MODELING VOLCANIC ASH DISPERSION AND ITS IMPACT ON HUMAN HEALTH AND COMMUNITY RESILIENCE

TECHNICAL REPORT AND PRELIMINARY RESEARCH PROPOSAL

Graham A. Tobin
Department of Geography

Linda M. Whiteford
Department of Anthropology

Charles B. Connor
Department of Geology

University of South Florida

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GLOBALIZATION RESEARCH CENTER
UNIVERSITY OF SOUTH FLORIDA

EXECUTIVE SUMMARY

This technical report outlines the potential for a research project on volcanic hazard modeling to be carried out in the vicinity of Cerro Negro, Nicaragua. Preliminary fieldwork was undertaken by the three PIs in February 2002 with funding provided by the Globalization Research Center at the University of South Florida.

The primary objective of the proposed research is to increase our understanding of the human consequences of natural disasters by integrating geologically based models of volcanic ash dispersion with hazard models (geographical and anthropological) of human health and resilience. The long-term goal is to develop a predictive model for volcano hazard mitigation by linking methods in numerical simulation of volcano eruption phenomena, natural hazards science, and our growing understanding of community response to natural hazards during crises. In particular, we are concerned with the effect of ash falls emanating from volcanic eruptions, and how they have short- and long-term consequences for people living in the shadow of volcanoes. Short-term consequences may be measured in terms of malnutrition and infectious disease rates, while the longer-term effects may be seen in overall community resilience. The general aims of the research, therefore, are to assess the applicability of ash dispersion models developed by Connor and others to the model of community health and resilience presented by Tobin and Whiteford.

Specifically, the research will:

1) refine the ash dispersion model developed by Connor.
2) track disease rates (especially respiratory) following ash fall
3) assess local and national perceptions of the assistance programs with particular attention to post-evacuation economic development
4) evaluate socio-economic impacts following ash fall and evacuation strategies
5) build a model to improve community resilience following ash fall and disaster-related evacuation
6) provide transfers of technology and training between the Nicaraguan and US participants.

The proposed research is a development of currently funded research on human health and community resilience during volcanic crises, undertaken in Ecuador by Tobin and Whiteford, and research on the development of models of volcanic eruption phenomena by Connor. This major research initiative is designed to generalize our interdisciplinary approach to natural hazards and diverse socio-economic settings.

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OBJECTIVES AND AIMS

The primary objective of the proposed research is to increase our understanding of the human consequences of natural disasters by integrating geologically-based models of volcanic ash dispersion with hazard models (geographical and anthropological) of human health and resilience. In particular, we are concerned with the effect of ash falls emanating from volcanic eruptions, and how they have short- and long-term consequences for people living in the shadow of volcanoes. Short-term consequences may be measured in terms of malnutrition and infectious disease rates, while the longer-term effects may be seen in overall community resilience. Although measures of community resilience are still exploratory, we combine them with more established indicators including socio-economic, demographic, infra-structural and leadership variables. The general aims of the research, therefore, are to assess the applicability of ash dispersion models developed by Connor and others (Conner *et al.* 2001; Hill *et al*. 1998, 1999, 2001) to the model of community health and resilience presented by Tobin and Whiteford (2001a, 2002a) and Whiteford *et al.* (2002a, 2002b).

Specifically, the research will:

7) refine the ash dispersion model developed by Connor *et al.* (2001)
8) track disease rates (especially respiratory) following ash fall
9) assess local and national perceptions of the assistance programs with particular attention to post-evacuation economic development
10) evaluate socio-economic impacts following ash fall and evacuation strategies
11) build a model to improve community resilience following ash fall and disaster-related evacuation
12) provide transfers of technology and training between the Nicaraguan and US participants.

Long-Term Goals

The long-term goal of this research project is to develop a comprehensive model for volcano hazard reduction by linking methods in numerical simulation of volcano eruption phenomena, natural hazards science, and our growing understanding of community response to natural hazards during crises. This research will integrate the normally disparate views of natural hazards found in the natural and social sciences through the implementation of modern information technology research (ITR) strategies. Such a research program will dramatically enhance the utility and timeliness of many types of hazard assessments, and improve the economy of data collection in areas exposed to extreme geophysical events. Our goal is to take the "crisis" out of community response to natural hazards by developing a predictive model.

We will test our initial ideas about application of ITR methods in one arena of natural hazard reduction – volcanic eruptions, and in a region adversely affected by eruption phenomena –

central Nicaragua where one of the PIs (Connor) has considerable research experience. The proposed research is a natural development of currently funded research on human health and community resilience during volcanic crises, undertaken in Ecuador by Tobin and Whiteford (Tobin and Whiteford 2001a, 2001b, 2002a, 2002b, 2002c; Whiteford *et al.* 2002a, 2002b, 2002c) with support from the Center for Disaster Management and Humanitarian Assistance, and research on the development of improved models of volcanic eruption phenomena, funded under NSF's ITR small-grants program (Connor *et al.* 2001). This major research initiative is designed to generalize our interdisciplinary approach to diverse natural hazards and socio-economic settings.

LITERATURE REVIEW

There is a growing literature on ash modeling, hazard response, and disaster mitigation practices that encompasses a range of academic disciplines (Alexander 1993; Mileti 1999; Oliver-Smith 1999; Quarantelli 1998; Sigurdsson, 2000; Smith1996). Much of this research has been extremely productive, enhancing our understanding of hazard processes, facilitating the building of explanatory models, and leading to practical applications of the findings. The proposed research reflects a multidisciplinary perspective, and as such the literature reviewed will encompass geology, hazards, and infectious disease reports. This review focuses on a small portion of the literature, looking specifically at volcanic risk models related to transportation and deposition of tephra; human health, particularly infectious diseases; and hazards, particularly community resilience issues associated with long-term, on-going disasters. The significance of vulnerability and marginalization is also addressed within the context of prevailing cultural, economic, and political factors. In addition, while lessons can be learned from all natural hazards, here special attention is given to the volcano hazard.

Volcanic Risk Modeling

Volcano science strives to improve the quality and timeliness of volcanic risk assessments and to provide these assessments in a form amenable to hazard reduction. Most often, volcanic risk assessments are based on real-time or near real-time observations of volcanic activity, such as rates of seismic energy release and ground deformation (Carey 1996; Hill *et al.* 1999). These data have been proven repeatedly to be excellent qualitative indicators of the potential for volcanic eruptions. Unfortunately, the geophysical indicators of magma intrusion provide little or no valuable information about the potential magnitude of eruptions, the areas around the volcano most likely impacted by eruptions, the nature of these impacts, or the longevity of volcanic unrest.

Evaluating the range of possible outcomes of geologic processes, such as volcanic eruptions, may be achieved by utilizing probabilistic techniques that propagate uncertainty estimates through stochastic simulations (Armienti *et al.* 1988). This is certainly true in volcanology, a field in which estimates must bound the range of possible consequences of volcanic activity, drawing from the geologic record, from analogy, and from an understanding of the physics of volcanic processes (Scarpa and Tilling 1996). Funded work is currently underway at USF to develop a first-generation data and model assimilation system for volcanic forecasting to meet these requirements (Connor *et al.* 2001).

Numerical models to determine tephra deposition and accumulation are important tools in assessing risks associated with volcanic eruptions (Glaze and Self 1991; Koyaguchi 1996). Such tools can be used far in advance of future eruptions to calculate possible hazards as conditional probabilities. That is, given that a volcanic eruption occurs, what is the expected range of outcomes? An empirical model developed by Suzuki (1983) uses specific characteristics of a volcanic eruption to calculate the ash accumulation at points away from the vent. Cast as a probabilistic model, Suzuki's model uses characteristics of historical eruptions or data from analogous eruptions, to predict the expected tephra deposition from future eruptions. For example, according to a risk assessment study by Hill *et al.* (1998), the potential tephra fall from Cerro Negro in León, Nicaragua, is calculated as 2.2 mm/yr until 2006, with 95 percent confidence that deposits will be less than 11 cm thick.

However, the geologic record is biased toward large, infrequent events that leave a distinctive geologic record. Smaller, generally more frequent, eruptions often leave no discernable geologic record. Furthermore, the historical record is very short for most volcanoes and hence poorly reflects the full range of activity a given volcano might have experienced.

The disparity between historical and geological records is particularly evident at Telica volcano, Nicaragua, where there is nearly complete disjunction between historical and stratigraphic records. Dozens of explosive eruptions have been recorded in the last 500 years, but few scoria layers from this period are preserved in the geological record. It is clear that the preserved sequence includes just a fraction of the eruptive events, biasing the geologic record toward large eruptions. Nevertheless, the style of eruptive activity may have also changed over time. Modeling these data and estimating parameter distributions that best fit the data can help resolve this disparity. For example, if complex, multi-modal parameter distributions are needed to model the historical and geological data sets together, non-stationary behavior in eruption style may be indicated. Alternatively, if comparatively simple parameter distributions model both historical and geological data sets, then the brevity of the historical record may account for the disparity. As this disjunction between geological and historical data sets is a classic situation, common to many volcanoes, a crucial activity in this work will be to formulate methods to reconcile geological and historical records through model fitting and parameter estimation.

Community Resilience: Vulnerability and Marginalization

To address community resilience, attention must be given to the contextual conditions of society, notably to issues of vulnerability and marginalization. Human vulnerability to disasters is described by Blaikie *et al*. (1994) in terms of a model in which underlying factors and root causes embedded in everyday life give rise to dynamic pressures that affect particular groups and lead to unsafe conditions. Research has shown that groups that are socially, economically, or politically removed from the mainstream of society, tend to experience disproportionately high impacts of natural hazards. Hewitt (1997) describes vulnerability as "…a product of the circumstances that put people and property on a collision course with given dangers, or that make them less able to withstand or cope with disaster." Vulnerability, therefore, depends upon pre-existing conditions of material and social life, not merely the geo-physical event itself. Thus Hewitt (1997:148) states,

> In a disaster, those most likely to be harmed are distinctly more disadvantaged, and in multiple respects. Some people seem driven into, or trapped by, vulnerability 'syndrome.' Rather than some single weakness or category, they are victimized by a whole social context.

As pointed out by Mileti *et al*. (1991:78) refugees from the 1985 eruption of Nevado del Ruiz in Colombia,

> …suffered from low education levels, lack of economically viable skills, and poverty even prior to the disaster. This could be because… a high proportion of survivors had lived in outlying areas populated by low-income groups. It has also been found that those with enough resources to reestablish themselves will not normally be found in the refugee camps. Previous disaster research indicates that economic and social marginality prior to a disaster affects the ability of individuals and families to reestablish themselves after a disaster. Those with personal resources or strong support networks of kin move away from dependence on assistance programs and reestablish themselves using these other resources.

Various studies support this finding. Rees (1979) points out that ash requires the addition of fertilizers before corn will produce, the cost of which may make farming uneconomical for small farmers in underdeveloped areas. In the Mexican community that Rees studied, farmers whose cattle died as a result of ash fall also lost the means to plow their land. Similarly, Chester (1993) shows that in addition to economic and demographic factors, deep-seated historical, cultural and social characteristics are also of importance. Thus, the consequences of volcanic hazards may impact some groups in society more than others, including particular ethnic groups (Chester 1993). Finally, the disruption caused by volcanic disasters can lead to societal changes. Blong (1984), for instance, from his analysis of the longer-term social changes associated with eruptions of Mt. Lamington (Papua New Guinea, 1951) Paricutin (Mexico 1943-52), Tristan da Cunha (Azores 1961-62), and Niuafo'ou (Tonga 1946), recognizes that volcanic eruptions hastened social change in these less-wealthy countries. Thus, volcanic disasters can act as catalysts accelerating the rate at which adjustments in social and political institutions occur.

While early sociological work suggested that hazards have a therapeutic effect creating community solidarity with an altruistic perspective (Drabek and Key 1984; Perry and Lindell 1978; Western and Milne 1979), recent literature has shown this period does not last and conflicts within social systems invariably arise (Bolin, 1998). Such conflicts develop because of competition for limited resources, and those with the least resources in a social system facing a disaster are usually the hardest hit and least able to cope (Peacock and Ragsdale 1997; Yelvington 1997). Indeed, hardships could be multiplied many times over for populations facing adversity on a daily basis under disaster conditions, as was demonstrated with the poor populations of South Dade County, Florida who remained homeless nearly a year following Hurricane Andrew (Dash, *et al*., 1997). Thus, researchers have suggested that community resilience requires that local officials and disaster response teams be prepared for negative effects due to disasters (Bolin 1988; Noel 1998; Robertson 1998). Such preparation might include extensive mapping of communities, noting population characteristics and areas of increased vulnerability (Girard and Peacock 1997) and provision of resources to mitigate the negative effects (Bolin 1988). Community resilience, therefore, depends on how communities respond to crises in pre and post-disaster situations. Community resilience is also dependent on both pre-existing social, economic, and political conditions, as well as post-disaster responses, relief efforts, mitigation strategies and longer-term rehabilitation programs. Furthermore, vulnerability is integral to resilience and requires greater understanding (Boyce 2000).

Infectious Diseases

Infectious disease rates and peoples' ability to withstand them, have long been considered measures of community health. McNeil, in his classic book, *Plagues and Peoples* (1976) credits epidemics with the collapse of New World Civilizations. Even Napoleon was unable to defeat epidemic disease. According to Zinsser (1976:162) Napoleon's army was defeated at the Russian front by "increasing sick rates, at this time largely due to respiratory infections, including pneumonia and throat anginas – probably diphtheria. Typhus cases [also] began to appear." Weakened by exhaustion, malnutrition, bacteria and viral infections, the French army was no match for the onslaught of natural forces. Likewise, people who have been forced to leave their homes, live in unusual surroundings, experience the loss of their traditional life ways and sources of emotional and economic support are at high risk for infectious disease.

The disruption of water and sanitation systems following disasters can lead to outbreaks of cholera, typhus, and other infectious/communicable diseases which often kill more people than the geo-physical event itself. Similarly, long-term evacuation and the consequential personal and familial disruptions may not kill directly, but can render those affected less able to fight off disease, and contribute to the hard work of putting their lives together again. Thus community recovery will be compromised.

Attempts to measure the relationship between health/illness and quality of life have been codified by the World Health Organization and the World Bank as QALYs (quality adjusted life year). "The unit of analysis is most often some measure of life saved, adjusted for the health and other conditions of life...[s]ome authors interpret the QALY as a measure of the utility of the outcomes of a project (hence the name cost-utility analysis (CUA).... [T]he CUA ratio used for making decisions is thus a measure of dollars per QALY" (Jack 1999:250). However, as the author points out: "Because it remains an average cost concept, it suffers from the same problems regarding project size as the standard cost-effectiveness ratio" (Jack 1999:250). Serious problems remain with the use of QALYs to measure effectively, let alone provide insight in the experience, of living with chronic or actual illness. QALYs are designed to provide a gross measure of the difference between living (and, especially, working) with two "fully working limbs" rather than one working limb and a broken leg (Jack 1999:250).

Triangulation for the Study of Infectious Disease: Inhorn and Brown (2000) recommend that the study of infectious disease be pursued using a combination of research techniques drawn from epidemiology and cultural anthropology, by employing approaches such as in-depth interviews, direct observations, retrospective and prospective data collection methods, and surveys. By combining both ethnographic and epidemiological methods, the research may diminish observer effects and other untoward consequences of over-reliance on a limited research schema. In addition, including a focus on the individual, household, and community levels allows researchers a wider context in which to understand responses to the initial hazard as well as to the on-going risk (Coreil 1991; Coreil *et al*. 2000; Whiteford *et al*., 1999).

On-Going Hazards

While all natural hazards represent ongoing threats, in the sense that an area is hazard prone, most are not considered *active* for long periods. The actual flood or earthquake, for instance, occurs and is then over, leaving the community to deal with the post-disaster event. The *threat* remains because the flood or earthquake will inevitably occur again. The hazards literature, then, is replete with studies examining immediate post-disaster impacts, but long-term concerns have received less attention (Mileti 1999). This research focuses on the longer-term, particularly those events that constitute continuing, on-going problems to community health and resilience associated with volcanic eruptions.

The Volcano Problem: Volcanoes, especially those associated with strato-volcanoes that have a potential for major eruptions, often present on-going hazard problems. Certainly major eruptions would be devastating for adjacent areas, as witnessed by the explosion of Mt St. Helens in 1980, which destroyed thousands of hectares of forest (Cook 1981). However, more pervasive are the smaller scale, secondary activities, in the form of minor eruptions, ash falls, pyroclastic flows, lahars, lava flows, mud flows, landslides, and flooding. These can continue intermittently for months or even years, and hence represent on-going problems that cause damages and losses for a long time (Chester 1993; Sigurdsson 2000; Smith 1996). For instance, ash falls destroy crops, harm livestock, contaminate water supplies, and are implicated in the increase in respiratory diseases (Baxter 2000; Malillay *et al.* 1997; Whiteford *et al.* 2002a). Communities in such areas, therefore, face a continuing battle, and recovery efforts can be curtailed by further geo-physical activity. Unfortunately, studies of the impacts of these on-going events on local populations are not common and they rarely address the context of cultural, political, and economic conditions that help precipitate the disasters. Thus, further research is necessary to model how communities cope in such hazardous environments.

Evacuation Strategies

One response to the imminent threat of disaster is evacuation to remove people from the impact area (Lindell and Perry 1992). Indeed, evacuations associated with tropical cyclones, flooding and even tornadoes have been credited with significantly reducing the number of deaths accruing from such events (Tobin and Montz 1997). However, there are other impacts associated with evacuation practices that must be examined, especially when people are away from their homes for prolonged periods. Social disruption, unusual economic straits, increased communicable disease exposures, and political turmoil are possible outcomes that are not fully understood (see Cernea 2000 for review).

The effectiveness of evacuation practices is, in part, contingent upon (i) the decision to evacuate and dissemination of the warning message; (ii) the practical management of the evacuation; and (iii) the conditions of the place of refuge relative to previous domestic conditions. It is essential, for instance, that the threat be perceived as real if individuals are to take effective remedial action. They must not only believe the message, but also perceive that the consequences of not taking action places them at high personal risk (Lindell and Perry 1992). Unfortunately, the initial reaction is usually one of skepticism, and scrutiny of the warning source invariably follows (Perry 1982). Thus, perception of risk is an important variable in determining the effectiveness of proposed evacuation projects and need to be examined carefully. Employing forced evacuations, perhaps through military intervention, can overcome this particular difficulty and save lives, but in the long-term may introduce additional problems (Tobin and Whiteford 2001a). Faith in the military can be diminished and there can be negative political fall out for community leaders. A positive response to evacuation warnings is also contingent upon (i) the individual or family unit perceiving a positive outcome from their action; and (ii) the family or household being assembled as a unit (Chester 1993; Lindell and Perry 1992). These two factors will help determine to some extent how people react and hence must be addressed. Thus, research should focus on modeling such behavior with a view to improving warning response rates.

Volcanoes and Evacuation: Response to any warning message is closely related to perception of risk (Tobin and Montz, 1997), although in the case of volcanoes this can be a multifaceted problem because of the many secondary effects of the hazard. While these secondary events can be destructive, they also provide growing reminders of the volcano threat, and research has shown that visual evidence can significantly enhance hazard perception and hence elicit a better response to warnings. For instance, Lindell and Perry (1992) demonstrated that physical clues, particularly ash deposits and minor eruptions, were important influences on peoples' decisions to evacuate. Thus "minor" events may help precipitate better responses. On the other hand, if a volcano has been dormant for some time, it may be difficult to initiate an effective evacuation (Punongbayan *et al*. 1996). Mileti *et al*. (1991) in Colombia in 1985, and Newhall and Punonbayan (1996) in the Philippines, showed that limited local experience with volcanic hazards was associated with poor perception of the risk, which led to inappropriate responses.

Evacuation also raises questions of leadership and threatens social stability at the new location. How should the resettlement be organized to maintain stability while promoting self-sufficiency? Development literature indicates that relief, such as food, money and other resources, can significantly undermine traditional economies and exacerbate long-term difficulties for evacuees (Bautista 1996: Blaikie *et al*. 1994). There is also the possibility that evacuees will eventually ignore the risk and return home, as occurred in Baños, Ecuador (Tobin and Whiteford 2001a). In fact, aid from governments and Non-Governmental Organizations (NGOs), while extremely important in terms of disaster relief, can lead to dependency issues and often fails to address underlying causes of vulnerability, such as poverty (Farrington *et al*. 1993; Natsios 1997). Ties with development issues in less wealthy countries, therefore, further complicate the hazard relief picture (Edwards *et al*. 1999; Whiteford *et al.* 2002a). In addition, decision-making can have political and electoral consequences for leaders as the social system changes (Punongbayan *et al.* 1996). It is this social change that has an impact on community resilience and recovery that needs to be addressed in the research.

Well-Being and Evacuation: Other factors, such as cultural and religious beliefs (Blong 1984), fear that property left behind will be stolen (Lindell and Perry 1992), and close ties to family income sources (e.g. farmland and animals) in the home location (Cola 1996) also contribute to a willingness or reluctance to evacuate. Indeed, a strong attachment to place is closely correlated with a reluctance to evacuate (Cola 1996; Dibben and Chester 1999). Cola (1996:148) stated that,

> Those who evacuated longed for the community that had nurtured them and had provided them with a sense of security produced by generations of patterned interactions. Leaving their community entailed changing one's economic base and also leaving a social world in which they were adept and comfortable.

This tie to place was exemplified by the behavior of residents in Baños, Ecuador, who broke down military barricades to return home following a forced evacuation (Tobin and Whiteford 2002a, 2002b) Thus, impacts on local social networks, and traditional economic systems must be considered more fully particularly if evacuation is to be long-term. In the final analysis, people are often faced with two choices: return home where the risk of death or injury may be severe, or remain in the evacuated area and suffer significant social and economic disruption that may place their long-term livelihood in question.

Conditions at the new location may also contribute to the decision to return home. It is not unusual for refugees to be housed in less than satisfactory conditions, including tents, portable buildings, and large halls with communal facilities. In some cases, evacuees are placed in shelters that are over-crowded and supplied with few resources. Communicable childhood diseases, such as chickenpox or measles, can sweep through a shelter where many non-immunized children may be living in close quarters (Tobin and Whiteford 2001b; Whiteford *et al.* 2002a). Under these conditions, the spread of infectious diseases can be a significant problem (Inhorn and Brown, 2000). Nutritional status may change as a result of reduced access to food supplies, or reliance on unfamiliar foods (Whiteford and Tobin 2001a). Furthermore, after several weeks living in such conditions, violence and other anti-social activities can break out (Yelvington 1997). In other instances, evacuees have been resettled within local communities. While these communities may at first welcome the displaced persons, after a time antagonism can develop amongst groups as competition for resources increases as was found in Quimiag, Ecuador (Tobin and Whiteford 2001a). At times, evacuees may receive more direct aid than the locals. Again, such population movements can destroy traditional social networks and alter perception such that safety is compromised (Hewitt 1997; Lindell and Perry 1992). Thus, dissatisfaction with the new community can exacerbate a feeling of loss of well-being and nostalgia for the old location (Neumann 1997) and further promote the return of evacuees.

Therefore, the effectiveness of evacuation measures is determined by the interplay of different cultural, economic, and political forces. These forces must also be placed within the temporal (historical) and spatial context of the specific location, if we are to understand fully the ramifications of evacuations. As with all forecasting and warning decisions, then, there is a trade-off between the reducing risk exposure through evacuation and the concomitant increase in social, economic, and political disruption. It is this area that needs to be addressed more fully by hazard researchers.

Health and Disasters

The third part of this research looks at the related issue of public health and disasters. This literature can be divided into two broad categories: (i) community and public health indices following a disaster, particularly patterns of infectious disease and malnutrition (Baxter 2000; Brown 2000; Cody *et al*. 2000; Howarth 1997; Inhorn and Brown 2000; McClain 2000; Mull 2000; Nations and Monte 2000; Nitcher 2000; Noji 1997a); and (ii) mental health of disaster survivors (Caplan 1976; Cohen and Ahearn 1980; Institute for the Studies of Destructive Behaviors and Los Angeles Suicide Prevention Center 1978; Lystad 1985, 1988; Saleh 1996; Shannon 1994; Ursano *et al*. 1994; U.S. Department of Health and Human Services 1995).

All people with compromised immune systems, people under high stress, those whose bodies have experienced various assaults are at high risk of respiratory infections. The elderly and the very young are most at risk, and pregnant and nursing mothers are often unable to resist the upper and lower respiratory infections that sweep through crowded areas like schools or shelters. Upper respiratory infections are expressed as sore throats, and irritation and infections of the upper chambers of the lungs and bronchii, while lower respiratory infections often manifest themselves as pneumonia and other more compromising infections. Individuals experiencing an on-going threat of a natural hazard such as a volcano, or those having been moved from their homes into temporary shelters will be of the highest risk category for infectious disease, particularly respiratory disease. Thus, a concern of disaster and health literature is public health issues including morbidity, mortality, and the spread of communicable diseases (Noji 1997a). Much of this work relies on epidemiological and ethnographic methods that attempt to identify and explain patterns of health outcomes among various different groups (Noji 1997b).

The combined ethnographic and epidemiological perspective is valuable within disaster research because it focuses directly on prevention of adverse health effects and can predict probable health outcomes (Janes *et al.* 1986; Noji 1997b; Trostle 1986; Whiteford and Manderson 2000). Indeed, since the late 1970s, there has been an increasing recognition of the utility of ethnographic as well as epidemiological research applied to infectious diseases such as HIV (Singer 1994; Green 1999), Tuberculosis (Farmer1999), sexually transmitted diseases (Kielman 2000), dengue fever (Coreil, *et al*. 2000; Whiteford 1999), diarrhea (Bentley *et al.* 1988; Nichter 1993; Scrimshaw and Hurtado 1988; Whiteford 1999) and respiratory infections such as acute respiratory infections (ARI) (Gove and Pelto 1994: Hudleson, *et al*. 1994; Mull and Mull 1994; Nichter and Nichter 1994; Pelto 1996) to name but a few. In addition, public health officials conduct needs assessments of survivor populations in order to help mobilize much needed resources to disaster areas (U.S. Department of Health and Human Services 1992).

Researchers in the arena of international health have long noted the high child mortality rates caused by infectious diseases. In 1995, acute respiratory infections (ARIs) killed more than 4 million children worldwide (Kirkwood, *et al,* 1995 cited in Mull, D. 2000). Many variables are implicated in childhood ARIs, including poverty, malnutrition, lack of access to prompt, accessible, and inexpensive healthcare, crowded living conditions, indoor air pollution, and food insecurity. According to Mull (2000), most of these deaths are due to infections of the lower respiratory system, such as pneumonia. Thus, in volcanic areas, ARI is an important outcome variable because both ash fall, which can act as an irritant, and evacuation, which brings about changed living conditions with overcrowding and increased food insecurity, can influence morbidity and mortality patterns. Many people, but especially children die from treatable diseases like pneumonia in the mistaken assumption that they are suffering from some other, less severe but similar disease. In the case of childhood pneumonia, the child is often assumed to be suffering from a cold instead of more life-threatening form of ARI. This is not unusual; in the 1993 cholera epidemic children died because they were not treated with antibiotics because their caretakers assumed the "just had diarrhea" (Whiteford 1999).

In addition to increases in levels of infectious disease and malnutrition, public health can be adversely affected during and following a disaster event in many ways. Public utilities may be destroyed or temporarily rendered unfit for use (Noji 1997c). Basic health services may be disrupted, which can be particularly detrimental in developing countries because they often lack the resources to set up alternative forms of health care (Noji 1997c; Whiteford *et al.* 2002a). Moreover, shelters and other forms of temporary housing, can serve to spread a number of communicable diseases quite rapidly (Noji 1997a; Tobin and Whiteford 2001a).

Studies of the mental health of disaster survivors have focused on how different social and cultural variables affect levels of Post-Traumatic Stress Disorder (PTSD) following a disaster (Bolin 1988; Marsella *et al.* 1996; Shannon 1994). This work has highlighted the significance of pre-existing structural conditions of communities, particularly social inequalities and conflicts that affect stress (Dash, *et al*. 1997; Peacock and Ragsdale 1997; Yelvington 1997). For example, women and minorities may exhibit lower levels of emergency mobilization and/or increased levels of disaster-related stress due to a number of inter-related variables (Dash, *et al.* 1997; Enarson and Morrow 1997; Gladwin and Peacock 1997; Ollenburger and Tobin 1998; Tobin and Ollenburger 1996).

Other health-based studies have focused on the correlation between the disaster severity and individual or community mental health (Figley 1985; Green 1985); the effects of particular kinds of disasters (Bolin 1982; Greenson and Mintz 1972; Leivesley 1977); and the range of mental health responses to the various phases of a disaster (Figley 1985; Zusman 1976). Studies indicate that children disaster survivors can exhibit adverse behavioral and emotional effects that are also correlated with gender, race, and ethnicity (Burke *et al*. 1986; McFarlane 1987; Shannon 1994). Mental health, however, is not addressed in this particular research.

This research, therefore, seeks to integrate ash dispersion models from the physical sciences with humanistic models of community resilience and health.

RESEARCH HYPOTHESES AND THEORETICAL FRAMEWORK

RESEARCH HYPOTHESES

In an attempt to facilitate more effective hazard mitigation in volcanic areas, the PIs will attempt to:

1) refine the ash dispersion models so that it is possible to predict, not only the time of an eruption, but also ash fall distribution across the landscape; and
2) model community resilience, with special attention to community health.

The integration of these models should enhance hazard mitigation and decision-making and consequently ameliorate hazard impacts.

> It is hypothesized that the incidence of infectious and respiratory diseases will be highly correlated with frequency and depth of ash falls and with the evacuation, and that specific evacuation practices, notably the use of displaced person shelters, will exacerbate health problems. Specifically, community resilience and health will be compromised by the length of time spent in shelters and the extent and frequency of the ash falls.

Research Questions

Several research questions develop from this hypothesis:

1. How do different ash characteristics, such as depth, frequency, and composition, affect local communities?
2. Does exposure to high levels of ash fall cause people to experience higher levels of both upper and lower respiratory problems than those not living in high ash fall areas?
3. Does evacuation cause higher levels respiratory disease as measured by levels of upper and lower respiratory problems, when compared with non evacuated populations? Does shelter experience increase the likelihood of respiratory disease?
4. Are there fewer respiratory health problems among people living in areas where they neither experienced high ash fall nor were evacuated than those either evacuated or living in high ash fall areas?
5. Do people who experienced evacuation also experience higher levels of nutritional disease and food insecurity than those not having been evacuation? If so, is this due to loss of crops/income during the evacuation period?
6. Are levels of malnutrition and/or nutritional distress higher among populations living in areas of high ash fall? For example, due to crop failure caused but the corrosive effect of ash on the crops.
7. Is there a relationship between the time spent away from the home and increased disruption within the community and that could be correlated with measures of community resilience?

THEORETICAL FRAMEWORK

Geo-physical aspects of disasters combined with mitigation strategies, such as evacuation, can have direct impacts on community resilience and population health. Indeed, the ability of the community to recover is contingent upon not only a healthy population but also an effective response to the hazard. Thus, to fully understand how community resilience and health can be enhanced, we need to understand the workings of the social, economic, and political forces that operate within a community, looking at all phases of a disaster (pre-impact, impact and post-impact).

Ash Dispersion Models

The goal of probabilistic volcanic hazard assessment is to translate complex volcanological data and numerical models into practical hazard estimates for communities potentially affected by volcanic eruptions. Probabilistic volcanic hazard assessment quantifies volcanic hazards and illustrates uncertainties about the magnitude and consequences of volcanic activity. Planning based on probabilistic volcanic hazard assessment has the potential of mitigating the effects of volcanic eruptions before they occur.

One way to model volcanicity, is to assign conditional probabilities to different components of volcanic activity. Connor *et al.* (2001) looked at this with regard to Cerro Negro volcano in Nicaragua (Figure 1). The event tree for this volcano shows a conditional probability of 12.5 percent for a tephra accumulation of 1 to 4 cm following a moderate volcanic eruption of VEI 2 (Volcanic Explosivity Index). However, these probabilities are based on historical events and geological records, which means that data are limited regarding range and quantity. For instance, Cerro Negro has had no eruptions greater than VEI 3. Consequently, the model is subject to considerable error.

Numerical simulation builds on such decision-trees. The overall benefit of numerical simulation lies in the promise of improved ability to quantify the expected variability in the volcanic system and consequently to improve hazardous estimates (Connor *et al.* 2001). Development of tephra fallout models has recently been reviewed by Carey (1996), Sparks *et al.* (1997), and Rosi (1998). The present study illustrates the integration of tephra fallout models into a probabilistic volcanic hazard assessment using the model developed by Suzuki (1983) and subsequently modified and applied to volcanic eruptions by Armienti *et al.* (1988), Glaze and Self (1991), Jarzemba (1997), and Hill *et al*. (1998). Suzuki's model is empirical; the erupting column is treated as a line-source reaching a maximum height governed by the energy and mass flow of the eruption. A linear decrease in the upward velocity of particles is assumed, resulting in segregation of tephra particles in the ascending column by settling velocity, which is a function of grain size, shape, and density. Tephra particles are removed from the column based on their settling velocity, the decreasing upward velocity of the column as a function of height, and a probability density function that attempts to capture some of the natural variation in the parameters governing particle diffusion out of the column. Dispersion of the tephra that diffuses out of the column is modeled assuming a uniform wind field and is governed by the diffusion-advection equation with vertical settling. Thus, this model relies on estimation of numerous parameters that describe the volcanic eruption and the atmosphere it penetrates. Although not as comprehensive in addressing the physics of the eruption column (Woods 1988, 1995), the computational ease of the approach of Suzuki (1983) makes it a worthwhile method for risk assessment, especially in light of practical difficulties inherent in characterizing the variability in eruption and meteorologist parameters (e.g., GVN 1999).

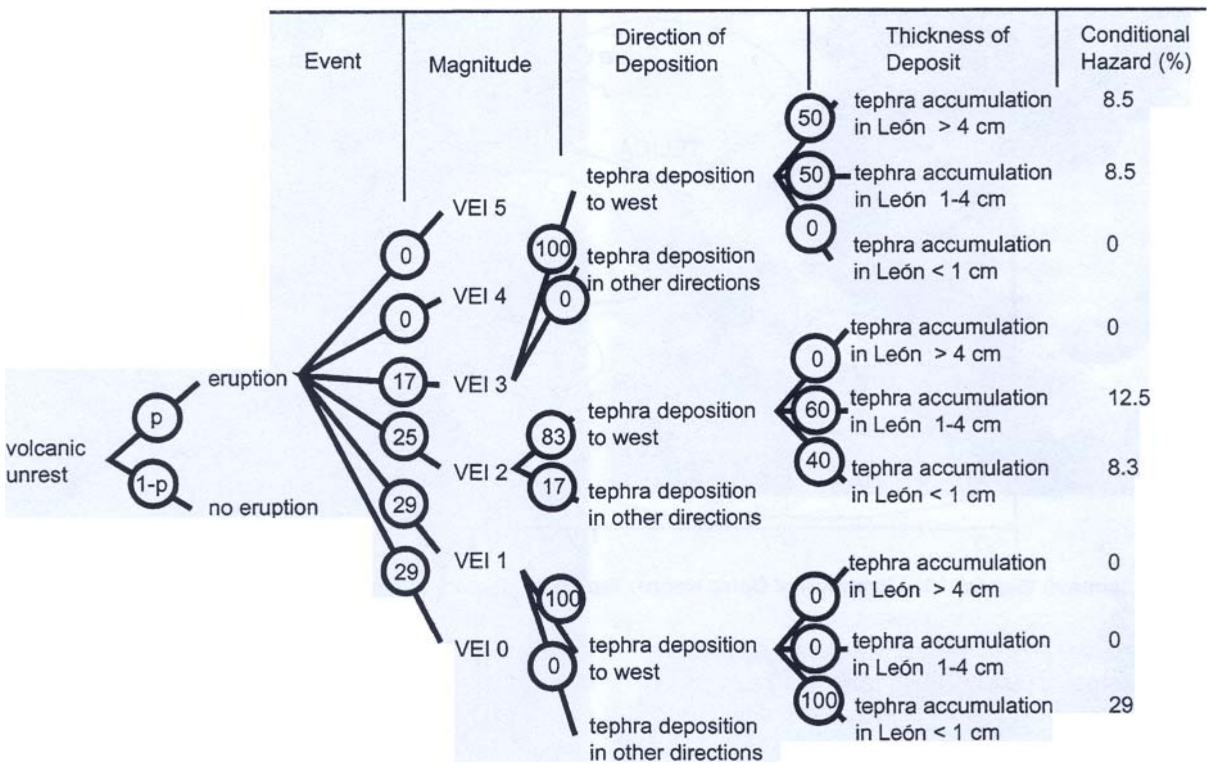


Figure 1. Cerro Negro Volcano: Event tree for tephra accumulation in Leon; Probabilities based on historical and geological records of past eruptions. (Adapted from Connor *et al.* 2001).

Hazard Response Models

Community Resilience: The approach taken here is interdisciplinary, utilizing aspects of the socio-political ideas put forward by Bates and Pelanda (1994), and the political-economy and human ecology approach outlined by Hewitt (1983), and as applied to health (Coreil *et al*. 2000; Whiteford 1999; Whiteford and Manderson 2000). Thus, structural-functional views, conflict theory, competition for resources, and other geo-sociological and anthropological principles are raised here as frameworks in understanding community resilience (Kreps and Bosworth 1994) and ultimately health. Figure 2 provides a framework for this analysis (Tobin 1999). Three separate models have been adapted to demonstrate how resilient communities might be created; the mitigation model proposed by Waugh (1996), the recovery model described by Peacock and Ragsdale (1997), and a structural-cognitive model put forward by Tobin and Montz (1997). The figure depicts a dynamic system, not necessarily one that is in balance. The flows or arrows indicate important relationships between components of the system that must be understood from a structural context, so that when one element changes, an appropriate response can be made to keep the system in some sort of dynamic equilibrium. The ultimate goal is to achieve community sustainability and resilience in the face of prevailing natural hazards, so that better health care can be maintained. Indeed, sustained level of good health is a significant outcome measure of a resilient community.

Figure 1: Healthy and Resilient Communities in Hazardous Environments: A Framework for Analysis

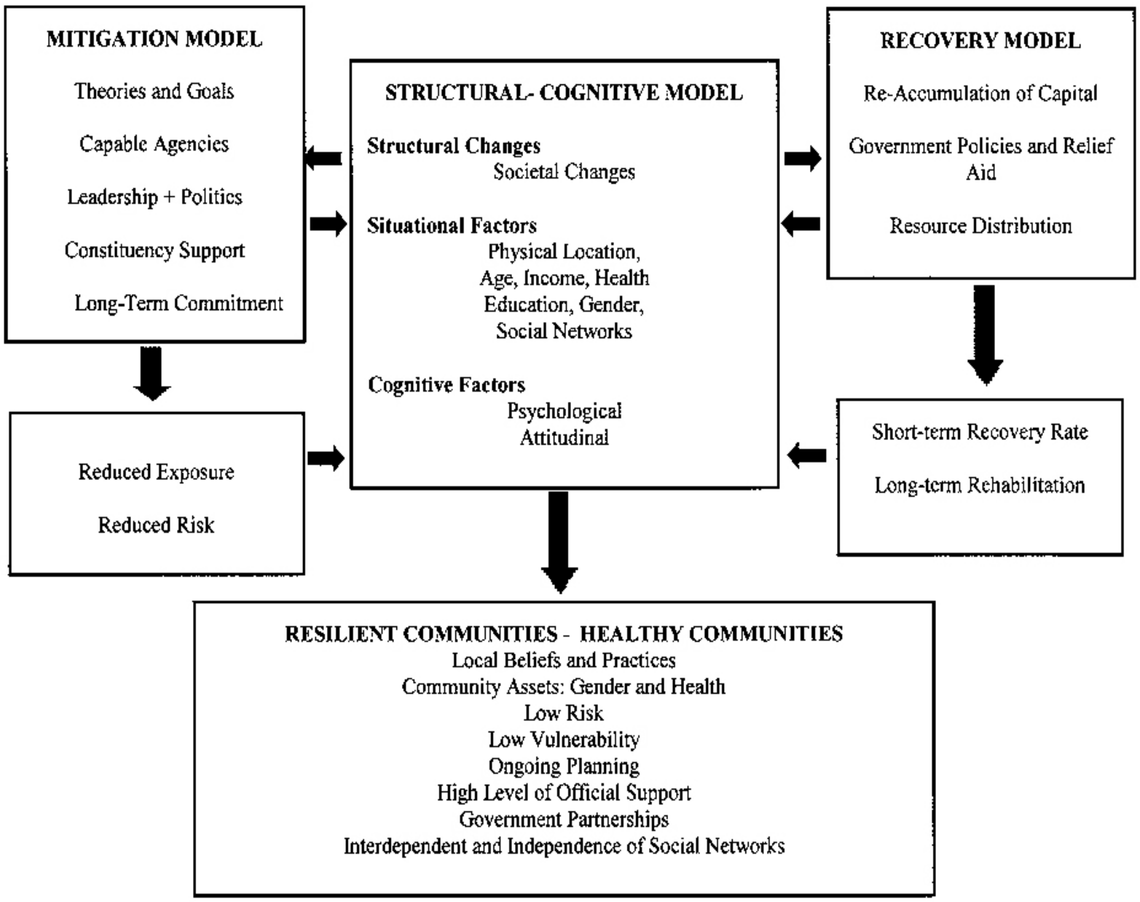


Figure 2. Framework for analysis: Hazard response looking at community resilience and sustainability. Adapted from Peacock and Ragsdale (1997); Tobin and Montz (1997) and Waugh (1996).

(1) Mitigation Model: In a broad context, it is through mitigation programs that risk is reduced. However, not all projects are necessarily successful and can on occasions exacerbate problems. Thus, the implementation of mitigation policies requires that certain conditions be met if success is to be assured. Waugh (1996), utilizing the work of Mazmanian and Sabatier (1983) proposed a set of conditions for effective implementation.

(2) Recovery Model: Given the severity of many geophysical events, combined with limited resources, it is certainly not possible to eliminate all disasters, and many communities, because of their spatial location, will remain hazard-prone. Therefore, a focus on recovery and those factors that are conducive to facilitating recovery is pertinent. Furthermore, recovery does not entail simple clean-up and restoration operations to get a community back on its feet, but it requires long-term rehabilitation (such as improvements in health care facilities and access to them) processes that are themselves affected by prevailing socio-economic conditions and structural constraints (Tobin and Montz 1994).

(3) Structural-Cognitive Model: Comprehensive planning for sustainability requires a third filter, one that incorporates changes in the structure and thinking of society to accommodate hazards within the framework of day-to-day affairs. Without such modification of societal processes, many factors can act as constraints on mitigation policies. These constraints might be structural in nature, whereby situational conditions serve to deter development by preserving the old system, or cognitive, in which psychological and attitudinal perceptions create unfavorable environments. For instance, physical, social, cultural, and economic factors may all constrain (or promote) remedial action. Thus, gender, age, family structure, wealth, ethnicity, education, and neighborhood characteristics may lead to varied outcomes (Ollenburger and Tobin 1999). For example, wealthier people generally have a greater variety of options when confronted with disaster and clean up in comparison with economically marginalized individuals.

Evacuation Impacts: The Impoverishment, Risks, and Reconstruction (IRR) model pertaining to displaced persons, that is re-settlers and refugees, forms the theoretical framework for this aspect of the research (Cernea 2000). This model contends that factors such as landlessness, joblessness, homelessness, marginalization, food insecurity, increased morbidity and mortality, loss of access to common property assets, and community disarticulation will greatly influence outcomes of population relocation strategies. There are two aims to the model; (i) explain what happens during displacement of populations; and (ii) guide policy and planning in development programs. Through this framework, then, some understanding of community resilience might be addressed

The literature suggests, therefore, that characteristics of healthy and resilient communities must include:

- *Legitimization of community knowledge; validation of community-based practices.*
- *Recognition of the role of women in household health: practices and beliefs.*
- *Lowered levels of risk to all members through reduced exposure to the geophysical event.*
- *Reduced levels of vulnerability for all members of society.*
- *Planning for sustainability and resilience must be ongoing.*
- *High level of support from responsible agencies and political leaders.*
- *Incorporation of partnerships and cooperation at different governmental levels.*
- *Strengthened networks for independent and interdependent segments of society.*
- *Planning at the appropriate scale.*

Health Models: Health relationships are modeled utilizing epidemiological records and standard anthropological research methodologies (Coreil *et al.* 2000; Whiteford, 1999). Indeed, as noted above, the combined ethnographic and epidemiological perspective is valuable within disaster research because it focuses directly on prevention of adverse health effects and can predict probable health outcomes. Since the late 1970s, there has been an increasing recognition of the utility of ethnographic as well as epidemiological research applied to infectious diseases. Thus, in depth qualitative research strategies can be employed to uncover health characteristics.

CONTEXT: NICARAGUA, LEÓN AND CERRO NEGRO

Geography

Nicaragua is the largest country in Central America with a surface area of 129,494 sq km. It extends 490 km from east to west, and 470 km north to south at its widest points (Encarta 2001). It shares a northern border with Costa Rica and a southern border with Honduras (Figure 3). The country can be divided into three regions: the Pacific coastal plain, which has numerous volcanoes; the Atlantic coastal plains, and the central interior mountains. The lowlands have a tropical climate, while the highlands are somewhat cooler. Nicaragua has 910 km of coastline on the Pacific Ocean and the Caribbean Sea, and has the largest freshwater body in Central America, Lake Nicaragua. The country has a variety of natural resources: gold, silver, copper, tungsten, lead, zinc, timber, and fish (CIA 2002), although one of its greatest assets is the fertile soil produced by frequent volcano eruptions. As of 1993, land use constituted 9 percent arable land, 1 percent permanent crops, 46 percent permanent pastures, 27 percent forests and woodland, and 17 percent other (CIA 2002).

Figure 3. Nicaragua (Source: CIA 2002)

Government

In the 2001 elections, Liberal Party candidate Enrique Bolaños Geyer succeeded President Arnoldo Alemán Lacayo, who had led Nicaragua since 1997 (PAHO 2002). The Republic government has 15 departments and two autonomous zones on the east coast, established in the 1987 constitution, giving greater powers and freedom to local governments. There are 143 municipal governments authorized to elect their own officials. Nicaragua has a civil law system, a congress, and a Supreme Court, which may review administrative acts. The two largest political parties are the traditional Liberal Party and the Sandinista National Liberation Front (FSLN).

Economy

The capital and largest city in Nicaragua is Managua, followed by Léon, the second largest. The official currency is the gold córdoba, which exchanged at 14.29 per US dollar in August 2002 (World Information 2002). Nicaragua is one of the poorest countries in Central America as it faces low per capita income, flagging socio-economic indicators, and huge external debt. The economy grew 2.5 percent in 2001, with overall GDP reaching US$2.44 million in 2001 (PAHO 2002). In 2001, the global recession, combined with a series of bank failures, low coffee prices, and a drought, caused the economy to retract (PAHO 2002).

In 1996, Nicaragua's debt-level is more than US$6 billion and is dependent upon international aid and debt relief under the Heavily Indebted Poor Countries (HIPC) initiative (World Information 2002). Unemployment increased from 16.1 percent of the total population in 1996 to 20 percent of the total population in 1999. Fifty percent of the population falls below the poverty line (CIA 2001); an estimated three percent of the population survives on less than $1 a day, with poverty levels highest in rural areas (Encarta 2002). This poverty and unemployment contribute to widespread housing shortages, malnutrition, and poor health care. In 1996, 82.4 percent of the urban population and 30.1 percent of the rural population had drinking water service (PAHO 2002). Nicaragua's industrial markets are food processing, chemicals, machinery and metal products, textiles, clothing, petroleum refining and distribution, beverages, footwear and wood. The country's economy is based largely on agriculture, specifically coffee, bananas, sugarcane, cotton, rice, corn, tobacco, sesame, beans, beef, veal, pork, poultry, and dairy products. Again, these traits put Nicaragua at the high end of vulnerability to natural hazards.

Demographic Characteristics

In 2002, Nicaragua's estimated population was 5,023,818 (Encarta 2002). The birth rate (27 per 1,000 people) greatly outpaces the death rate (5 per 1,000), contributing to an annual population growth rate of 2.15 percent (Encarta 2002). The population consists of 69 percent mestizo, 17 percent white, 9 percent of African descent, and 5 percent Amerindian (CIA 2001). Most of the population, 61.5 percent, lives in the Pacific region (PAHO 2002). Eighty-five percent of the population is Roman Catholic and the remaining population is mainly Protestant. As a result of steady migration from the country to the cities between 1940 and 1955, the percentage of the population living in urban areas gradually increased from 30 percent to 57 percent (PAHO 2002). Leading causes of death during 1990 through 1995 were diseases of the circulatory system, intestinal infectious diseases, and certain conditions originating in the perinatal period (PAHO 2002). The occurrence of tropical diseases, such as malaria and dengue fever, has increased since the 1980s.

León

León, founded in 1524, is the second largest city in Nicaragua with an estimated population of 200,000 (2000). Formerly the capital of Nicaragua until 1852, it is the capital of the Léon

Department and is considered the liberal hub of the country (Figure 4). It is the center of transportation and cotton-trading for the surrounding agricultural region and it manufactures furniture, shoes, and leather goods. The city is the site of the Autonomous National University of Nicaragua (1812) and an 18th-century cathedral, one of the largest in Central America. León is located 20 kilometers from Cerro Negro, one of Nicaragua’s most active volcanoes. In addition to the inhabitants of León, an estimated 100,000 people live in the surrounding area, with active agricultural communities located as close as 1 km from Cerro Negro crater (Connor *et al.* 2001).

Figure 4. León, Nicaragua (Source: Connor).

Natural Hazards

Natural hazards in Nicaragua include earthquakes, volcanoes, landslides, floods, droughts, and severe hurricanes, while deforestation, soil erosion, and water pollution are endemic (Figure 5). Indeed, there is a long history of struggles against extreme geo-physical events. Furthermore, the country is still recovering from the ravages of Hurricane Mitch, and currently extreme drought is devastating the agricultural community. There are also many other environmental issues facing the country. For a brief review of the hazards affecting Nicaragua see Tables 1 and 2, which have been adapted from Office of Foreign Disaster Assistance/Center for Research on the Epidemiology of Disasters (OFDA/CRED) International Disaster Database, at the Université Catholique de Louvain, Brussels, Belgium.

Figure 5. Lahar that killed 2,000 people near León in October 1999 (Sources: Connor; Tobin).

TABLE 1. NICARAGUA: TOP 10 NATURAL DISASTERS

DEATHS

DISASTER	DATE	KILLED
Earthquake	23-Dec-1972	10,000
Wind storm	26-Oct-1998	3,132
Earthquake	31-Mar-1931	1,000
Earthquake	Aug-1951	1,000
Earthquake	4-Feb-1906	1,000
Flood	Oct-1960	325
Earthquake	1-Sep-1992	179
Wind storm	22-Oct-1988	130
Wind storm	23-May-1982	71
Epidemic	Apr-1967	53

PEOPLE AFFECTED

DISASTER	DATE	AFFECTED
Wind storm	26-Oct-1998	868,228
Earthquake	23-Dec-1972	720,000
Wind storm	22-Oct-1988	360,278
Volcano	10-Apr-1992	310,075
Drought	22-Sep-1997	290,000
Drought	Jul-2001	187,645
Wind storm	10-Aug-1993	123,000
Flood	Sep-1999	107,105
Flood	May-1990	106,411
Drought	Jul-1994	80,000

Source:EM-DAT: The OFDA/CRED International Disaster Database, Université Catholique de Louvain, Brussels, Belgium.

Notes: **(1)** For some natural disasters (particularly floods and droughts) there is no exact day or month for the event, and for other disasters (particularly pre-1974) the available record of the disaster does not provide an exact day or month.
(2) In order for a disaster to be entered into the database at least one of the following criteria has to be fulfilled: 10 or more people reported killed; 100 people reported affected; a call for international assistance; declaration of a state of emergency.

TABLE 2. CHRONOLOGICAL TABLE OF NATURAL DISASTERS IN NICARAGUA

TOTAL; DROUGHTS/FAMINES; EARTHQUAKES; EPIDEMICS; FLOODS

Year	Total Events	Total Killed	Total Affected	Drought/famines			Earthquakes			Epidemics			Floods		
				Events	Killed	Affected	Events	Killed	Affected	Events	Killed	Affected	Events	Killed	Affected
2001	2	16	212,511	1	-	187,645	-	-	-	-	-	-	-	-	-
2000	5	9	15,487	1	-	-	1	7	7,477	-	-	-	1	-	5,500
1999	4	11	113,300	-	-	-	-	-	-	-	-	-	1	11	107,105
1998	4	3,139	871,581	-	-	-	-	-	-	3	7	3,353	-	-	-
1997	1	-	290,000	1	-	290,000	-	-	-	-	-	-	-	-	-
1996	1	42	10,724	-	-	-	-	-	-	-	-	-	-	-	-
1995	4	56	40,491	-	-	-	-	-	-	2	18	13,406	1	38	15,085
1994	1	-	80,000	1	-	80,000	-	-	-	-	-	-	-	-	-
1993	1	37	123,000	-	-	-	-	-	-	-	-	-	-	-	-
1992	2	181	351,064	-	-	-	1	179	40,989	-	-	-	-	-	-
1991	2	2	381	-	-	-	-	-	-	1	2	381	-	-	-
1990	2	4	106,411	-	-	-	1	-	-	-	-	-	1	4	106,411
1989	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1988	1	130	360,278	-	-	-	-	-	-	-	-	-	-	-	-
1987	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1986	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1985	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1984	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1983	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1982	1	71	52,000	-	-	-	-	-	-	-	-	-	-	-	-
1981	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1980	1	-	40,000	-	-	-	-	-	-	-	-	-	1	-	40,000
1979	1	-	30,000	-	-	-	-	-	-	-	-	-	1	-	30,000
1978	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1977	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1976	1	16	8,000	-	-	-	-	-	-	-	-	-	1	16	8,000
1975	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1900-74	12	13,413	732,254	1	-	-	5	13,000	722,000	2	53	444	2	325	1,560

Source: EM-DAT: The OFDA/CRED International Disaster Database, Université Catholique de Louvain, Brussels, Belgium

Note: Prior to 1974, only relatively few major disasters are recorded. Therefore the data from preceding years has been lumped together for this table.

TABLE 2. CONTINUED

SLIDES; VOLCANOES; WILD FIRES; WIND STORMS; OTHER: EXTREME TEMPERATURES-WAVES/SURGES-INSECT INFESTATIONS

Year	Slides			Volcanoes			Wild Fires			Wind Storms			Other		
	Events	Killed	Affected	Events	Killed	Affected	Events	Killed	Affected	Events	Killed	Affected	Events	Killed	Affected
2001	-	-	-	-	-	-	-	-	-	1	16	24,866	-	-	-
2000	-	-	-	-	-	-	-	-	-	2	2	2,510	-	-	-
1999	-	-	-	2	-	6,195	1	-	-	-	-	-	-	-	-
1998	-	-	-	-	-	-	-	-	-	1	3,132	868,228	-	-	-
1997	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1996	-	-	-	-	-	-	-	-	-	1	42	10,724	-	-	-
1995	-	-	-	1	-	12,000	-	-	-	-	-	-	-	-	-
1994	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1993	-	-	-	-	-	-	-	-	-	1	37	123,000	-	-	-
1992	-	-	-	1	2	310,075	-	-	-	-	-	-	-	-	-
1991	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
1990	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1989	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1988	-	-	-	-	-	-	-	-	-	1	130	360,278	-	-	-
1987	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1986	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1985	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1984	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1983	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1982	-	-	-	-	-	-	-	-	-	1	71	52,000	-	-	-
1981	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1980	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1979	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1978	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1977	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1976	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1975	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1900-74*	-	-	-	1	-	3,600	-	-	-	1	35	4,650	-	-	-

Source: EM-DAT: The OFDA/CRED International Disaster Database, Université Catholique de Louvain, Brussels, Belgium

Note: Prior to 1974, only relatively few major disasters are recorded. Therefore the data from preceding years has been lumped together for this table.

The Volcano - Cerro Negro

Cerro Negro (2953 ft), one of most active volcanoes in Nicaragua, is located only 20 km west of León, and is part of a group of four young cinder cones in the Maribios Range 5 km northwest of Las Pilas volcano (Figure 6). Cerro Negro is a basaltic cinder cone that has erupted 23 times since its birth in 1850, and seven times in the last 30 years, in 1968, 1969, 1971, 1992, May-August 1995, November-December 1995, and August 1999 (Connor *et al.* 1993; McKnight 1995; McKnight and Williams 1997; Hill *et al.* 1999). Most eruptions at Cerro Negro produce both pyroclastic material and lava flows, while strombolian eruptions at intervals of every few years to several decades have constructed cones that rest on older lava flows that have been enlarged during earlier eruptions. According to Connor *et al.* (2001), many of the early eruptions are poorly documented, although a reasonably complete record of volume of tephra falls is available since 1900 (Table 3). Since 1968, for example, four eruptions have produced tephra volumes in excess of one million cubic meters each (Hill *et al.* 1999; La Femina *et al.* 1999).

Figure 6. Cerro Negro 2002 (Source: Connor).

In October 1968, Cerro Negro erupted with frequent large ash explosions, precipitating the evacuation of many villages. Ash fall amounted to 0.5-1 cm in thickness in León, and ash ranged up to 3 mm in diameter at a distance 0.5 km (Connor *et al*. 2001). Volcanic rock was ejected into the air and ash was carried to the Pacific Ocean by strong winds. The ash covered roofs of houses and cars, roads and trees, and thousands of acres of croplands around Cerro Negro were severely damaged (Connor *et al*. 2001).

Table 3: Cerro Negro volcano eruption history, 1850-1995

ERUPTION YEAR	CUMULATIVE VOLUME (km^3)
1850	0.006
1867	0.010
1899	0.011
1914	0.012
1919	0.012
1923	0.039
1929	0.039
1947	0.051
1948	0.051
1949	0.051
1950	0.068
1954	0.068
1957	0.074
1960	0.095
1961	0.095
1962	0.096
1963	0.096
1968	0.115
1969	0.115
1971	0.142
1992	0.152
1995	0.152
1995	0.160

Source: Hill *et al.* (1998)

The April 1992 eruption was the worst in Nicaragua history, producing a Plinian column that reached 7.5 km high and depositing 1.7 million tons of ash over a 200 sq km area in Léon (Malillay *et al*. 1997) (Figure 7). The eruption caused at least $20 million in damage to cropland and buildings, and forced the evacuation of 28,000 people (Figure 8). In addition, nine people were killed by tephra (Hill *et al.* 1998). After this eruption, the Japanese government donated telemetry-equipped seismic instruments, which were installed in November 1993. Following the 1992 eruption, Malillay *et al.* (1997) evaluated the health of approximately 300,000 residents. They concluded that the rates of visits to health care facilities for acute diarrheal and respiratory illnesses increased in two study communities, one within and one near the disaster zone.

Specifically, visits for acute diarrhea were nearly 6.0 times more numerous than before the eruption in both communities, while visits for acute respiratory diseases were 3.6 times more frequent in Malpaisillo, the community near the disaster zone, and 6.0 times more frequent in Telica, the community within the disaster zone.

Figure 7. Cerro Negro Eruption 1992 (Source: Connor).

Figure 8. Ash damage from 1992 eruption (Source: Connor).

The main eruption of Summer 1995 produced 8 x 10^6 m^3 of basalt from Cerro Negro over 13 days of activity, and deposited 5 mm of ash in the city of Léon (Hill *et al.* 1998). More than 1,200 people were evacuated and damage estimates exceeded $700,000 (Connor *et al.* 2001). Early June aviation reports noted sporadic columns of ash to 2 km altitude. Fine-grained ash was deposited north of the cone, with 1 mm ash thickness extending 5 km north of the vent.

Compared with the 1992 and May-August 1995 activity, ash content was low during the November 1995 eruptions (Figures 9 and 10). These eruptions built a new lava cone, lava dome, and lava flows within the summit crater; lava flowed 1.5 km down the north flank. Flames of burning gas reached 100-200 m above the crater. Ash fall deposits were reported in Léon and Corinto, covering an area of at least 200 sq. km (Figures 11 and 12). Satellite imagery indicated a possible low-level ash cloud at 4,500 m altitude and moving southwest at 30 km/hr for a total of four ash plumes altogether. An estimated 12,000 people were affected by this eruption, about 6,000 of whom had been evacuated from 15 rural communities. Farmers and their families lost acres of land during the important harvesting season.

Figure 9. Cerro Negro eruption of 1995 (Source: Connor).

Figure 10. Cerro Negro 1995 (Source: Connor).

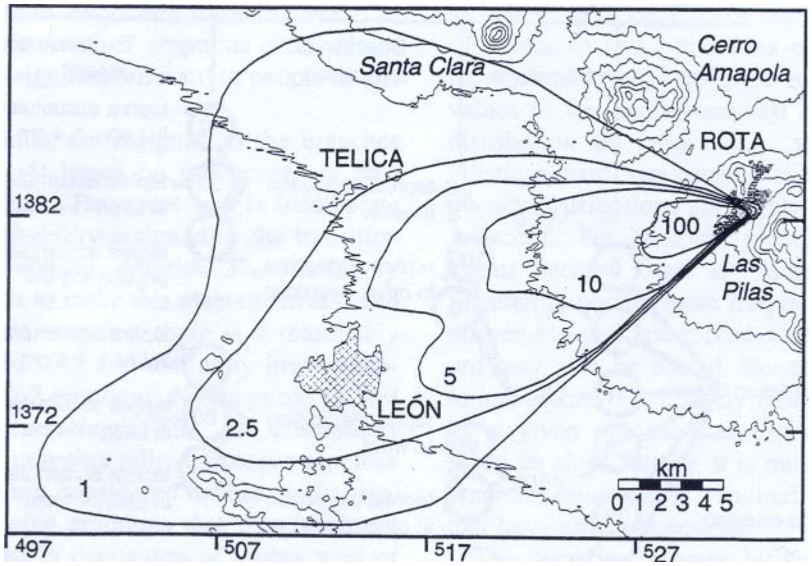


Figure 11. Isopach map for 1992 eruption of Cerro Negro; Tephra thickness shown in cm. (Connor *et al.* 1993)

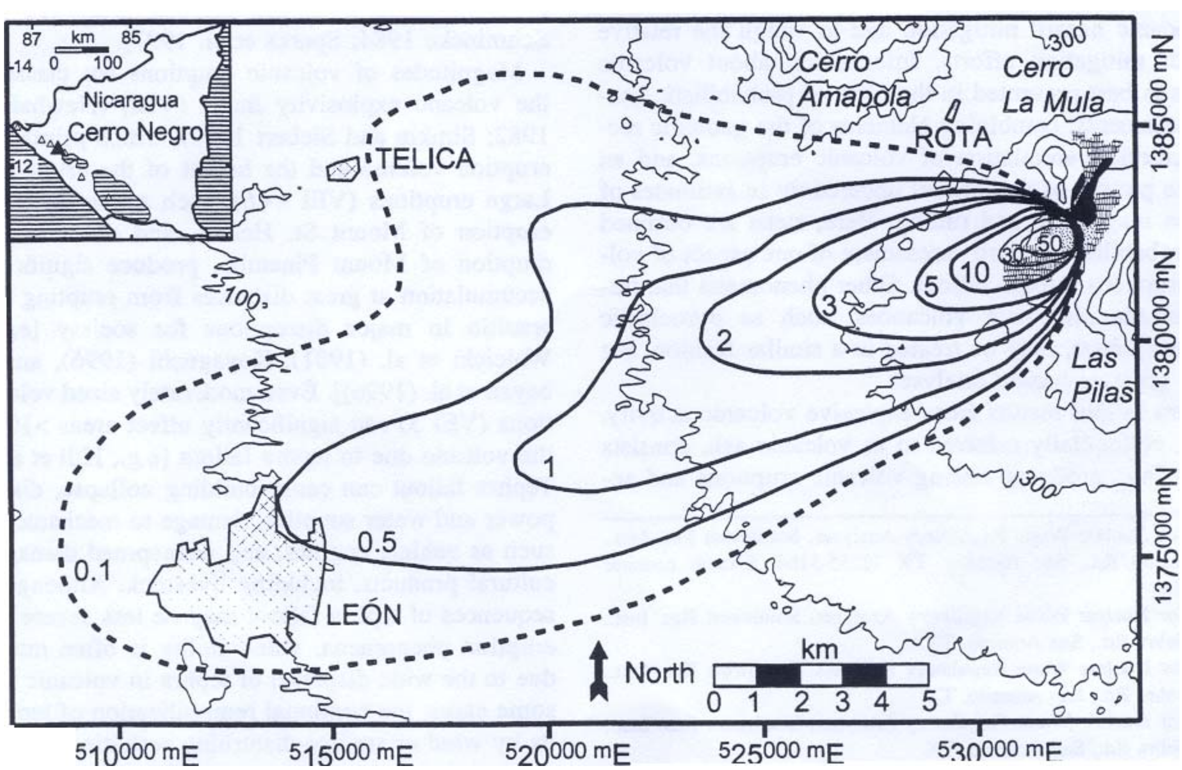


Figure 12. Isopach map for 1995 eruption of Cerro Negro; Tephra thickness shown in cm (From Hill *et al.* 1998)

The Nicaraguan government issued a state of maximum alert when Cerro Negro erupted in August 1999. Approximately 1,700 people were evacuated on the third day of activity. This eruption followed a series of large earthquakes that destroyed a number of homes (Figure 13). According to Hill *et al.* (1999) time-volume relationships were successful in forecasting this eruption.

Figure 13. Cinder cones formed during 1999 eruption of Cerro Negro (Source: Tobin).

METHODOLOGY AND RESEARCH PROTOCOL

DATA COLLECTION

Ash Data

The ever-present but relatively inarticulate player in this research is the volcano, Cerro Negro. Volcanic activity will be traced using data from the Instituto Nicaraquense de Estudios Territoriales (INETER) in Managua. The Director of the Institute is a familiar with the project and will help in the collection of data concerning the dates and degrees of explosions, the amount of ash fall in the focal cities and surrounding areas, and the chemical content of the ash at various times. Levels of sulfur, silicon and other components may accelerate respiratory diseases. These data will be geo-coded to produce a map of the physical impacts of the hazard.

In our approach, geological and/or historical records of volcanic eruptions play a central role in estimation of the conditional probabilities of volcanic risk, because these data are the best guide to possible outcomes of eruptive activity in the absence of information that can only be obtained during an eruption crisis. We plan to use such records to improve parameter estimations in numerical simulation of volcanic phenomena. For example, given a volcanic eruption, what is the likely amount of volcanic ash that will accumulate 20 km from the volcano. In a sense, it would be ideal if sufficient information existed to construct a risk curve for volcanism directly from the geologic record, without estimating parameters or using a numerical model. The geologic record of eruptive activity, however, is usually limited both in terms of the distribution of outcrops and of the types of volcanic events preserved. For example, tephra sections at many volcanoes in Nicaragua are limited to a handful of outcrops, where the tephra-stratigraphy is well exposed and preserved. These outcrops rarely correspond to the locations where hazards are most important to assess, such as population centers and critical facilities such as ports, water plants, and power plants. Therefore, expected volcanic events in most areas must be modeled, using the geologic record as a control.

This research presents an approach developed to estimate volcanic hazards related to tephra fallout and illustrates this technique with a tephra fallout hazard assessment for the city of León, Nicaragua, and the surrounding landscape. Tephra fallout from eruptions of Cerro Negro volcano has caused damage to property and adverse health effects and has disrupted life in this area. According to Connor *et al.* (2001) based on a steady-state model of cumulative volume of material erupted from Cerro Negro, a volcanic eruption is expected to occur before 2005 with a 95 percent confidence. Significantly, past eruptions have deposited up to 4 cm of ash on León; this scenario, therefore is expected to occur again. A further refinement of this model can be seen in Figure 14 which shows an exceedance probability plot ("hazard curve") for León.

For this range of input parameters, 50 percent of eruptions result in tephra accumulation of less than 0.2 cm in León, approximately 26 percent of eruptions result in tephra accumulation of more than 1 cm, and 11 percent of eruptions result in tephra accumulation greater than 4 cm, in reasonable agreement with the historical record. The numerical simulation suggests that the probability of tephra deposition of over 10 cm in León is 5 percent. The probability of tephra accumulation between 1 and 4 cm is contoured for the region about Cerro Negro for the population living closer to the volcano than León (Figure 15). See Appendix A for details of model and extreme events for Cerro Negro. The goal, therefore, is to produce a predictive model of ash dispersion that will be of value to hazard decision-makers.

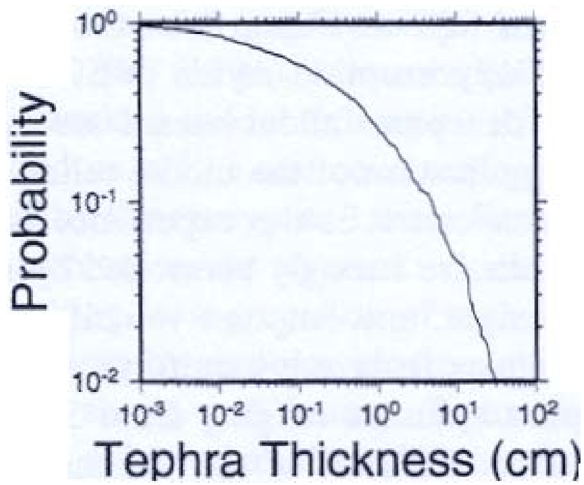


Figure 14. Conditional Hazard Curve for Tephra Accummulation in Léon. (Source: Connor *et al.* 2001).

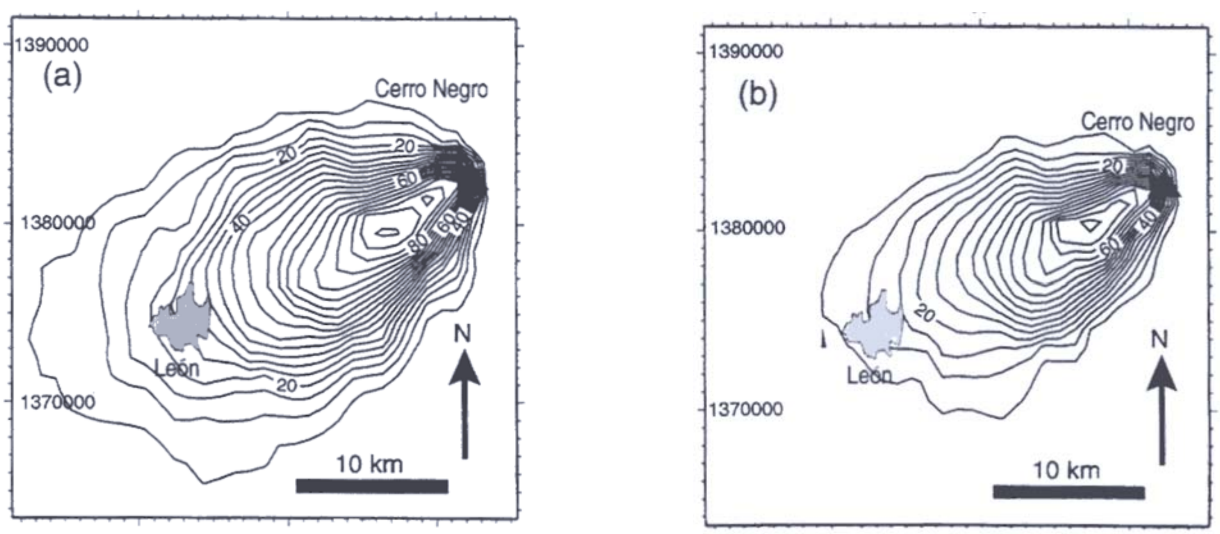


Figure 15. Probability Maps for Tephra Accumulation from an Eruption of Cerro Negro. Contoured at 5 percent Contour Intervals: (a) Probability of tephra more than 1 cm per eruption; (b) Probability of tephra more than 4 cm per eruption. (Source: Connor *et al.* 2001).

Community Resilience and Health Data

To investigate the relationship between the incidence of respiratory diseases and ash fall exposure patterns on forced population movements (evacuation) and community resilience, we propose using a controlled comparison among four communities adjacent to Cerro Negro volcano in Nicaragua (Table 4). These four communities will be comparable in size and have similar demographic neighborhoods; however their experience of ash fall and evacuation will differ. In addition, a control site, which has experienced neither ash fall nor forced evacuation will be included in the study. All research sites, therefore, share the experience of on-going risk, but they differ according to the degree of risk and exposures. Volcanic risk for the control site will differ.

Table 4. Proposed Research Communities

	ASH DEPTH	EVACUATED
Community I	Low	No
Community II	Low	Yes
Community III	Heavy	No
Community IV	Heavy	Yes
Control Site	None	No

Respiratory distress will be measured through a combination of techniques, including national and regional health surveillance records maintained by the Nicaraguan Ministry of Health, a review of regional and local health data, clinic-based interviews, community observations, and ethnographic interviews. Based on the results of prior research conducted in-country with some of these populations, we anticipate an increase in tuberculosis (TB) among populations affected by the volcano's activities. To ascertain clinical cases of TB, we will use sputum tests of clinic populations not previously diagnosed.

Nutritional levels will be assessed using a variety of techniques. We will rely on the Nicaraguan Ministry of Health's (MOH) system of nutritional surveillance for baseline data and will combine that with standard anthropological techniques of 24 hour-food recalls and anthropomorphic measures such as skin fold, and weight-for-height statistics. We will seek help from the Director of Epidemiology for the Nicaraguan MOH to assist in facilitating access to community health centers and epidemiological data. Community-based interviews will also be employed.

While less directly implicated in the spread of infectious disease, the socio-cultural context of the communities will be studied with particular attention to the presence and extent of potable water, sanitary systems, access to health care facilities and personnel and treatment levels. Given the recent political and economic crisis, family economic data and sources of income and support will be elicited through personal interviews to place the research in context.

One potential outcome of the proposed research, therefore, is a explanatory model to track infectious diseases as they relate to both the geophysical dimensions of the hazard, and the resultant political decision-making (i.e. response) pertaining in this case to the evacuation. To do this, we will employ GPS and GIS techniques of spatial analysis (see below).

Community resilience, that is the ability of a community to recover from disaster, is dependent on the interplay of many social, economic, and political forces operating at different temporal and spatial levels. Briscoe (2000) defined community resilience as the ability to respond to stressors and make positive adaptations. While these forces are difficult to measure accurately, three variables would appear to be significant in this regard: health, economic resources, and political power. A healthy community with considerable resources and sound leadership has more prospects for recovery than a community typified by poor health, limited resources and weak leadership. Thus, this research utilizes these variables as an *indication* of community resilience. Data on infectious diseases will be collected from both interviews and observations and epidemiological studies to characterize the actual and perceived changes in the pattern of community health in the time since the evacuation. Similarly, data on economic strengths will be derived from familial networks, again using objective sources and perception-based questionnaires. Leadership, of both formal and informal groupings, will be measured through changes in the actual and perceived power base of the community. In this way, a testable model of community resilience will be developed.

Research Strategy

The following phases are both temporal and conceptual. Phase II follows on and employs the results and knowledge learned during phase I, it also incorporates another set of research and analytical techniques from those employed during phase I.

Phase I Community Mapping: The first phase of the research will include mapping of the five communities, categorization of *barrios* within the communities, and selection of appropriate barrios to study. In order to create a representative sampling grid, the research team will map the communities using GPS. There are some good-quality, large-scale digital maps now available that will also be used to map the surrounding landscape (Figure 16). A geographical information system will be used to analyze these data.

In this way, comparable neighborhoods, in terms of wealth and income, can be selected. The mapping, therefore, will be used to control for income variation, and will be used to identify neighborhoods or barrios occupied by families with few economic resources. Neighborhoods identified as being primarily composed of living units with minimal amenities will be selected for further sampling. Until the initial sampling is conducted, it is not possible to identify exactly which variables will be employed to determine the communities. Once a range of barrios has been examined then variables will be selected. The maps will then be used to define barrios that are neither destitute nor well off, but rather somewhere in between. For the purpose of this research, it is less important that the economic level of the barrios to be included in the sample be identified *a priori*, but rather that the barrios included be of the same economic level.

While the criteria cannot be identified until later, previous research indicates that home ownership, presence of indoor plumbing, potable water, crowding, population density, mixed use, level and kinds of employment, and types of transportation may be significant variables. The research team of four students (two from the US and two from Nicaragua) will be responsible for the community mapping, while the three PIs will facilitate the process and will interview both elected and informal communities leaders. The PIs and Nicaraguan consultants will work with neighborhood leaders to explain the proposed research and secure permission for the research to be conducted in their neighborhoods. This phase of the research will provide the four graduate students with training in GIS mapping, GPS procedures, and research and sampling techniques.

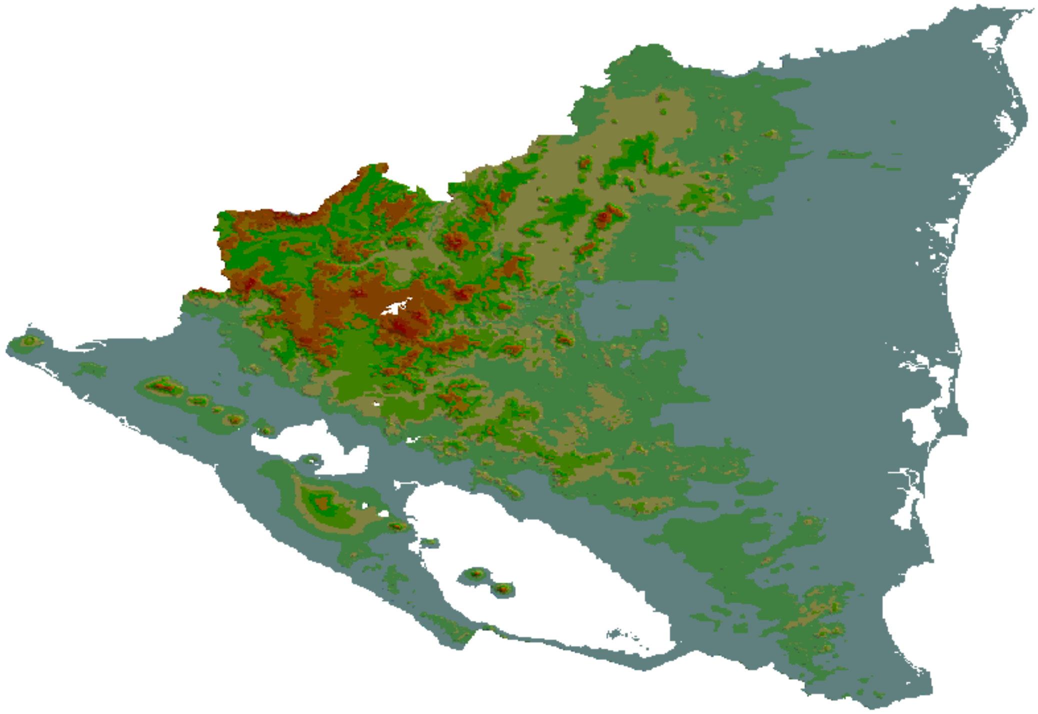


Figure 16. Model of elevations, Nicaragua

Phase II Retrospective Collection and Analysis of Health Records and Volcanic Activity*:* The second phase of the research focuses on health data and geo-physical data. Background statistics on health will be collected in Nicaragua by in country workers. Dr. Medrano, who has worked with USF faculty before, will assist in collecting epidemiological data. The PIs will facilitate and oversee the Nicaraguan team members as they conduct retrospective reviews of records in the Health Centers for the five communities for the period preceding and post-eruptive phases to identify cases of: 1) nutritional problems, 2) upper respiratory problems, 3) lower respiratory problems, 4) tuberculosis, and 5) hepatitis. These data will be entered into a database using Epi Info (software for epidemiological analysis). The information generated from the review of clinic records will be used to suggest tendencies in respiratory and infectious disease over the 24 months preceding the interview phase of the research. These data will also be used to identify geographical areas or neighborhoods in which to focus the research. Simultaneous to the review of clinic records, the US team will develop a codebook for the neighborhood data so that information can be digitized into an SPSS program.

Also during Phase II, geo-physical data will be collected on the frequency of eruptions, their relative intensities based on the Volcano Explosivity Index (VEI), and spatial patterns of the ash falls. Furthermore, ash will be collected and the content correlated with the epidemiological patterns in the five communities. The volcanic activity around Cerro Negro is being monitored quite extensively and these data are collected and stored at INETER. Dr. Strauch, the Director of INETER, will facilitate this side of the data collection. The US team will provide computer assistance and will undertake data entry as well as the preliminary analysis, but full collaboration amongst all of the participants is expected. All four students will be trained in epidemiological research techniques, GIS applications, and SPSS data analysis techniques.

Phase III Prospective Data Collection and Ethnographic Community Interviews: Both US and Nicaraguan team members will conduct community-based interviews, clinic-based interviews, and administer anthropomorphic measures and nutritional recalls. A random sample of at least ten percent of the houses in each of the previously identified barrios will be selected for household interviews and observations. Two teams of students, each comprised of two US students and two Nicaraguan students, will interview the self-identified head of household, conduct 24 hour nutritional recall tests with whoever is responsible for family food preparation, and do skin fold and height for weight measures on all children under five living in the household. We anticipate at least one hundred households per community will be included in the sample. This phase of the research is designed to provide health, nutrition, and economic information critical to the research questions, but unavailable from extant sources. In addition, it provides training in ethnographic, nutritional, and anthropomorphic research techniques to the four graduate students on the team.

Phase IV Data Analysis and Modeling: Data analysis will be on-going during each of the three previous phases of the research. The fourth phase of the project will bring together the data previously analyzed concerning the following key variables: 1) community spatial organization, 2) determinants and distribution of disease, 3) community social organization, and 4) patterns of volcanic activity and ash content. From these findings, a model, or models, will be developed to track respiratory disease, ash fall and evacuation, using the community where neither event occurred as the control case. This phase will expose students to techniques for modeling and analysis. The ultimate goal is to integrate the ash fall dispersion models with community resilience and health in a predictive model to facilitate mitigation efforts.

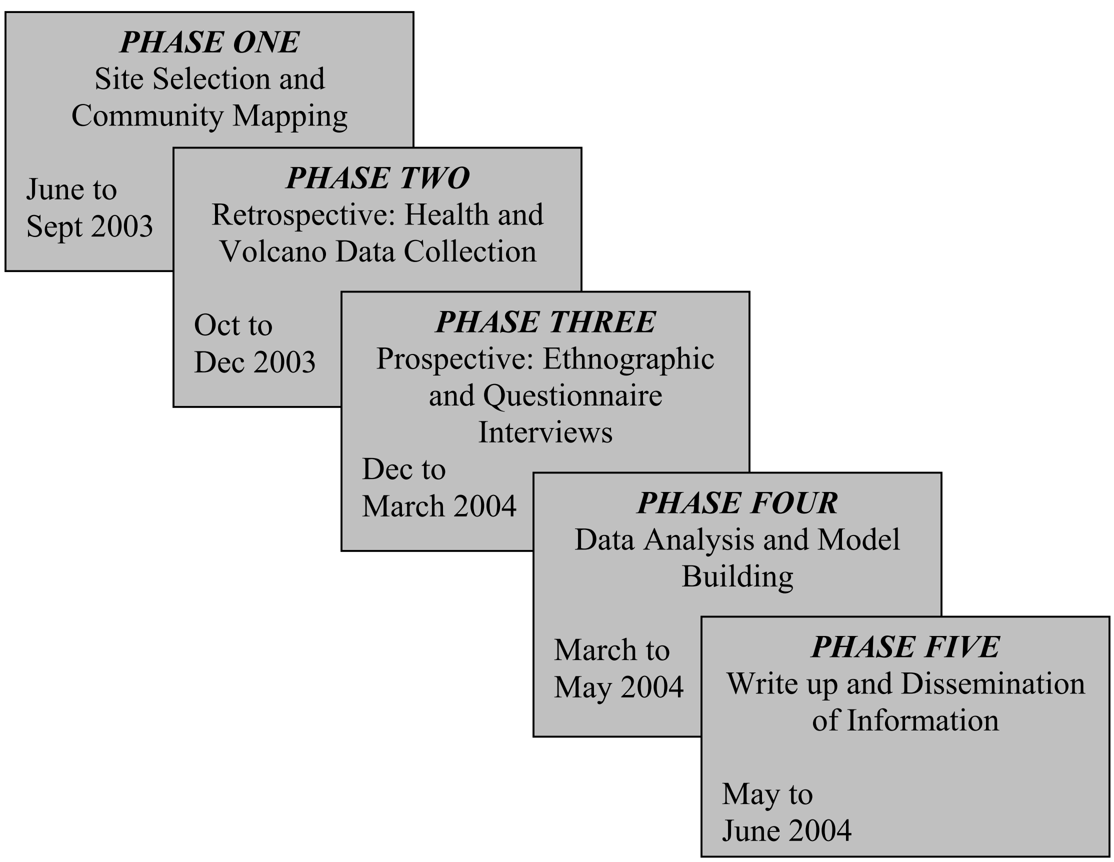
Phase V Write-up and Dissemination of Information: This project is a bi-national, multidisciplinary collaboration of three experts in Geology, Geography and Hazards Research, Medical Anthropology, Volcanology, and the Epidemiology of Infectious/Contagious Diseases. In addition, four graduate students from geography, anthropology, geophysics, and epidemiology will be trained in a series of research techniques such as GPS, GIS, ethnographic and survey interviewing, retrospective and prospective clinical research, geophysical analysis, tracking of diseases, and modeling.

Furthermore, this research has implications for future movements of populations whether for evacuation or resettlement, and how those strategies affect or effect the spread of infectious/contagious diseases. Not least, the results of this research will be shared with the Nicaraguan government to enable them to plan further evacuations. It is imperative that the results of this research be made available in such a form as to be useful to governments and planning agencies where they can be used. Consequently, both academic papers and technical reports will be produced. We will present at least one paper in scholarly sessions at national meetings in geology, geography, and anthropology, and publish the research results in both disciplinary and applied journals. Finally, we propose to host a roundtable presentation and discussion of the final report in Managua, Nicaragua, to which appropriate governmental and non-government agency heads will be invited. In addition, we propose a similar roundtable for the funding agency in the US.

SCHEDULE

The project is scheduled to run from June 2003 through May 2004. Several tasks will be undertaken at the same time with work progressing in Nicaragua and in Tampa. The first tasks will include site selection and mapping of the communities using GPS equipment, which will involve student and PI activities. Retrospective data will be collected in the second phase of the research bringing together long-term health and geo-physical data. This will set the scene for phase three, where we will interview approximately 500 respondents regarding their health and perceptions of the hazard. In phase four, we will analyze the data and develop the model of health and community resilience. Phase five will involve writing and publishing the results. However, to disseminate the information further we will also hold roundtable discussions in Nicaragua with the Ministry of Health. In this way, the results should have applied value and be useful for mitigation policies in future disasters.

SCHEDULE



APPENDIX A

TEPHRA FALLOUT HAZARDS CURVES FOR CERRO NEGRO

(from Connor *et al.* 2001)

TEST OF THE ASH DISPERSION MODEL

In practice, the ash dispersion model is calculated numerous times using a range of input parameters (e.g., total mass, column height, etc.) that reflect the historical range of activity at Cerro Negro. Each realization represents a possible combination of eruption style, magnitude, duration, and atmospheric conditions that control the amount and distribution of tephra fallout. Using the stochastic approach, the range of likely eruption styles (VEI 0-3) and their consequences for tephra fallout hazard are evaluated.

Successful application of the model relies on well-chosen input parameters. It is suggested that model results are strongly controlled by eruption volume, column height, and eruption velocity. Eruption volumes were sampled from a log-uniform random distribution with tephra volumes ranging from 5×10^5 to 1×10^8 m^3, based on estimates of the volumes of past eruptions. Column height was sampled from a uniform random distribution ranging from 2 km to 8 km. The relationship between column height, mass flow, eruption duration, and total eruption volume were used to check these input parameters. Eruptions with very long durations, over120 days, were eliminated from the sample set because long duration explosive activity at Cerro Negro has never occurred. Eruption velocity was sampled from a uniform random distribution of 50 m/s to 100 m/s, independent of mass flow. Wilson and Head (1981) suggested a relationship between eruption velocity and mass flow that, for Cerro Negro, yields eruption velocities much lower than the 75 to 100 m/s velocities that have been observed (Conner *et al.* 1993; Hill *et al.* 1998) or the eruption velocities predicted for buoyant tephra columns at low mass rates of 1×10^6 kg/s (Woods and Bursik 1991).

Wind speed and direction also have strong influences on the tephra accumulation. At Cerro Negro, tradewinds are quite consistent. Average monthly wind direction is to the west or west-southwest, and average wind speed on the ground is 4 to 6 m/s, with maximum wind speeds of 15 m/s measured during most months (National Climate Data Center 2000). Furthermore, with the exception of the 1914 eruption (McKnight 1995), all significant tephra deposition has occurred west of Cerro Negro, with León lying near the major axis of dispersion for the 1968, 1971, 1992, and 1995 eruptions. Therefore, wind speed was sampled from a U[5 m/s, 15 m/s] distribution and wind direction from a range of -5^o to -35^o distribution, where wind direction is with respect to due west. In the absence of meteorological observations, it is assumed that these ranges apply to wind data at higher elevations. This assumption at least works well for the 1995 eruption, during which wind speeds in the tephra plume were 9 m/s (Hill *et al.* 1998). This may not be the case for all future eruptions, however.

Tephra grain size distribution was integrated from -5 to 5ϕ with mean grain size = -1ϕ and standard deviation = 1ϕ. Clast density was varied from 0.9 gm/cm^3 to 1.2 gm/cm^3, equant grains were used ($p_f = 0.5$), and $\beta = 0.5$. This value for β forces a higher proportion of erupted pyroclasts to elevations close to the top of the eruption column, a choice consistent with field observations and thermo-fluid-dynamic models of volcanic plumes (Woods 1995). For the parameters distribution, then, simulated tephra accumulation in León varies from much less than 0.1 to 30 cm in 500 iterations of the model.

EXTREME EVENTS AT CERRO NEGRO

In addition to the probable outcomes described above, it is useful to produce worst-case scenarios of volcanic activity in order to communicate the potential magnitude of hazards. Worst-case scenarios bound the consequences of volcanic activity, with the goal of conveying the limits of potential devastation based on reasonable or conservation assumptions. Volcanologists often hesitate to convey worst-case scenarios because of the fear, often well-founded, that worst-case scenarios will be misinterpreted as "base case" or "expected." Conversely, worst-case scenarios can be ridiculed as overly conservative or alarmist. Nevertheless, it is worthwhile for volcanologists and public officials to think freely about large magnitude events and their impact on risks to public health and safety (Figure 17).

Development of worst-case scenarios can be made palatable through the introduction of the concept of upper limit values (ULVs). Essentially, ULVs, are deterministic assessments of hazard using conservative assumptions. The concept of ULVs (also known as screening distance values) was developed in seismic risk assessment for sensitive facilities, such as nuclear power plants, that must be located in areas of very low geologic risk. These techniques have now been extended to volcanic hazards for nuclear facilities (IAEA 1997) and are readily adapted to general hazard mitigation efforts.

Accurate development of ULVs relies on basic geologic investigations at many volcanoes, not necessarily those most likely to erupt. For example, the recent (<5000 year bp) history of Crater Lake suggest that eruption in this magmatic system are highly unlikely in the upcoming decades. Nevertheless, the history of Crater Lake, and ancestral Mount Mazama provides a benchmark for the potential magnitudes for future silicic volcanic eruptions in the Cascade Mountains (Bacon 1983): In constructing hazard assessments for other Cascade volcanic systems, such as South Sister, geologic insights from studies of the Mount Mazama eruption can be considered through the use of ULVs. Similarly, the Katmai eruption of 1912 and Mount Pinatubo eruption of 1991 (Newhall and Punongbayan 1996) should not be considered expected events in the Cascades during the next several decades, but such eruptions are completely within the realm of possibility and can be considered in hazards assessments through the use of ULVs.

As an example, a ULV for tephra accumulation in León is constructed, based on a set of parameters outside the range of past activity, but nonetheless possible, given eruptions from basaltic cinder cones in general. This model assumes an 8 km high eruption column, 100 m/s eruption velocity, and total volume of 1×10^8 m^3. For comparison, the 71 day eruption of Tolbachik volcano, Kamchatka, sustained 13-10 km high eruption columns and erupted 9×10^8 m^3 (0.42 km3 dense rock equivalent) of tephra (Doubik and Hill 1999). It is also assumed the León lies on the major axis of dispersion and that the wind speed is 15 m/s during the eruption. Such an eruption, larger than past eruptions at Cerro Negro, is at the approximate upper bound of

VEI 3 activity. Given these parameters and based on the Suzuki model, the ULV for tephra accumulation in León is 47 cm.

Figure 17. Red Cross camp at Cerro Negro, 1992 (Source: Connor).

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