally faster than velocities expected for typical flows at Kīlauea. Radial vent eruptions on Mauna Loa's north and west flank occur outside the rift zones (e.g., 1859 eruption and 1877 submarine eruption, Fig. 1c; Trusdell 1995) and could represent a greater problem than rift zone eruptions because of their potential to begin closer to or within developed areas. Each instance will require rapid emergency response. Such response decisions are made by the administrator of the Hawai‘i County Civil Defense Agency (HCDA).

The logistics involved with evacuating areas in Kona are a concern. The few roads that provide access may simplify planning for evacuation but create a problem should lava flows sever these roads. Highways 11 and 190 are the primary roads in Kona and they are sub-parallel to the coast (Fig 1c). One secondary road provides access to the ocean in South Kona where the lava flow hazard is highest. This and other more minor roads may be essential in the evacuation of people to the ocean if people are trapped by bifurcated lava flows. However, many of these minor roads are narrow, winding and in places are located on steep terrain, especially in South Kona. There are three small-boat harbors in Kona (Fig 1c), so the limited number of roads and harbors may combine to complicate the evacuation of people to the ocean. During the 1950 eruption of Mauna Loa, low cloud-cover and smoke and gases from burning forests ignited by lava flows caused poor visibility. A National Guard aircraft was used to contact a group at risk of isolation by advancing lava flows (Finch and Macdonald 1950). The group included police and scientists and underscored the danger that lava flows in forested areas in Kona can pose to anyone.

Tight controls on use of roadways would be needed to preclude looting and vandalism, which are often concerns among people who resist evacuation from their homes. Looting and vandalism were reported by more than half of the homeowners evacuated during eruptions of Kīlauea in the 1960s, but were reported only once in each of the eruptions in 1977 (Sorensen and Gersmehl 1980), 1985 and 1990 (H. Kim, pers. comm. 2003). The near absence of looting and vandalism in these later eruptions was attributed to Civil Defense authorities having warned the public of the serious consequences of such criminal actions, and having gained the community's trust in the officials' ability to safeguard personal property. Moreover, Civil Defense maintained strict enforcement of security in and around the hazard zone (H. Kim, pers. comm. 2003).

Warning systems (general and volcanic)

General warning system

Civil Defense instructions in Hawai‘i may simply be broadcast over radio in less extreme events, or over radio, television and cable television systems using the Emergency Alert System (EAS) and through police, fire department, civil defense, and civil air patrol aircraft in emergencies. Sirens are located on all the Hawaiian Islands to alert the public to potential emergencies. These sirens could be employed in volcanic eruptions. In a survey in Hilo, Lachman et al. (1961) found that understanding of the meaning of the sirens was ambiguous during the tsunami of 23 May 1960 that destroyed much of Hilo. These authors reported that at that time the siren meant simply "alert," with no indication of what behavioral response was expected of the public upon hearing it. Only 4.6% of respondents in the survey were aware of this. Currently, the siren is defined as an "Attention Alert Signal." A siren sounding of 3-minute duration is intended to prompt the public to tune to a radio or television for more information. The sirens are tested monthly in Hawai‘i; however, we are unaware of any published studies that describe the effects of these tests on individual and collective preparedness to respond to warnings (Mileti and Sorensen 1990; Mileti and O'Brien 1992) or evaluate current understanding of the sirens throughout the island(s).

Response to volcanic hazards

Volcanic crisis response in Hawai‘i is currently based largely on strong but informal relationships among scientific groups, emergency managers and community associations. Response begins with interpretation of monitoring data collected by the US Geological Survey's Hawaiian Volcano Observatory (HVO). Once signs of renewed volcanic unrest are detected and confirmed (e.g., significant ground inflation or prolonged volcanic tremor), HVO reports the activity directly to HCDA, which then makes decisions on informing, alerting, warning, or

Table 1 Time of onset of volcanic tremor, time of eruption of lava, and warning times for the best constrained eruptions of Mauna Loa volcano

Eruption date (A.D.)	Time of tremor onset[x]	Time of eruption[x,y]	Warning (minutes)[z]
1926	0136	>0300	~84[a]
1933	0543	<0700	<77[b]
1940	2259	<2330	<31[c]
1950	2104	<2125	<21[d]
1975	2251	2342	51[e]
1984	2330	0125	115[e]

[x] Times given in Hawai'i Standard Time (first two digits equal hours; second two digits equal minutes)
[y] Time of eruption corresponds to the first account of visual observation of lava at the ground surface or detection by satellite in the case of the 1984 eruption
[z] Warning is the time difference between the time of tremor onset and the time of eruption
[a] Finch (1926)
[b] Jaggar (1933)
[c] Macdonald (1954)
[d] Finch and Macdonald (1950)
[e] Lockwood et al. (1987)

evacuating the public. HCDA has a standard operating procedure for volcanic eruptions and may choose to form an emergency operations center to manage public response to volcanic unrest.

Historically, the earliest reports of some eruptions were made by people other than HVO staff or equipment, caused in part by problems with monitoring equipment (Sorensen and Gersmehl 1980; Lockwood et al. 1987). This suggests a need for redundancy in the monitoring and warning network, especially in areas where eruptions may impact society quickly, as a consequence of either fast moving lava flows or eruptions that begin in developed areas (e.g., areas of Kona and the districts of Puna and Ka'ū, Fig. 1b).

The need for advanced intensive instrumentation monitoring, and a rapid response capability, is exemplified in Table 1, which indicates that warning times (e.g., as provided by detection of volcanic tremor) are short for the best constrained 20th century eruptions of Mauna Loa. The ability to detect volcanic unrest or an imminent eruption has improved since the last Mauna Loa eruption in 1984, but the short-term warning period will likely be of the order of tens of minutes to a few hours rather than days. The number and sensitivity of seismic stations on Mauna Loa have increased, and other monitoring techniques (e.g., real-time tilt and strain meters, near real-time GPS data) have been deployed (US Geological Survey 2003). However, the infrequency of recent Mauna Loa and Hualālai eruptions, compared with those from Kīlauea, has limited our understanding of what precursors to expect, suggesting an obvious need for advanced preparedness for eruptions in Kona and, also, in neighboring Ka'ū.

Unless based on systematic research into the interaction between volcanic hazards and people in Kona, as opposed to simply extending plans developed for, say, the Puna District, the quality and efficacy of plans may be limited (Sorensen and Gersmehl 1980). Response planning and mitigation should link social networks with formal administrative and scientific agencies. Thus planning should include developing mechanisms required to empower the community rather than imposing strategies (Paton 2000).

Disaster preparedness information

Disaster Preparedness Information (DPI) in Hawai'i is disseminated by Civil Defense agencies via telephone books. Neither a discussion of volcanic hazards nor lava flow hazard-zone maps are provided in the DPI, although lava flow warning information was provided from 1960–1982. Our survey evaluated public awareness of some features of the DPI, as well as the extent to which its recommendations for general preparedness have been adopted. The value of this means of disseminating preparedness information may be limited. Ballantyne et al. (2000), in a New Zealand study, showed that respondents confused their knowledge of the existence of a source of hazard information with thorough understanding of that material. If people overestimate existing knowledge in this way, they may be less responsive to new information, less likely to perceive a need for preparation, and may reduce the risk they attribute to a hazard (Paton et al. 2000). 'Self-reporting' of measured and perceived preparedness should be treated cautiously and must be verified to ensure accuracy of reporting and to accommodate measurement problems associated with self-report data (Paton et al. 2000).

The Survey

Purpose, methods and people

Purpose

We set out to evaluate awareness of primary disaster information and the meaning of the alert siren, the extent of preparedness for evacuation, and perceptions of emergency response. Findings are discussed in the context of lava flow hazards, monitoring systems and response plans.

Methods

Survey questionnaires were modified from Ronan and Johnston (2001). Surveys were administered between May 2001 and January 2002. Data were derived from five separate groups (i.e., 9th grade students at Kealakehe High School (N=132) on Hualālai in North Kona and Konawaena High School (N=104) on Mauna Loa in South Kona (Fig. 1d); parents or guardians of these students (N=117 and 44), respectively; and adults at-large (derived from a random survey of Post Office box holders (N=51) and surveys of residents of Kona awaiting flights to Kona at the international airport in Honolulu (N=14)). We refer to these groups as North and South Kona students, North and South Kona parents, and Adult-at-large. Return rates for students and airport samples were 100%, North Kona parents (89%), South Kona parents (42%), and mail-out adults (10%). The district in which a student attends school is a reasonable proxy for the district in which they reside.

People

A total of 462 questionnaires were returned. Demographic data for the students and adults, respectively, are: mean age (14.7 years, sd=0.763 and 44.4 years, sd=9.389); gender (male=52.8 and 31.1%; female=47.2 and 68.9%). Home and land ownership for adults only is: 57.1% own their home, 31.6% rent, 19% own land in another town and 16% own a second home. Ethnicity, on average, is: White 41.1%; Hawaiian, part-Hawaiian and Pacific Islander 36.5%; Japanese 16.7%; Filipino 12.2%; other 29.6% (percent does not equal 100 because respondents could record multiple responses). Demographic characteristics, while not corresponding exactly to US Census Bureau (2000) data, do provide a representative profile of major ethnic groups and allow the tentative generalization of these data to the wider population.

Results

Awareness of disaster preparedness information and warning siren

It is unlikely that significant portions of society will relate the DPI describing other hazards to volcanic hazards, partially because perceptions and understanding of risk from volcanic hazards are so low (Gregg et al. 2004). On average, respondents showed a good awareness that DPI material was in the telephone book (70%, N=122; these data apply only to the adult-at-large and South Kona groups). However a slight majority (51.6%) of the 122 had neither read the material nor read it between one and five years ago. The ability to recall specific information is of a greater significance than simple awareness. We tested the recall ability of those respondents who indicated they had read the disaster preparedness information in the telephone book (N=99) through cross-tabulations with a question regarding the meaning of the warning siren, which is explained in the DPI. On average 51% of these respondents were aware of the meaning of the siren, but adults were much more aware (73.4%) than students (8.6%). However, whether or not the respondent was aware of the DPI being in the telephone book, or whether respondents ever read the material, does not significantly change awareness of the meaning of the siren. This suggests that sources of information other than the DPI (e.g., familiarization during routine monthly tests of the siren, or discussions with other people) are influencing levels of awareness of the meaning of the siren, although these were not tested. Overall, 45.9% of the respondents are aware of the meaning of the siren (Table 2), although again awareness was much higher among adults. The district within which respondents live was not a significant factor in influencing awareness of the siren.

Preparedness

In the DPI, Civil Defense recommends that individuals develop a response plan for an emergency. Having and practicing this plan can strengthen an individual's ability to cope with adversity during hazard events. On average, only one-third (N=149) of the respondents indicated that their families had an emergency plan for a lava flow, hurricane, or earthquake. Furthermore, only one-third claimed to have practiced what to do during an emergency at home (N=145); and only slightly more claimed to know the location of an emergency evacuation shelter near their school or home. These data can be contrasted with those of Menzer (2000) for the eastern portion of the island, where 59% of those surveyed claimed to have a household evacuation plan.

Table 2 Perceived meaning of the emergency warning siren[a]

	Students		Adults		Total	
	N	(%)	N	(%)	N	(%)
Attention alert signal, listen to radio or television for instructions from local authorities	57	27.1	134	65.0	191	45.9
Don't know	80	38.1	45	21.8	125	30.0
Hurricane warning issued	45	21.4	22	10.7	67	16.1
Hurricane watch issued	28	13.3	5	2.4	33	7.9
Total	210	100	206	100	416	100

[a] Respondents were asked to select a meaning from those shown above

We asked, “Have you ever practiced what to do during an emergency at home, at school (students only), and at work (adults only).” We also asked, “Has your family practiced together what to do if there is an emergency?” Some caution in the interpretation of these data is required. For example, if responses relate to more commonly occurring activities such as fire drills, these data may reflect people inferring a capability to respond to each of the hazards that could affect them (i.e., volcanic versus earthquake, versus tsunami) from their practicing fire drills, with the possible consequence of people overestimating their preparedness. Emergency response plans are practiced less at home (33%, N=145) than at work (40.9%, N=83) and much less than at school (79.6%, N=189). An individual whose family has an emergency plan of action is 2.2 times as likely to have practiced what to do during an emergency at home and is 3.2 times as likely to practice with their family. Thus, a household plan of action facilitates both individual and group practice of how to respond to an emergency. A limitation in interpretation of these data is that the adequacy of the response plans was not evaluated. It does, however, provide a good basis from which to develop more hazard specific preparedness.

Having a designated rendezvous place for the family or a place to leave a message during an emergency is suggested in the DPI. Given the uncertainty of vent locations and the large areas affected in eruptions, establishing a single rendezvous place that will be effective in all eruptions may require a location at least several tens of kilometers from one’s home. On average, less than one-third (29.6%) claimed to have a rendezvous place. We cross-tabulated the responses of those who indicated earlier that their family had a plan of action (N=149) with this question. The percentage who designated a rendezvous point only increased to 47.3% and suggests some deficiencies in the quality and content of the response plans. In contrast, Menzer (2000) found that 57% (N=251) of those in the eastern side of the island had designated a meeting place, suggesting a higher level of preparedness there. This greater level of preparedness may reflect the higher incidence of lava flows or other hazards in that part of the island.

The DPI also recommends that people pick an emergency contact in another town. On average, only 29% (N=129) in our study claimed to have done so. Together these data suggest a low level of adoption of basic disaster preparedness measures recommended in the DPI.

Responding to lava flows

Fewer than 5% of Kona respondents have experience with damaging lava flows and only 37% have seen active lava flows (probably relatively slow moving flows at Kīlauea; Gregg et al. 2004). These data contrast starkly with the 85% of respondents who experienced eruptions in the Puna District (Murton and Shimabukuro 1974). Mauna Loa and Hualālai volcanoes will almost certainly erupt again, so consideration of people’s reactions is important in order to anticipate human behavior during future eruptions and to ensure that strategies developed to encourage preparedness can counter misconceptions. We asked respondents, “What would you do if a lava flow threatened you in your home?” (Table 3). The “other” data from Table 3 includes write-in responses presented in Table 4. Overall, the data suggest that there is no single and primary means of responding, and no clear picture of how to react to lava flows. A frequent response (61.6%) was to remove valuables from the home. While we did not evaluate the types of valuables that are expected to be removable during an eruption, we infer that these respondents believe that lava flows will move sufficiently slowly to permit removal of valuables. Removal of valuable property from houses, and whole structures themselves, has been common practice during recent eruptions at Kīlauea, because there is generally sufficient time between an alert and the arrival of lava flows in inhabited areas (US Geological Survey 1997). Combining the response “move to higher ground in order to avoid the flow” (Table 3) with the write-in responses “go to a safe place” and “go out to sea” (Table 4) into a general response of “evacuate,” makes it the second most frequent response (N=287; 63% of 456).

Table 3 Perceived response if a lava flow threatened respondent at home[a]

	N	(%)[b]
Listen to the radio/television for instructions from local authorities	321	70.4
Remove my most valuable possessions from my home	281	61.6
Move to higher ground in order to avoid the flow	221	48.5
Contact authorities for information	216	47.4
Immediately go out and take a close-up look at the lava	76	16.7
Other	108	23.7

[a] Respondents were asked to select a responses from those shown above
[b] Column does not equal 100 because respondents could record multiple responses

Table 4 Perceived response if a lava flow threatened respondent at home[a]

	N	(%)[b]
Go to a safe place	43	39.8
Go out to sea	23	21.3
Check on family	16	14.8
Check on neighbors	9	8.3
Spray water, construct barricade	6	5.6
Pray	4	3.7
Get pet	4	3.7
Other	14	13.0

[a] These are write-in data for the 108 respondents who wrote a response in the “other” category of Table 3
[b] Column does not equal 100 because respondents could record multiple responses

These data are interesting in light of the time available for response to lava flows in Kona. Several of these choices require a time frame that could be unrealistic. For example, the time needed for officials to confirm an eruption and disseminate evacuation information could exceed the time available before lava flows impact developed areas. Similarly, the time required for individuals to contact authorities, particularly if high traffic volumes clog telephone lines, could delay self-evacuation and removal of property. For responses that include checking on family, the lack of selection of an appropriate meeting place for family members could complicate response to an eruption unnecessarily. Also, more specific information on what constitutes "a safe place" and the types of valuables expected to be removed needs to be determined (given the potential for short warning periods).

The DPI advises that the telephone should be used only in serious emergencies in order to keep the lines clear for emergency communications. We assume, however, that the 47% who indicated they would contact authorities (Table 3) would do so using a traditional telephone or cellular phone. The data presented above suggest that the number of respondents who would call the authorities, if extrapolated to the community as a whole, is likely to exceed the capacity of the telecommunications systems and complicate the task of emergency management and scientific agencies to obtain, collate and disseminate information by telephone. The telephone system is unlikely to crash per se, but could yield busy signals for specific telephone numbers. While not examined specifically here, this point highlights the need for dedicated inter-agency information and decision-management systems to be developed, tested and implemented (Paton and Flin 1999). Currently, HVO and HCDA are connected by telephone, cell phone, radio, email and fax. Radio links are tested monthly.

In contrast to our data, Murton and Shimabukuro (1974) found that, in response to a question asking what action could be taken when an eruption occurred, 98 of 101 Puna respondents indicated "evacuate" and only two indicated "remove valuables." This latter percentage is in stark contrast to the nearly 62% of our Kona respondents. The low response for removing valuables at Kīlauea is surprising considering the frequency with which property has been removed from the paths of lava flows during recent eruptions. However, it is also encouraging. Some residents at least may have realized how quickly an eruption can evolve. Awareness of other adjustment options among respondents at Kīlauea was evident from further questioning by the interviewers. Caution should be used in contrasting the Kona and Puna data, because the Kona data are based on a written questionnaire whereas Murton and Shimabukuro's data were based on interviews, with additional questioning to extract more information. Our questionnaire provided only space for write-in answers. Nonetheless, the contrasts do suggest differing opinions regarding response to lava flows. Specifically, people in the Puna District had a common perception of how to respond (evacuate without removing valuables), whereas respondents in Kona were largely undecided (a majority listed three responses and no single response was selected by more than 70%).

Discussion

The absence of information about lava flow hazards in the DPI is a concern and could contribute to uncertainty about how to respond to them. It is unclear why the information is absent, given the recent and frequent impacts of lava flows on developed areas of the island, but it may reflect a degree of uncertainty about how to describe appropriate preparedness and response actions.

Responding to lava flows

Scientists, emergency response agencies and the community at large lack experience in dealing with Kona lava flows because of the long time since lava flows last occurred there. This lack of experience may hamper evacuation of people and valuable property. Some people will likely need to be evacuated to the ocean or by helicopter, owing to the limited number of roads in Kona that can be used for evacuation. For these reasons, there is a need for evacuation planning, followed by outreach programs to improve public response capabilities. Furthermore, curiosity will draw sightseers (residents and tourists) to the eruption; evacuation and response plans must include how to manage the logistics of these people.

Our respondents underestimated the velocity with which lava flows can travel in Kona and so may overestimate the available time to react and thus their current levels of preparedness. More outreach is needed to alleviate this perception. Also, the short time frames within which scientific, emergency management, and community responses must be made, say between the onset of tremor and the arrival of lava in inhabited areas, is another potential concern. There is a clear need for advanced planning for eruptions in the areas of highest hazard and risk. This largely includes the entire Kona population from the terminus of the 1859 flows in North Kona southward to the 1868 lava flows on Mauna Loa's southwest rift zone (Fig. 1c, Hawai'i State Civil Defense 2002).

Weisel and Stapleton (1992) reported that many evacuees of Kalapana (Fig. 1b) on Kīlauea chose to evacuate to a temporary camp in Kalapana as opposed to official shelters some 12 miles away. This reiterates the importance of official plans that accommodate local values and opinions. If planning is not done, evacuation may contribute to, rather than ameliorate, stress among affected people. There is a need to evaluate the public's options and intentions regarding temporary shelter.

The siren

Awareness of the meaning of the siren by only a minority of residents (46%) is a significant concern, particularly for students. The provision of siren information in the telephone book, and routine siren tests, have not promoted high levels of understanding of the siren, indicating a need to reevaluate how this important information is disseminated.

What now?

The following are suggested starting points for improving the official and public capacity to meet effectively the demands of future lava flows in Kona.

– Development of evacuation plans based on an assumprion that certain key roads will be blocked, as recommended as implementation strategies in the Lava Flow Hazard Mitigation Plan (Hawai‘i State Civil Defense 2002):
– Evaluation of the carrying capacity of public telephone and cell phone systems in light of the agencies that respondents intend to contact during eruptions;
– Co-ordination of monthly siren tests with radio and television advertising, and testing of the communities' interpretation of the siren, to raise understanding of the meaning of the siren and to ensure that repeated testing does not lead to people overestimating their capacity to respond;
– Creation of brochures that show evacuation routes (including the contingent routes – see above) and safe areas distributed to residents. A team of local officials from Kona communities should assist in the development of the evacuation and response plans (including advising people of areas they may wish to identify as family meeting places);
– Similar information provided for tourists and distributed via hotels and motels in a manner similar to successful exercises for hurricanes on Kaua‘i and tsunami in the State of Washington;
– Specific outreach for Kona to promote the development of effective home-based preparedness measures for lava flows. A range of educational materials specific to Kona are needed to raise the level of preparedness for lava flows. Techniques could include public seminars, media coverage, a web site, video and school lesson plans which have a homework component that promotes student and parent or guardian interaction. Preparedness should include, but is not limited to:

1. Knowing the range of volcanic threats and corresponding risk posed to individuals and their property;
2. Being familiar with natural warning signs of an eruption (e.g. tremor, earthquakes, lava glow, fume jets, etc) and knowing that the siren means to listen to a radio or television for information from officials;
3. Knowing how and where to obtain emergency information and assistance and to organize and maintain an emergency supply kit as described in the DPI;
4. Knowing the range of likely warning periods and the types of personal property items that can be removed within these periods;
5. Knowing evacuation routes and having an evacuation plan, and alternate plan in case roads are blocked, as well as knowing where and how to contact and meet family if they are separated.

– Modification of the DPI in the Hawai‘i telephone book to include volcanic hazards, particularly as they relate to *how to prepare for and respond to lava flows in* Kona. The expected range of warning times before the eruption begins, as well as the expected range of travel times for lava flows to reach developed areas should be clearly stated. The telephone book should not be the only means for disseminating this type of information.

Conclusions

Social and demographic characteristics and lava-flow hazards in Kona are generally different from those in areas of the Puna District where eruption frequency and experience in responding to lava flows is greater. These differences require that official and public preparedness and response measures for eruptions be tailored for Kona and even cultural differences between subsets of the Kona population. Future outreach efforts aimed at, for example, increasing understanding of the warning siren or adoption of preparedness and response measures, must acknowledge that people with contrasting backgrounds differ in the manner in which they receive, interpret, and utilize information prior to and during volcanic crises. It is critical to know the impact and value of future outreach efforts, which will necessitate longitudinal surveys of hazard perception and preparedness.

This exploratory survey has highlighted a number of problems and indicates a need for better links between volcanologists, emergency managers and Kona communities. It is crucial to focus efforts by these groups on promoting and enhancing preparedness intentions and actions, rather than further improvements in the supply of hazard information. A rapid, effective response, building on realistic understanding of the threat and risk to lava flows in Kona, is critical for community resilience in responding to future eruptions. The recent change from deflation to inflation at Mauna Loa, which has been interpreted as potentially an early precursor of future eruption, adds some urgency to this work (US Geological Survey 2003).

Although this paper has generally focused on the threat of faster-moving lava flows, all flows in Kona may not necessarily be emplaced rapidly. Slower lava flows can be expected during eruptions with lower effusion rates and in areas where the slope is low (e.g., portions of coastal North Kona).

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