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GIS Prototype Modeling of Landslide Susceptibility and Risk Perception - Aguas Calientes (Machu Picchu Pueblo), Peru: An Exploratory Approach

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Abstract

Tourism is an increasingly important and developing sector of the Peruvian economy and the country is fast-tracking development to accommodate an influx of tourists, reportedly over 1.8 million/year. Situated in the southwest region of Peru, Aguas Calientes (Machu Picchu Pueblo) continues to develop infrastructure to keep pace with this burgeoning tourism industry. Regional geology and hydrology are importation factors influencing the ability to accommodate tourism in Aguas Calientes. Located at the confluence of three rivers, the town is also situated in a watershed with high return intervals for flooding and mass wasting triggered by the sudden, intense rainfall characterizing the wet season. Using a prototype landslide susceptibility model expanded to analyze exposure and risk perception, this research examines the relationship between perception and modeled physical variations and processes across the landscape. The approach uniquely pairs qualitative, ethnographic methods with quantitative data and modeling to create susceptibility maps and a query-ready spatial database for use in resource management. Results also suggest the need for re-evaluation of the extent and classification of hazard zone for use in resource management and land use planning.

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GIS Prototype Modeling of Landslide Susceptibility and Risk Perception - Aguas Calientes (Machu Picchu Pueblo), Peru

An Exploratory Approach

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ABSTRACT

Tourism is an increasingly important and developing sector of the Peruvian economy and the country is fast-tracking development to accommodate an influx of tourists, reportedly over 1.8 million/year. Situated in the southwest region of Peru, Aguas Calientes (Machu Picchu Pueblo) continues to develop infrastructure to keep pace with this burgeoning tourism industry. Regional geology and hydrology are importation factors influencing the ability to accommodate tourism in Aguas Calientes. Located at the confluence of three rivers, the town is also situated in a watershed with high return intervals for flooding and mass wasting triggered by the sudden, intense rainfall characterizing the wet season. Using a prototype landslide susceptibility model expanded to analyze exposure and risk perception, this research examines the relationship between perception and modeled physical variations and processes across the landscape. The approach uniquely pairs qualitative, ethnographic methods with quantitative data and modeling to create susceptibility maps and a query-ready spatial database for use in resource management. Results also suggest the need for re-evaluation of the extent and classification of hazard zone for use in resource management and land use planning.

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TABLE OF CONTENTS

1. Introduction

Tourism is an increasingly important and developing vital sector of the Peruvian economy. The country is fast-tracking development to accommodate the influx of tourists to the Cuzco/Machu Picchu region, reportedly over 1.8 million foreign visitors/year (Anderson 2008; Thomas White Global Investing 2012; Municipalidad Distrital de Machu Picchu 2011). Situated in the southwest region of Peru, Aguas Calientes (Machu Picchu Pueblo) experienced a surge of urban development as a result of a 1998 UNESCO initiative. The development plan cited the growing tourism industry centered on the UNESCO World Heritage site, Machu Picchu Sanctuary (UNESCO 2002; Zan & Lusiani 2011), as the primary reason for the need for immediate and planned urban development. A global tourist destination, Machu Picchu Sanctuary attracts hundreds of thousands of tourists annually with as many as two million total visitors. According to a 2011 development plan compiled by the Municipal District of Machu Picchu, the annual number of foreign and national visitors to Aguas Calientes between 2001 and 2010, has increased from 420,870 to 699,831. The region stretching from Cuzco to Machu Picchu Sanctuary continues to undergo urban expansion primarily due to the increases in the tourism industry (Anderson 2008). In response, the town of Aguas Calientes, in an attempt to keep pace, is engaged in a frenetic development effort that has created a number of urban growth management challenges.

Recent research determined that the region including and surrounding Aguas Calientes and, in fact, much of Andes are located within a high-risk zone for landslides, which further complicates urban management and land use planning (Vilímek et al. 2006). The extreme mountain terrain, high annual precipitation rates, unique demographics, and increased tourism complicates the implementation of risk management plans (Ayuda Humanitaria y Proteccion Civil & INDECI (InstitutoNacional de Defensa Civil) 2012; Municipalidad Distrital de Machupicchu 2011). As of 2006, reports examining the impact of landslides, which frequently evolve into debris flows[i], on the region surrounding Machu Picchu Sanctuary cited increased tourism and unchecked growth in Aguas Calientes as significant factors complicating management solutions.

According to one study highlighting a particularly destructive debris flow in 2004, the local population increased threefold in the last two decades "without urban control" measures or landslide and erosion prevention plans (Bulmer & Farquhar 2010; Carreno & Kalafatovich 2006; Sassa et al 2003; Sassa et al 2004; Sassa et al 2005; Vilímek 2006). In summary, there is an identifiable need for sound growth and risk management plans in the region, in part due to the acknowledged urban growth in association with the tourism industry, and in part due to the need to preserve human life, culture, and agricultural production (Sassa 2009; UNESCO 2002, Zan & Lusiani 2011). How then is the gap bridged between observed conditions, research findings, and successful implementation of urban growth and emergency management plans?

The prototype landslide susceptibility model and methodology presented seeks to offer a novel method of analyzing the spatial distribution of risk perception and addressing the following questions.

- First, how does risk perception of the susceptibility of a landscape compare with modeled results and previous findings?
- Secondly, can a spatial analysis of risk perception reveal any unique information about the way residents of Aguas Calientes perceive and conceptualize landslides, debris flows (huaycos), and rockfall vulnerability?
- And, finally, what are the resulting implications of the consideration of risk perception in hazards modeling for urban management, disaster management plans, and resource management?

1.1. Project area

Aguas Calientes is located in the heart of the Peruvian Andes, just 44 miles northeast of Cuzco, the ancient capital city of the Incan Empire. The town is situated at the confluence of three perennial rivers - the Alcamayo, Urubamba (Vilcanota) and the Aguas Calientes (Figure 1). The unique geographic positioning of the town contributes to a subtropical vegetation zone contributing to a secluded, lush, and idyllic setting for tourists (Parskwatch 2004). However, proximity to the rivers and the steep granite slopes that are eroded by torrential peak flows experienced annually during the wet season (November to March/April) creates potential hazards and associated risk (Vilímek et al 2006; Ayuda Humanitaria y Proteccion Civil & Instituto Nacional de Defensa Civil 2012). Of the total annual precipitation of recorded annual rainfall for Aguas Calientes, 56-67% of that (824 mm to 979mm of 1,463mm) falls between November and April. In addition to the sheer quantity of precipitation, the frequency and intensity of the storms contribute to the high risks of flooding, debris flows, and landslides.

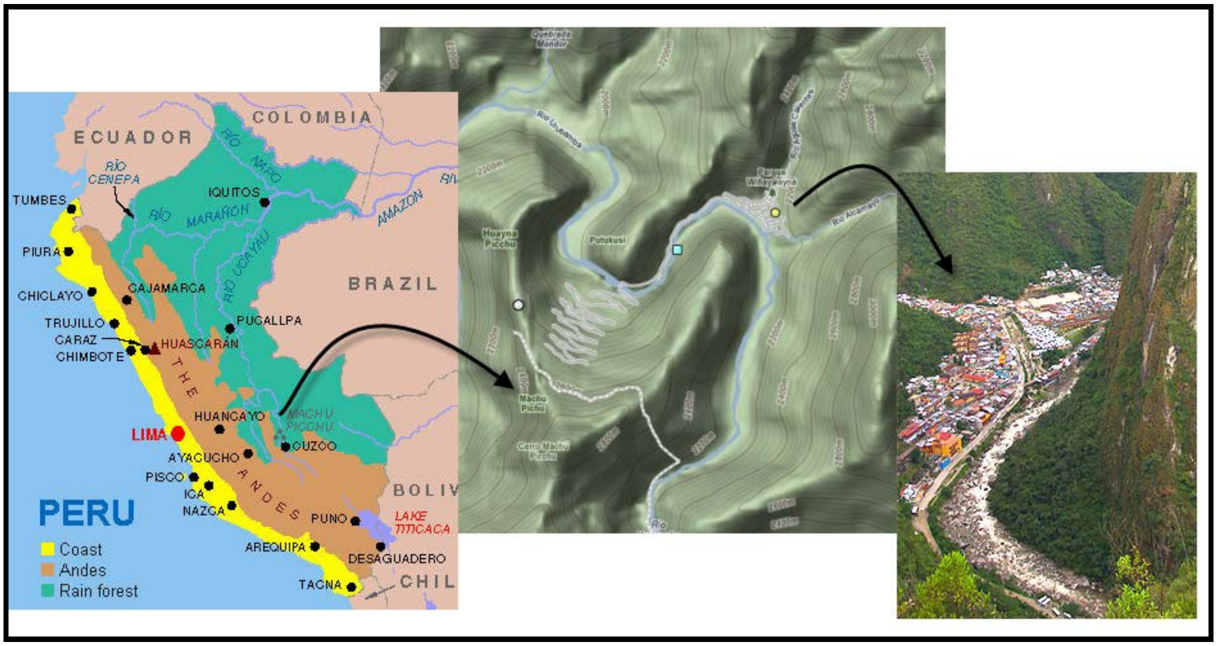


Figure 1. Location of project area, Aguas Calientes, located at the edge of two principle geographic regions,the sierra (or Andean highlands) and the rain forest. (Images compiled from: Google Earth, Inside Peru 2013; www.agutie.com)

Historical and recent events (most recently, damaging debris flows in 2004 and 2010) underscore the characterization of a landscape undergoing significant change, increasingly due to development impact, and is in need of effective management solutions (PREDES et al 2012). According to Carreno and Kalafatovich (2006), similar debris flows to the significant event of 2004 also occurred along the Alcamayo River in 1946, 1961, and in 1967 or 1969. In February 2010, a debris flow carried by the Urubamba River led to severe damage of the narrow gauge rail line from Cuzco to Aguas Calientes. This flooding along with several mudslides along the Inca Trail to Machu Picchu Sanctuary necessitated the prompt evacuation of visitors and residents from Machu Picchu Sanctuary, the trail, and Aguas Calientes (Bulmer and Farquhar 2010).

Much of the Inca Trail follows the Urubamba River. Consequently, landslides or rockfalls along the trail have the potential to impact downstream regions in addition to posing an immediate threat to tourists, guides, and porters hiking the trail. Aguas Calientes continues to expand along the rivers and creep up gentler slopes despite findings by UNESCO-funded research that sustainable urban growth management plans need to be put into place to mediate the imminent and high risk of landslides and debris flows (Sassa 2005). This growth occurs despite developing concerns over the devastating impact of debris flows. These flows originate from slides cascading down from slopes measuring over 4,000m with slope gradients as much as 70 degrees overlooking perennial rivers with high carrying capacity (Bulmer & Farquhar 2010, Carreno & Kalafatovich 2006). Any analysis, then, must take into account proximity to waterways or flow paths and slope gradient as these variables may increase the probability of a landslide mobilizing into a debris flow.

A recent geophysical study identified several key areas of “weathered and heavily fractured granite rocks” on the slopes around Aguas Calientes (Bulmer & Farquhar 2010). Slope stability is compromised by “heavily jointed” bedrock exposed to the chemical weathering experienced in this sub-tropical, humid, albeit montane environment. The decomposed granitoid soils found along some of the more densely vegetated slopes are more susceptible to failures such as landslides (Durgin 1977). According to Bulmer and Farquhar (2010), construction within the commercial district of Aguas Calientes continues on “unstable valley slopes”. Recent studies also state that the implementation of vital aspects of suggested management plans remains problematic (Bulmer & Farquhar 2010; UNESCO 2002). Residential areas of town continue to develop informally and without building codes or construction practices reflective of the threat and risk of landslides and rockfalls. Further complicating the situation is the erosivity of the Urubamba River during peak flow and as a channel for debris flows originating at higher elevations. The discharge rate of the Urubamba River is such that it frequently carries large granite boulders downstream. All of these characteristics of life in Machu Picchu support urgent and creative problem solving in order to identify sustainable solutions unique to both the geographic location and the resources available.

2. Literature Review

This section offers an overview of salient research, theory, and methodology used as the basis for the novel approach to analyzing the intersection between modeled landslide susceptibility and risk perception.

2.1. *Application of GIS to landslide modeling*

GIS modeling of landslide susceptibility attempts to account for a myriad of dynamic physical processes. Weathering, a natural wearing down of a landscape by elements in the environment (i.e. wind, water, and gravity), is an important process contributing to the likelihood of a mass movement event. Erosion is defined as the transportation of weathered material[ii] and mass movements are extreme, large-scale, and often sudden type of erosion. Mass movements can occur quickly within a matter of seconds or over longer periods of time such as weeks or months. The types of mass movement that are the focus of this study are landslides and debris flows. The primary cause of such movements is slope instability resulting from a reduction in the resistive forces to gravity that is often triggered by an intense rainfall event. There are a number of contributing factors, such as land use change and land degradation, that can increase the susceptibility of a hillslope to erode on the level of a landslide that, with sufficient water along a channel can develop into a debris flow (Alcantara-Ayala, Esteban-Chavez, & Parrot 2006; Selby 1982).

The unique and complex relationship between land cover type (especially vegetation type) and the corresponding soil characteristics also affect the ability of a hillslope to resist erosion (Cooke 1974). For example, loss of vegetation due to development or other land use change can greatly increase the erodibility[iii] of soil (Glade 2003). Contributing factors that can lead to an increase in the susceptibility of a landscape include the following factors:

- An area where a landslide event previously occurred.
- Human impact such as urban expansion resulting in reduced vegetation or cleared slopes.
- Steep slopes with weak or weakened geologic structure or weakened/fractured exposed bedrock or rock outcroppings
- Steep slopes experiencing the high erosion due to increased or unusually high surface runoff. (Burns et al n.d., Selby 1982).

The typical type of landslide affecting the region most often take the form of debris flows. These rapidly moving loose masses of soil, rock, and water travel down steep slopes under the influence of gravity and continue down natural drainage channels such as the Urubamba River (Iverson, Reid, & LaHusen 1997). As Aguas Calientes is situated at the confluence of three rivers and continues to grow alongside the natural pathways for water, the potential exposure to debris flows increases. In addition, development up the steep slopes bordering the western perimeter of the town has the potential to increase the susceptibility of the slopes to failures and slides. To date, no prior assessment of landslide susceptibility through the use of GIS modeling has been completed for this region.

There have, however, been geophysical assessments of hazard zones, areas of risk, and selected watershed assessments (Bulmer & Farquhar 2010; Gonzales Inca 2009; Pumayalli 2008) within the region. Bulmer and Farquhar (2010) conducted geophysical surveying and assessment of the channel carrying capacity of the Aguas Calientes River. As a result, they installed a monitoring and warning system in the Aguas Calientes River upstream from the town (Bulmer & Farquhar 2010). The authors also recommended further investigation and installment of a permanent monitoring system. The results of their research led them to affirm that the town lies in a high-risk zone for hazards and that the current emergency and hazard response and preparedness plans were inadequate. Of interesting note is a conclusion that the primary decision makers in the town are the non-experts and that successful implementation of plans requires effective communication with this segment of the population. Gonzales Inca (2009) and Pumayalli (2008) conducted larger-scale watershed assessments. Gonzales Inca (2009) identified a number of areas within the Cuzco watershed where sediment yield is increasing rapidly and suggested poor land use practices and impacts from tourism impacted these results. Pumayalli (2008) explored the use of GIS in natural resource management with non-expert populations where data sources, particularly for soil maps, are limited. He concluded that both new technology and GIS modeling are vital to the ability to successfully manage resources in the Andes.

These studies along with news reports of recent events support the fact that hazards are a common occurrence in this region and that landslides are the chief among these. Furthermore, these studies support the application of GIS modeling and of the integral role non-expert stakeholders play in developing and maintaining long-term, sustainable resource management plans. And, while no prior evaluation of the situation such as is presented in this paper exists, the findings explored in these studies played an important role in the development of the methods and in the calibration of the model.

Computer-based GIS modeling of natural hazards offers spatial as well as numerical analysis. As a result, analysis moves beyond the experience of consulting 2D paper-based representations of the area of concern or data-heavy mathematical analysis that tend to isolate select parameters. GIS analysis is now poised to address dynamic questions such as “why and what if” (Berry 2007; Goodchild 1993; Thomas & Sappington 2009). A thorough evaluation requires the application of robust quantitative data exploring the physical geography of the landscape (i.e., slope characteristics, influences of fluvial systems, soil type, and vegetative cover) within and without anthropogenic change. Evaluating and weighting parameters in geographic space allows for the inclusion of both qualitative and quantitative data and enables communication of the results in a meaningful way to non-experts. The concept of GIS modeling presented in this study allows for analysis and adjustment of the complex relationships among the factors affecting hillslope stability while also extending the evaluation to include perception.

Typical mass movement process flow models tend to focus on the physical processes at work and make numerical or statistical assessments based on probabilities. However, for the purposes of this study, a prototype susceptibility model is proposed for the purpose of identifying areas deserving of further research and allocation of resources. In addition, the model is expanded to examine the role of risk perception. Additional discussion of the application of this novel approach is presented later in this paper.

Typical susceptibility models in GIS space often examine the potential threat within a system by identifying the areas of significant vulnerability or disruption due to environmental change (Borga et al 2002; Vanacker et al 2003). A typical extension of such modeling may include an evaluation of the relationship between areas of high landslide susceptibility or risk and developed conditions occurring within those areas (based on direct and proximal occurrence of roads, railroads, utility lines, homes, and commercial buildings). For example, the railroad connecting Aguas Calientes with Ollantaytambo serves as one of two primary means of reaching the town. Damage to the railroad tracks by debris flows has occurred previously (2004 and 2010), stranding tourists and effectively isolating the town from access to resources except via helicopter. However, they do not typically include or account for a comparison of perception as a means of encouraging, expanding, or direction policy change. The landslide susceptibility model employed in this analysis, then, addresses relative landslide vulnerability as a function of susceptibility and risk perception and allows for several extensions of the model including evaluations for exposure and flow processes (Berry 1993; Berry 2007).

2.2 *Risk communication approaches*

Increasingly, emergency management literature and agencies highlight the vital need to interface with communities affected by natural hazards, both in the mitigation of and in response to the hazard. The findings revealed by studies within the field of hazard management and risk communication developed in the wake of current examples of “gross mismanagement” and the predicted impact of climate variability (FAO 2008; Haddow and Bullock 2005). Additionally, such findings are now taking into account the increasingly interconnected and global nature of the economic impact of natural hazards. No longer are hazards in developing countries isolated events with little meaning for regions beyond their borders. Therefore, identifying and communicating the threat and risk of hazards holds significance for the affected population as well as for countries and people dependent on the economic stability of that region.

Since the 1980s, theories and methods for inclusion of risk communication in emergency and urban management plans varied widely. It is only recently that the body of literature covering effective risk communication provided a framework with some degree of specificity reflective of a general theoretical and practical consensus (Leiss 2004). Further complicating hazard management in developing countries is the growing presence of and reliance on the tourism industry. This dynamic relationship results in a complex environment characterized by a short-term focus on development rather than the adoption of long-term sustainable growth management plans.

Appropriate means of managing the impact from a hazard may not always mean application of advanced technical methods. Sometimes it is necessary to identify whether incomplete perceptions or data exist that are in fact acting against any measures in place to manage development within an identified natural hazard zone (Cooke 1974). In particular when attempting to achieve buy-in from the population at risk, it is important to not only identify the key stakeholders but also to assess the presence and/or degree of misconceptions. Smerecnik et al. (2012) suggest that the field of physical geography is in a unique position to assist with education of a population in the process of developing management plans that adequately serves the needs of the population.

Efficient risk communication, then, requires a steeped understanding and appreciation of the unique character of the cultural, economic, political and social environment in the area of concern (Smerecnik et al 2012). Perceptions can vary greatly across different groups, cultures, and sub-cultures. Slaymaker and Spencer (1998) define risk perception as the "common sense understanding of hazards, exposure and risk, arrived at by a community through intuitive reasoning. Evaluations of whether the affected population feels safe or unsafe often drives public policy decisions even when these perceptions may be at odds with technical risk assessments (Slaymaker & Spencer 1998).

An added component of the process of evaluating risk, risk perceptions, and the appropriate means of communicating and managing the risk, arises wherever mistrust of agency-driven change may be present. In some cases, developing countries navigating significant economic growth as a result of tourism are becoming increasingly dependent on the need to preserve historical and cultural sites and rearrange priorities to respond to the impact from the tourism. In these circumstances, an evaluation of risk communication methods provides a unique opportunity to bridge knowledge gaps, lay the foundation for long-term research and risk management, and sustainable and “smart” growth. In addition, risk communication in such regions must respect the local belief systems particularly where issues of environmental risk are concerned (Laboy-Nieves et al. 2010).

Furthermore, engaging the local community and encouraging collaboration among agencies may provide the key to development of sustainable resource management plans. To this end, study of a community using survey instruments can prove useful. Such methods can reveal vital information about social and communication norms, class structures, and gaps in the local knowledge base which may or may not be in consonance with governmental or scientific terminology, classification systems, or priorities (Bernhardt nd; Swiss Agency for Development and Cooperation (COSUDE), Gobierno Regional de Cuzco, & PREDES 2011).

Thus, the methodology and analysis presented in this paper elucidates variables without which the numerically-based equation for a risk management plan fails. Nowhere is this perhaps more true than in developing countries where populations may face sharp contrasts between traditional methods and ideologies and the impact of new technology, global politics, tourism, and social norms. Beyond the need for increased consideration of risk management practices by land-use managers and local and national governments, researchers and managers must develop efficient, informed, and appropriate means of communication with local populations (Fischhoff 1995). Increasingly Public Participation GIS (PPGIS) is offering unique ways of studying and creating sustainable solutions to land use management challenges and the impact of natural hazards, particularly in developing countries (McCall 2008;

Rambaldi 2006).

In summary, this study proposes that to truly develop a sustainable growth management plan for Aguas Calientes, it is necessary to first evaluate the hazards impacted by or influencing growth. Second, management of growth is better informed when the perceptions of the population are understood. Perceptions are changeable and subjective. One assessment can only be a snapshot in time of those perceptions from within a representative sample. However, the inclusion of the local population in the GIS process (PPGIS) enhances the ability of appropriate risk communication and resource management to lead to a holistic and sustainable solution (Jordan nd; Weiner & Harris 1999). In addition, when solutions must be derived from limited data, the local knowledge or oral history can sometimes provide a useful starting point for further examination and application of resources. The methods and novel analysis presented in the following section demonstrate the unique benefit of combining a traditional GIS analysis of landslide susceptibility with an assessment of risk perception (Barroca et al. 2006; McCall 2008; Rambaldi et al. 2006).

3. Design and Implementation

3.1 Stage 1: Determining landslide susceptibility

Data for this analysis stage was largely prepared using ArcMap, the primary component of the ESRI ArcGIS 10.1 suite of tools. The model analysis is carried out in MapCalc Academic Learner. This grid-based software program provided by Red Hen Systems, Inc., offers users direct interaction with spatial analysis and spatial statistics tools. A primary motivation for the use of this modeling platform is the relatively low-cost and short learning curve necessary to perform the mathematical operations. When considering efficient and effective solutions, it is necessary to consider options that will meet the needs of a region with limited resources. However, significant data preparation was necessary due to a lack of current and usable data. The cost that would be associated with this data preparation is a necessary initial expense despite being a potential challenge.

3.1.1 Data preparation

The prototype landslide susceptibility model used slope, soil type, and land cover type to assess susceptibility. The selection of these initial, fundamental criteria stems from the consensus within the literature as to the essential roles these have in maintaining or permitting slope failure (Borga et al 2002; Günther et al 2013; Pradha n.d.; Vanacker et al 2003). The slope data was derived from a Digital Elevation Model (DEM) raster dataset provided by Mr. Gonzales Inca (Gonzales Inca 2009). The DEM was prepared in ArcMap by extracting the DEM to the project area (Figure 2). The continuous, integer, ratio, raster dataset was derived from aerial stereoscopy and has a resolution of 5m. It was provided by Mr. Carlos Gonzalos Inca who had conducted similar research in the region (2009).

Once the raster DEM ws imported into MapCalc, the terrain data was analyzed using the Slope command. This function uses the values represented in eight surrounding cells. The resulting continuous, ratio slope map is then renumbered into discrete ordinal data that generalizes the amount of steepness in percentage. This is done by a simple renumbering operation that assigns a new value to all original values within a user specified range.

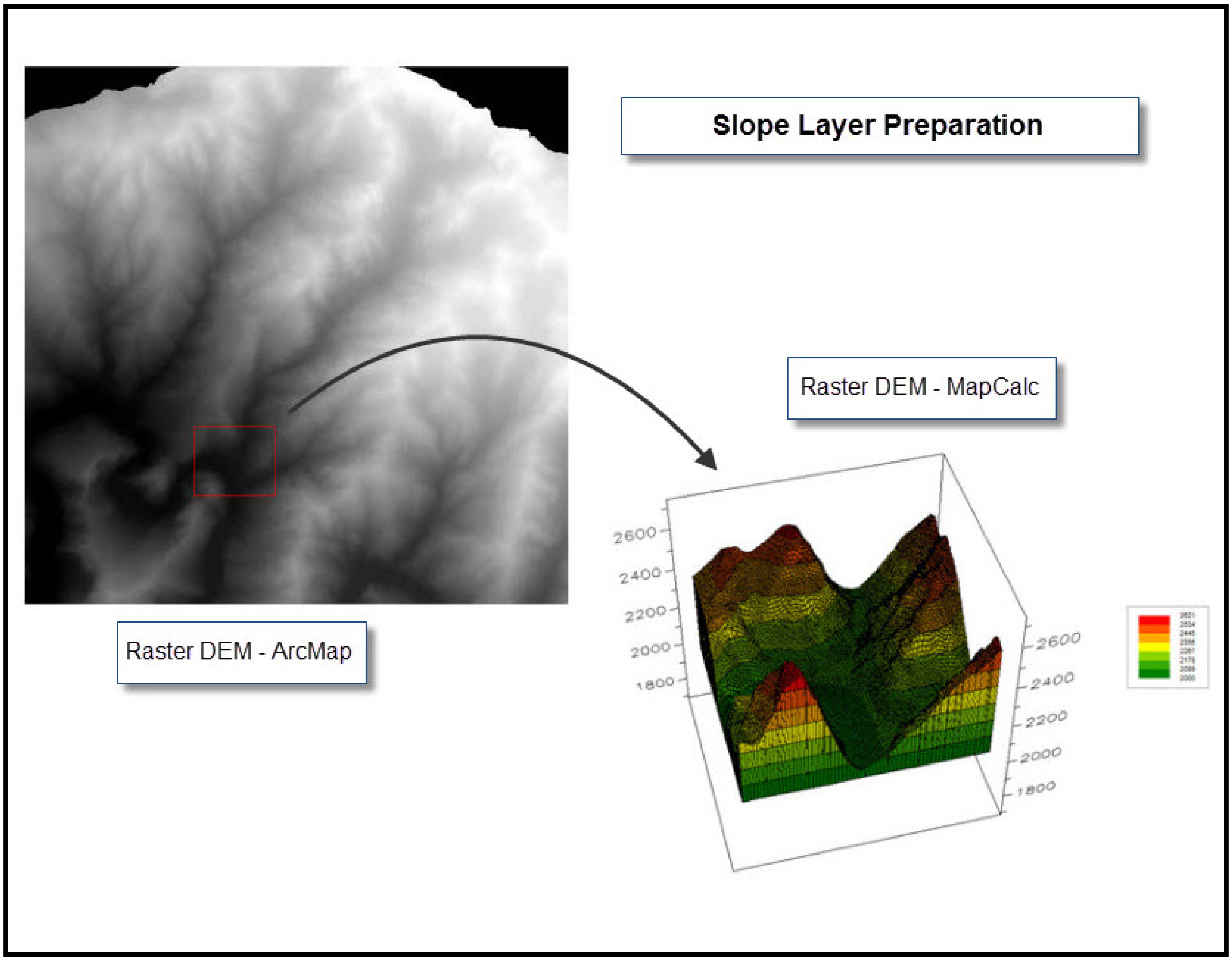
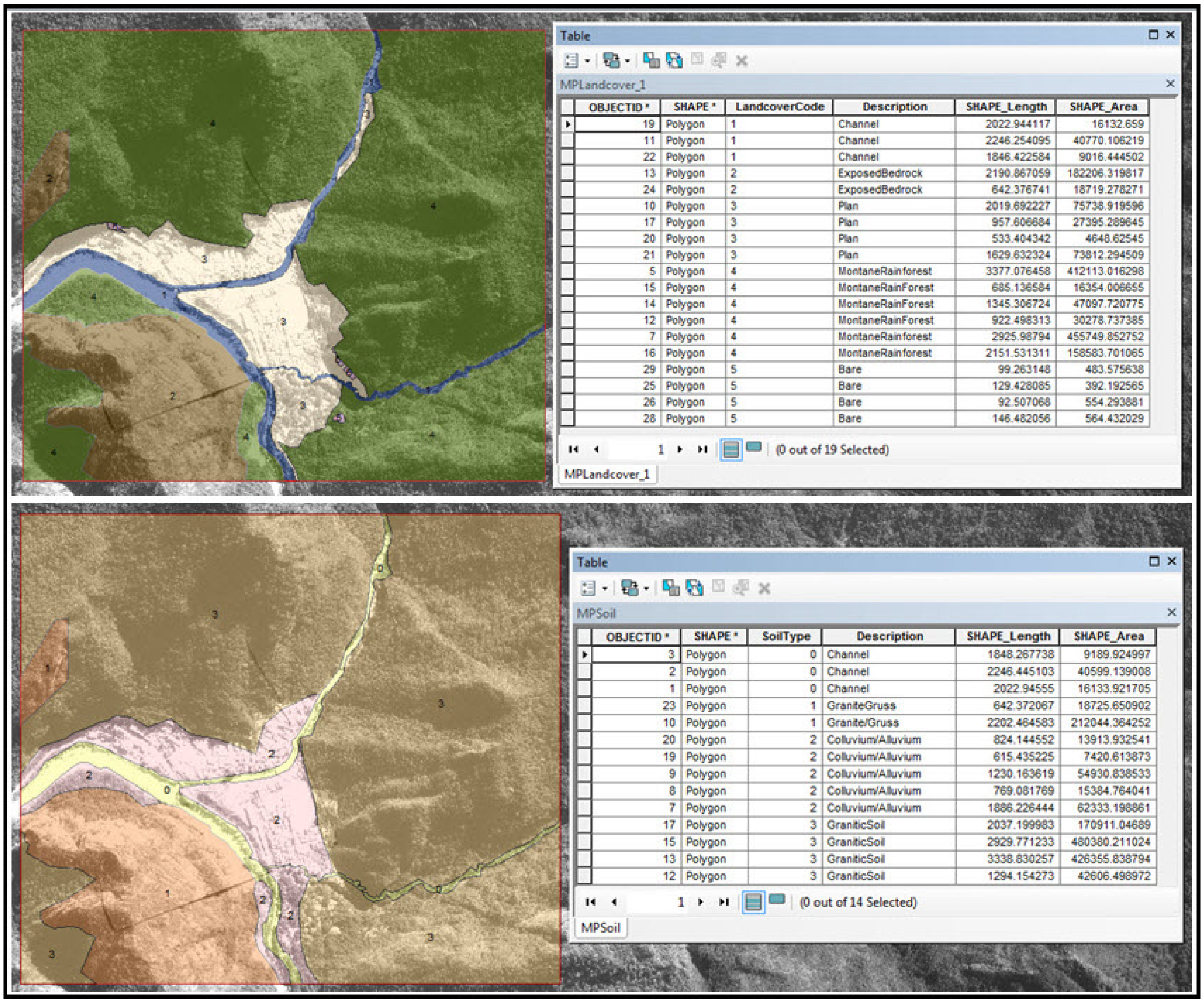


Figure 2. Illustration of raster DEM prepared in ArcMap and then imported into MapCalc.

The land cover type and soil type basemaps were developed and informed by the literature review, expert interviews, field-based/personal knowledge, satellite imagery, and an orthophoto (Bulmer & Farquhar 2010; Carlotto, Cardenas, & Fidel 2008; Carlotto, Cardenas, & Fidel 2008; Gonzales Inca 2009; Pumayalli 2008). Although later converted to raster datasets, the land cover type and soil type discrete, nominal data was first created as vector data. Polygon boundaries were determined through a combination of digitization of soil and land use maps created in AutoCad and observations made and recorded during field explorations of the terrain. The feature classes were created in ArcMap, converted into raster datasets and then imported into MapCalc and reclassified according to type (top inset in Figure 3). Land cover types include channel, exposed bedrock, plan (built development), montane rainforest, and bare ground. Soil type classifications include channel, granite/gruss, colluvium/alluvium, and granitic soils (bottom inset in Figure 3). It is the hope of the author that access to or the ability to assist with field verification of viable landcover and soil maps, these basemaps may be refined as needed. In the meantime, these maps were developed as a result of the resources listed above.



OBJECTID *	SHAPE *	LandcoverCode	Description	SHAPE_Length	SHAPE_Area
19	Polygon	1	Channel	2022.944117	16132.659
11	Polygon	1	Channel	2246.254095	40770.106219
22	Polygon	1	Channel	1846.422584	9016.444502
13	Polygon	2	ExposedBedrock	2190.867059	182206.319817
24	Polygon	2	ExposedBedrock	642.376741	18719.278271
10	Polygon	3	Plan	2019.692227	75738.919596
17	Polygon	3	Plan	957.606684	27395.289645
20	Polygon	3	Plan	533.404342	4648.62545
21	Polygon	3	Plan	1629.632324	73812.294509
5	Polygon	4	MontaneRainforest	3377.076458	412113.016298
15	Polygon	4	MontaneRainForest	685.136584	16354.006655
14	Polygon	4	MontaneRainForest	1345.306724	47097.720775
12	Polygon	4	MontaneRainForest	922.498313	30278.737385
7	Polygon	4	MontaneRainforest	2925.98794	455749.852752
16	Polygon	4	MontaneRainforest	2151.531311	158583.701065
29	Polygon	5	Bare	99.263148	483.575638
25	Polygon	5	Bare	129.428085	392.192565
26	Polygon	5	Bare	92.507068	554.293881
28	Polygon	5	Bare	146.482056	564.432029

(0 out of 19 Selected)

OBJECTID *	SHAPE *	SoilType	Description	SHAPE_Length	SHAPE_Area
3	Polygon	0	Channel	1848.267738	9189.924997
2	Polygon	0	Channel	2246.445103	40599.139008
1	Polygon	0	Channel	2022.94555	16133.921705
23	Polygon	1	GraniteGruss	642.372067	18725.650902
10	Polygon	1	Granite/Gruss	2202.464583	212044.364252
20	Polygon	2	Colluvium/Alluvium	824.144552	13913.932541
19	Polygon	2	Colluvium/Alluvium	615.435225	7420.613873
9	Polygon	2	Colluvium/Alluvium	1230.163619	54930.838533
8	Polygon	2	Colluvium/Alluvium	769.081769	15384.764041
7	Polygon	2	Colluvium/Alluvium	1886.226444	62333.198861
17	Polygon	3	GraniticSoil	2037.199983	170911.04689
15	Polygon	3	GraniticSoil	2929.771233	480380.211024
13	Polygon	3	GraniticSoil	3338.830257	426355.838794
12	Polygon	3	GraniticSoil	1294.154273	42606.498972

(0 out of 14 Selected)

Figure 3. Display of feature classes for both land cover type (top) and soil land cover type (bottom) created in ArcMap.

3.1.2. Model development

Initially, the prototype model developed was used to perform a landslide susceptibility analysis (Figure 4). The inputs to the model included slope, land cover type, and soil type. To streamline the model and pinpoint areas of susceptibility, other variables may be included later in the application and refinement of the model. However, given the lack of data for the specific project area and the region as well as the unique characteristics of the project area, the aforementioned inputs were chosen for development of the prototype model.

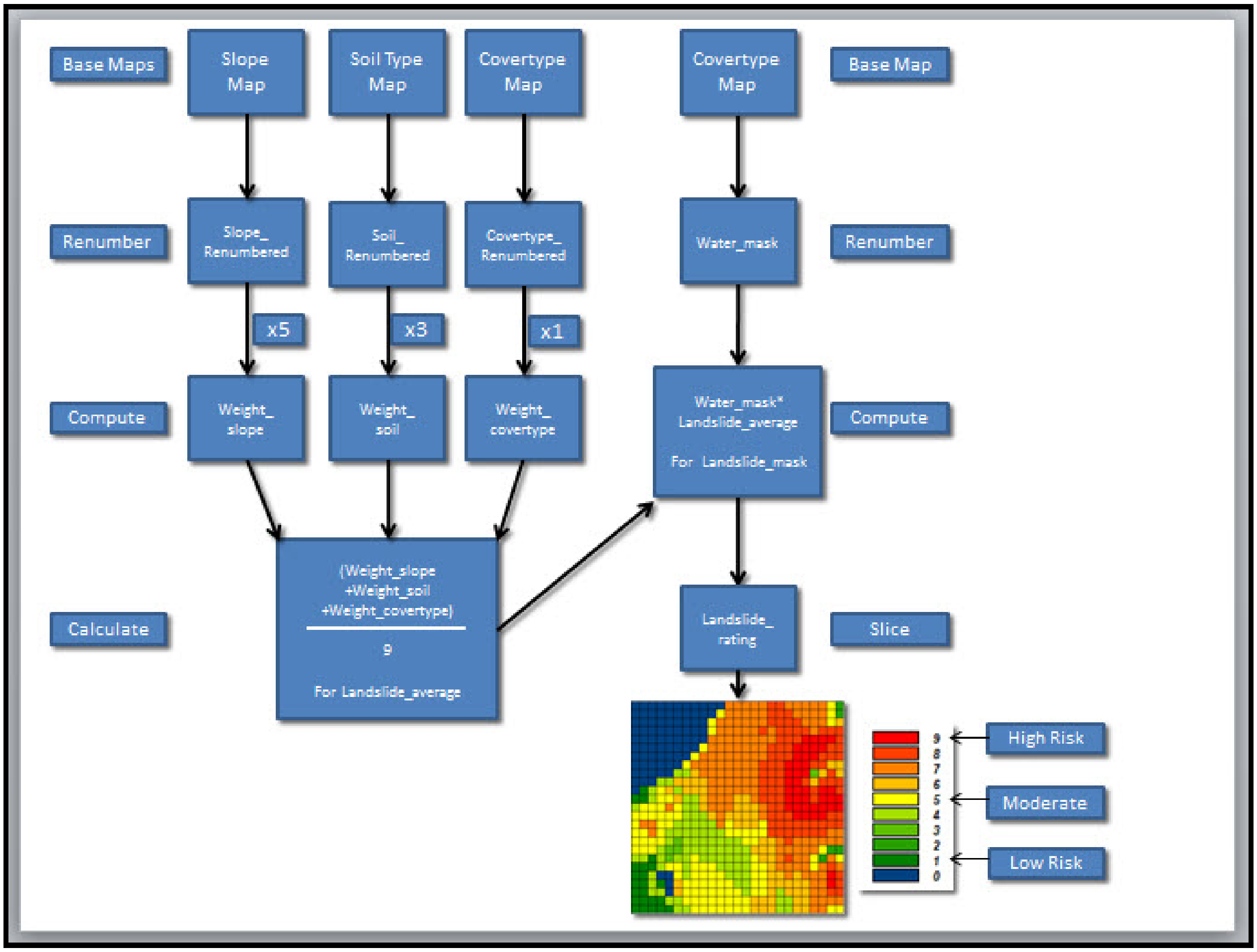


Figure 4. Process used to determine average overall landslide susceptibility.

The susceptibility maps developed using the criteria listed in Table 1 illustrate areas with high or low landslide susceptibility based on a pre-determined rating system used to calibrate or adjust actual conditions to a common susceptibility rating. In addition, all criteria are not treated as equal in the model with some receiving more weight (importance) than others. The rationale behind the weighting and ranking of the variables is supported by field observations, interviews with a local geoscientist as well as by a literature search where similar attempts were made to appropriately weight variables in a landslide model (Ayalew et al. 2004; Australian Geomechanics Society 2007; Diop 2012; Feizizadeh & Blaschke 2012). Slope, for example, has a greater impact on landscape change than does soil type or land cover type.

Table 1. Input criteria considered in landslide susceptibility analysis, Phase 1, Stage 1.

Calibration Rating Assigned	**Slope Conditions**	**Soil Type**	**Land Cover Type**
0=Not susceptible	NA	0=Channel	1=Channel
1=Least susceptible	0-3%	1=Granite/Gruss	2=Exposed Bedrock
2		NA	NA
3=Relatively low susceptibility	3-25%	NA	3=Plan*
4		2-Colluvium/Alluvium	NA
5=Relatively moderate susceptibility	25-70%	NA	NA
6		NA	NA
7=Relatively high susceptibility	70-400%	NA	4=Montane Rainforest
8		NA	NA
9=Most susceptible	>400%	3=Granitic Soils	5=Bare

*Plan=Natural environment modified into built development.

The structure of the rating system suggests some fundamental assumptions about the relationship between each of the criteria and landslide susceptibility. Rivers do not contribute to susceptibility for slides because landslide threat increases most directly with slope. However, they do play an integral role in the conveyance of debris flows. First, however, the model is used to analyze the initial detachment or slide that then oftentimes evolves into a debris flow.

The colluvium/alluvium soils are found primarily on the floodplain on which the town is built and do not contribute to a high degree of susceptibility. In other words, gently sloping terrain from the floodplain carries a minimal or low degree of susceptibility. Unique to this terrain and this project area is the sudden rise in elevation from floodplain to steep mountain sides with 100% slopes and greater. Not only are slopes being undercut by the rivers thereby increasing slope instability (and thus also susceptibility), but as land is cleared up slopes, bare, highly erodable soil is exposed to weathering processes (Selby 1982).

An increase in slope combined with the susceptible soil types and land cover types typically found in those higher elevations often results in a greater threat of landslides. However, these comparisons reveal only part of the picture. Weighting the different criteria allows for a more accurate determination of the true nature of the relationship between slope, soil types, and land cover type. These findings informed the reasoning behind the specific initial weighting used in this prototype model. The model could be improved with the inclusion of more detailed and field-gathered or tested data. This was beyond the scope of this project, but is certainly a viable extension of the analysis. Once the maps are multiplied by their weight, the weighted average of susceptible ratings for each of the three base criteria is calculated. This yields a map displaying overall susceptibility.

3.1.2. Model processing

In implementing the model, the first step requires that the three base maps shown above (slope, soil type, and land cover type) be reclassified (Figure 4). This step normalizes the data, allowing for direct comparisons to be made between maps, something that is impossible to do using the original data. For example, Table 1 identifies all areas where slope is greater than 400% as corresponding with "most susceptible". Therefore, all areas with slope >400%, in the reclassification process, are assigned a "9." The data themselves are not manipulated. It is merely reorganized into new categories, thereby normalizing the data with respect to the landslide susceptibility scale of "1" to "9".

In the second step, the reclassified maps are weighted as shown in the model flowchart (Figure 4). Slope is weighted and ranked five times more important, soils as 2.5 times more important, and land cover type as one. In essence the land cover type weighted map remains the same as the reclassified land cover type map. Weighting assigns the relative importance of each variable in the scope of the analysis. Again, the weighting of each of the variables was a first attempt to approximate the degree of influence or the role each of these variables has in resisting slope failure or reducing the susceptibility of a slope to a slide.

In the third step, the numerical value of the data in each of the three weighted maps will be added together and divided by the sum of all the weights (9) to yield the Overall Landslide Susceptibility-Unrated (Figure 4). However, the map in this form reveals little meaning about the numbers represented across Aguas Calientes even when shown over the terrain (elevation). The numbers represent the full range, but are not classified according to the rating system.

In the fourth step, as shown in Figure 4, reclassifying the data in the Land Use Type Map to produce Water Mask-Binary map, assigns a "1" to all values that are not water and "0" to all areas that are water. The regions representing water are then, essentially, disregarded from the analysis for landslide susceptibility by "masking" those areas. The result from this final process in Phase 1 is an output map illustrating the overall landslide susceptibility using the rating system found in Table 1 (Figure 4).

3.1.3 Stage 1.2: Buffer analysis

A buffer was established around the perimeter of the built development. Developed in ArcGIS, the feature class includes a buffer (~50ft) established around known and observed areas of continued development. Once the feature class file was converted to a raster file and converted to ASCI for use by MapCalc, this variable was added to the process used to develop an overall landslide susceptibility map.

Essentially, the purpose of adding this variable is to observe any changes in overall landslide susceptibility within the project area, but also specifically in those areas around the perimeter of the town where clearing of land up moderately steep slopes would likely result in exposed, loose soil. This zone of development was assigned a weighted value of 2 – higher than the weight of landcover but lower than that previously assigned to soil. This value for the weighting is based on understanding of the role bare and disturbed soil plays in susceptibility and mass erosion events (Selby 1982, Toy et al. 2002). This is an initial estimate on the appropriate weighting and further field testing of the influence of this assignation is needed. In the meantime, the resulting map might help establish a "no build/high risk" zone or at least open discussions regarding the impact of urban expansion up slopes.

3.2 Stage 2: Evaluating for risk perception

The second stage of the analysis involves the input of risk perception into the analysis. The primary data sources were compiled from the field component of the research. The field component of the research took place during a six-week stay in Aguas Calientes between June and August 2012. Twenty-five semistructured interviews were conducted during which participants completed a sketch map identified and classified areas of perceived risk of landslides, rockfalls, and huaycos (Quechua word for debris flow). Prior Institutional Review Board approval of the questions and methods was obtained prior to data collection.

Appendix A illustrates the informal schedule used in attempt to collect a truly representative sample while still randomizing the process of identifying participants. Prior to speaking formally with participants, approximately 10 days were spent exploring the town and building rapport and trust with residents. In addition to maintaining a record of observations, GPS data were collected of significant points of change in the landscape along the rivers and the slopes surrounding the town. Potential participants were then approached, the purpose of the study explained and the official IRB explanation of participation presented. Before conducting the interview, verbal consent was obtained. At the close of the interview, participants were asked to sketch areas of high, medium, and low risk (for landslide or slide detachment, debris flow, and rockfall), using pre-selected color and shape coding and a basic street map of Aguas Calientes.

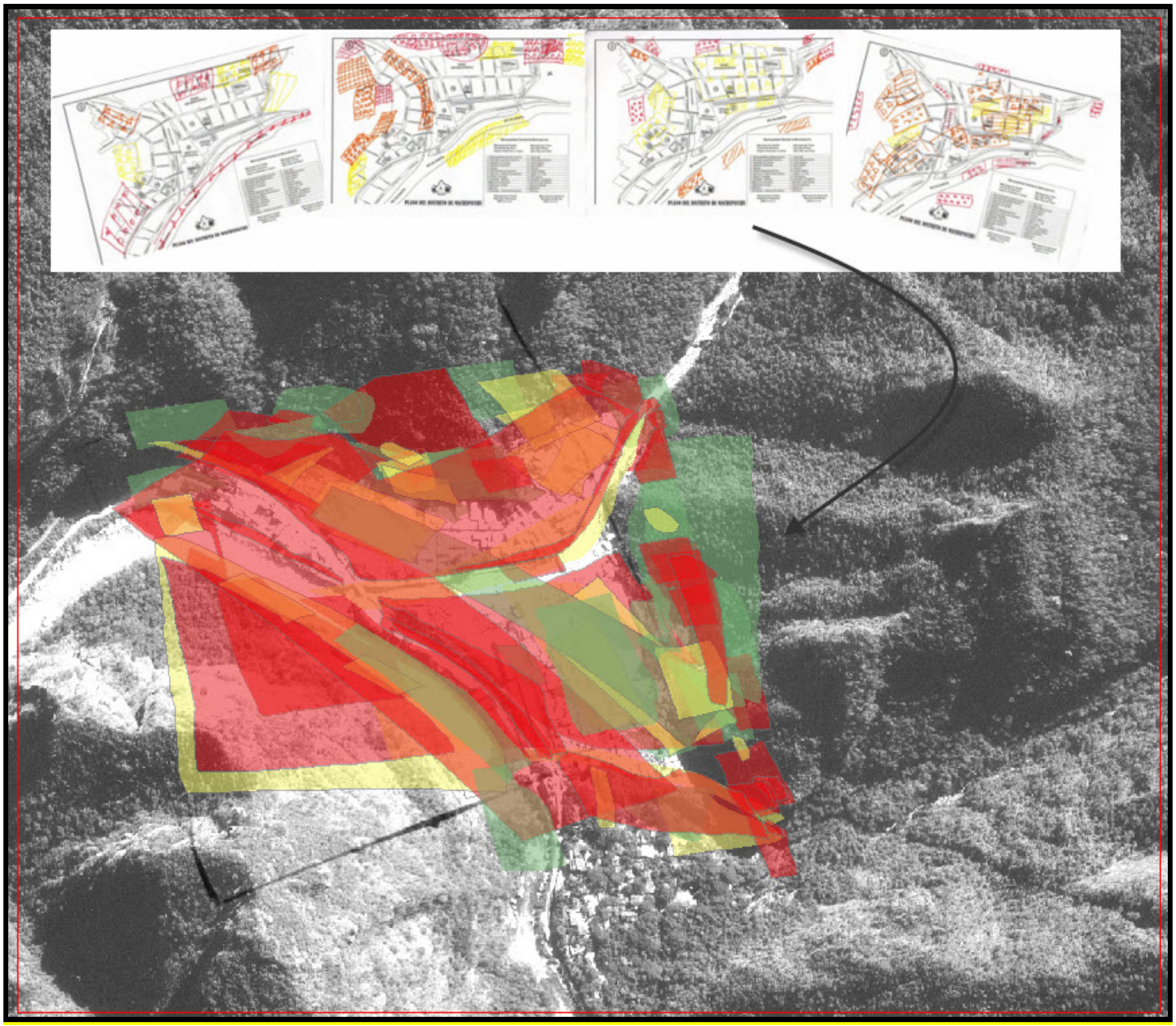


Figure 5. Representative digitized sketch maps displayed over 2000 ortho photo of Aguas Calientes.

Sketch maps are typically free hand maps drawn to illustrate geographic ideas and facts from the perspective of the participant (Bell n.d.; Jacobson & Kitchin 1995; Wise & Kon 1990). This powerful tool offers participants the opportunity to visually describe their perception and, in this case, their relationship to areas where past debris flows, landslides, and rockfalls occurred, the resulting impact from those hazard events, and areas thought to be safe from the danger of such events (Boschmann & Cubbon 2013). Following field collection, the sketch maps were scanned and digitized in ArcGIS (Figure 5).

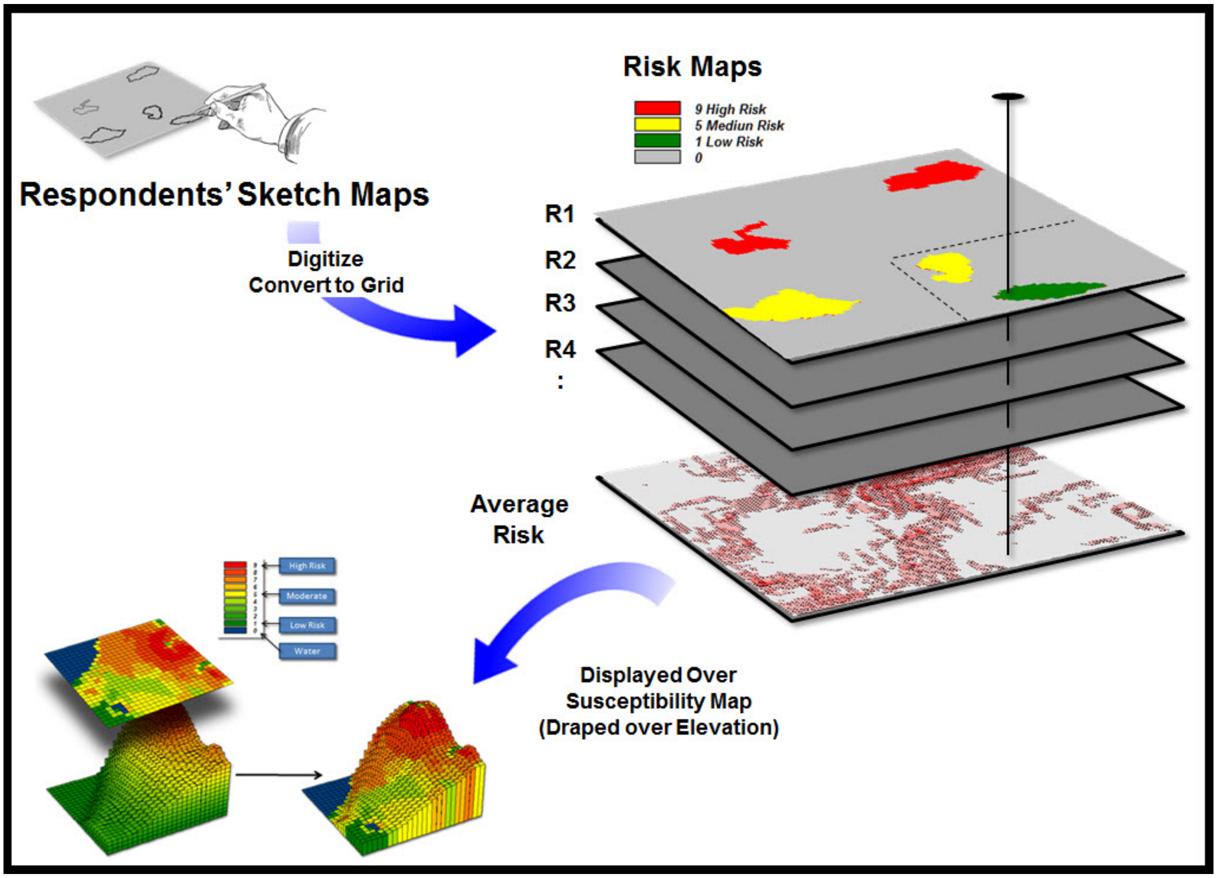


Figure 6. Sketch maps are digitized, averaged, and displayed over the landslide susceptibility map.

The digitized vector data were then converted to raster data, imported into MapCalc, averaged, and displayed over the landslide susceptibility map (Figure 6). This data layer provides an added visual presentation as well as spatial statistics that reveal information about how people position themselves within their environment and proximity to exposure of areas of susceptibility.

3.3 *Stage 3: Analyzing interview responses*

The creation of a geodatabase, comprised of the responses to the interviews, allows for spatial queries of the relationships that may exist between perceptions and proximity to areas of susceptibility (Figure 7). The makeup of the demographic and cultural heritage of the residents of Aguas Calientes is complex and includes a mixture of indigenous (mostly Quechua) peoples, Peruvians who transplanted to the town to take advantage of the tourism explosion, and travelers from various regions of the world (largely Europe) who decided to make their home there (or in Cuzco). However, all have a vested interest in the preservation of their businesses, the tourism industry, and in their personal safety.

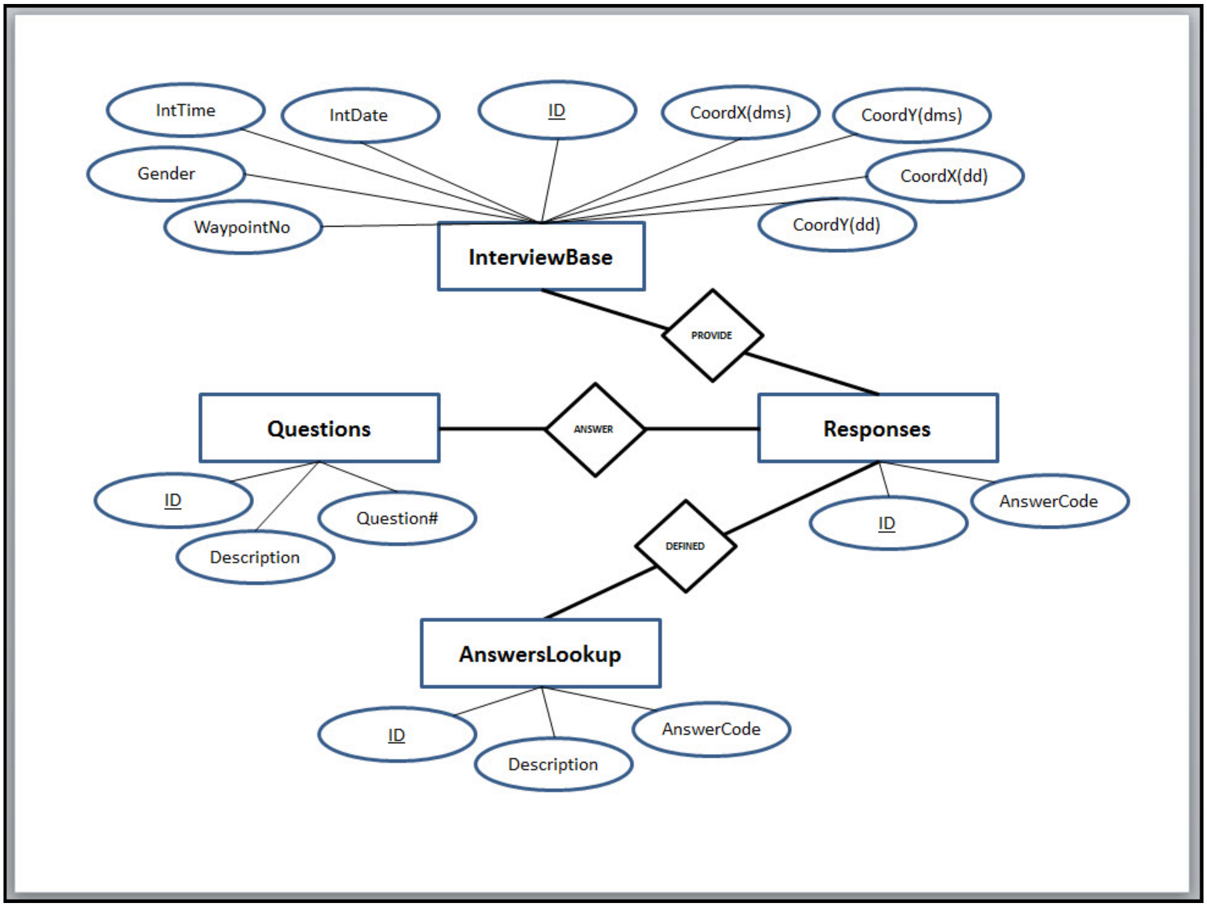


Figure 7. ER (entity-relationship) diagram of relationship between interview data used for performing spatial queries.

The interviews incorporated both open-ended and structured questions. Participants were asked to provide as well as rank information related to their knowledge, attitudes and beliefs. The questions and general nature of the interview related to three primary themes (Appendix B). First, the interview tool was used to assess the extent of local knowledge of past landslide events and the resulting impact to Aguas Calientes. Second, the interview tool was used to assess attitudes and beliefs about the existence of landslides, the individual or agency responsible for mitigation, and the role of unplanned urban growth. And, finally, the interview offered participants the opportunity to provide feedback about their personal safety with respect to location (home vs. work, near the river vs. base of a steep slope) through the use of a few structured questions using a ranking system and sketch mapping.

Initially, participants were allowed to orient the basemap of the town without any input or guidance. If they appeared confused or expressed concern, then color Google Earth satellites images of the region were provided. However, given enough time all participants were able to correctly orient themselves within the landscape. Not all participants were clear on the distinction between a slide, debris flow, and rockfall. However, this is not cause for concern As this is a study that in part can be used to assess the level of geographical knowledge of the local population, the level of knowledge about a geography term, the role of government agencies, or even the local laws governing new development, the lack of or incorrect understanding of a term or process is useful information. The placement of perceptions of the risk within the larger framework of the fundamental hierarchy of needs exposes facets of the growth management problem currently unaddressed.

After returning from the field, the interview responses were reviewed, translated, and transcribed, if necessary. The responses were then coded into a Microsoft Excel spreadsheet that was later imported into Microsoft Access where the relational database was created. The coded answer choices were designated based on the overarching categories or themes common among responses. In addition, a table was created for each respondent that included GPS point data for the location of the interview along with the approximate location for their home and work as indicated on the sketch maps. The creation of a relational geodatabase offers the opportunity to run spatial queries that can address questions such as whether proximity to a geographical feature or the location of a past hazard affected responses. Sample query results are shown in the Results section. Essentially, this portion of the analysis has great potential for use in a variety of studies of perception and knowledge base to aid local agencies in determining courses of action and development of sustainable emergency response and urban growth management plans with support and participation from the local population.

Results

The maps below illustrate the primary findings from the three stages of the analysis put forth in this paper as a means to capture the risk perceptions of the residents of Aguas Calientes. In order to evaluate the perceptions, first, a baseline of risk, or, in this case, susceptibility must first be established. This provides a kind of truth against which to compare the risk perceptions. To perform a basic assessment of the results of the landslide susceptibility model are evaluated with respect to the findings of Bulmer & Farquhar (2010). This comparison is presented in the Discussion section.

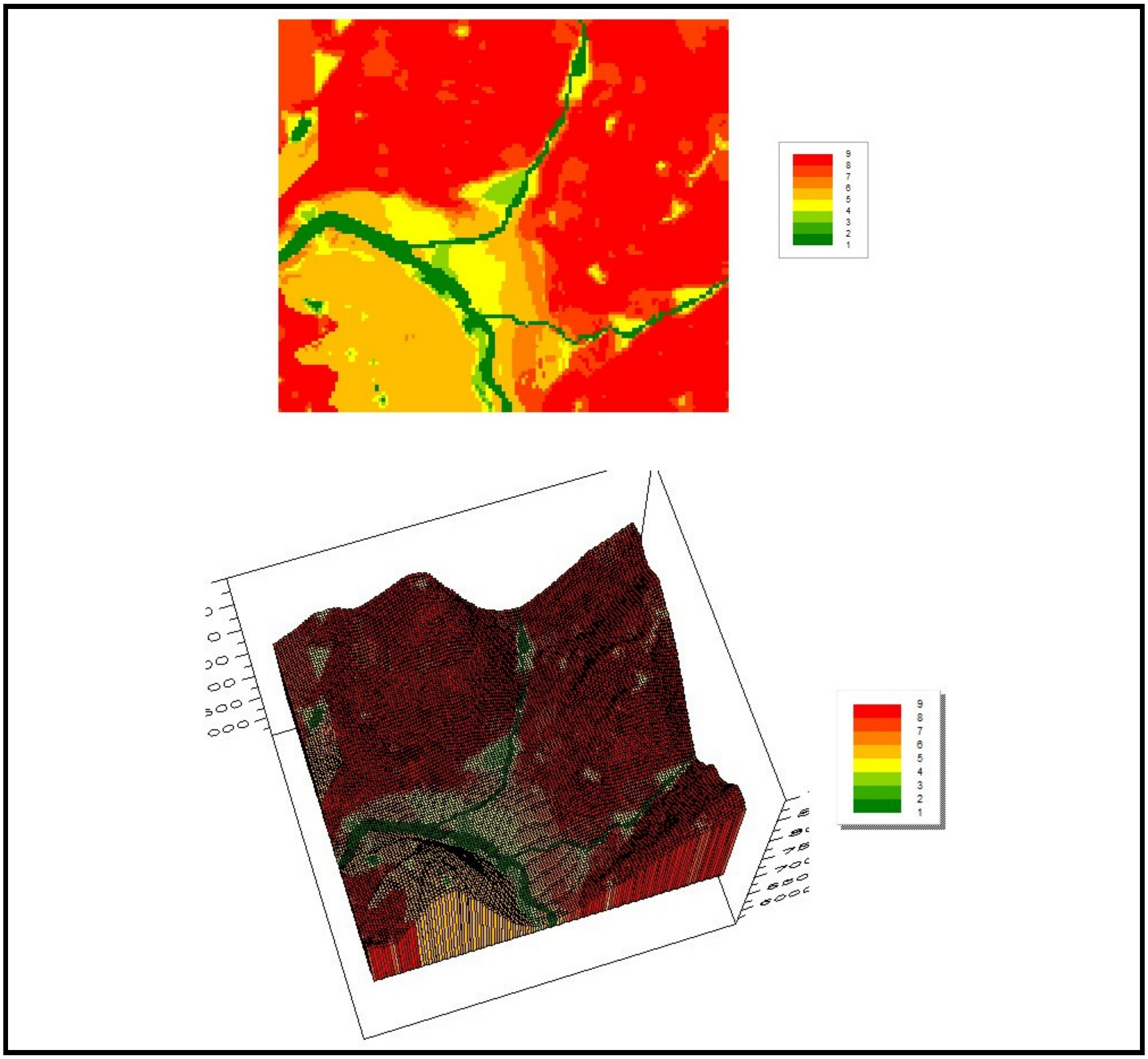


Figure 8. Rated landslide susceptibility maps for Aguas Calientes - basic 2D raster image (top) and 3D draped over elevation.

The result of analyzing the input of the variables of slope, soil type and land cover type to determine landslide susceptibility are shown above (Figure 8). Below the map is shown both as a 2D raster image and as a 3D image displayed over the DEM. Displaying the mapped result over the DEM offers the ability to view the variations in susceptibility rating with respect to relief. As expected, the rivers carry little to no susceptibility for landslides (as opposed to debris flows). The majority of the landscape characterized by built development carries low to moderate susceptibility. The west-facing granite slope opposite the town and across the Urubamba also carries moderate to low levels of susceptibility. This also was to be expected. That slope is currently not experiencing any significant failures and the chief hazard associated with that slope is rockfalls.

As an added component to measuring the level of susceptibility within and surrounding the town, a second level analysis was performed that accounted for any increase in susceptibility that might accompany urban expansion (Figure 9). Again, here we see that the area immediately encompassing the town carries relatively low susceptibility, but that the susceptibility dramatically increases within the buffer representing potential urban expansion. However, the addition of this buffer zone does reduce the overall range of susceptibility with no region exceeding relatively high susceptibility.

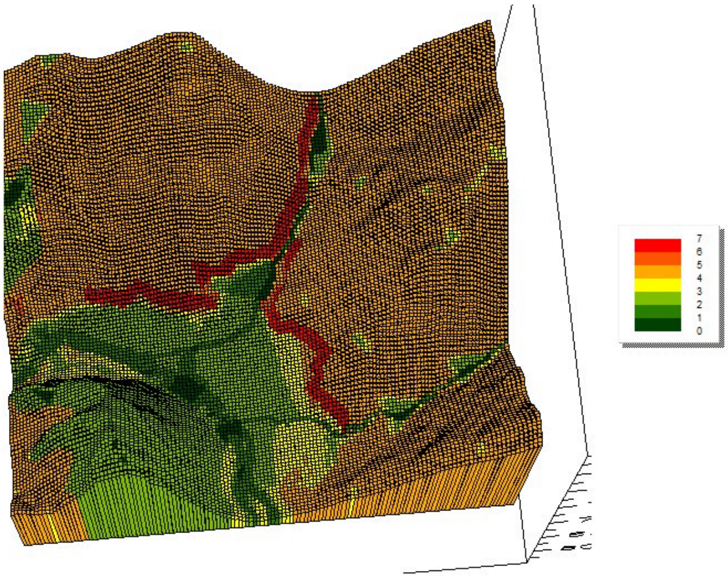


Figure 9. This map shows the resulting impact to landslide susceptibility should growth continue upslope.

The maps below illustrate the geographical distribution of risk perception as expressed through the sketch maps (Figure 10). The risk perception of landslide susceptibility displayed over the DEM is particularly revealing. While it was not possible to analyze risk perception over the entire project area, the data provided does allow for an examination of the distribution. This can then be compared to the results of the prototype model. Based on the mapped results below, the average perception of the region appears to be relatively high including portions along the rivers.

In addition, the regions at the base of the eastward facing slopes bordering the town are of note. The average perception rating is relatively very low in certain areas. There are also areas within the town that either carry very low relative susceptibility and relatively high susceptibility. These anomalies in perceived high risk may serve as an indication that further examination and research is needed to better understand the underlying causes for such a distribution.

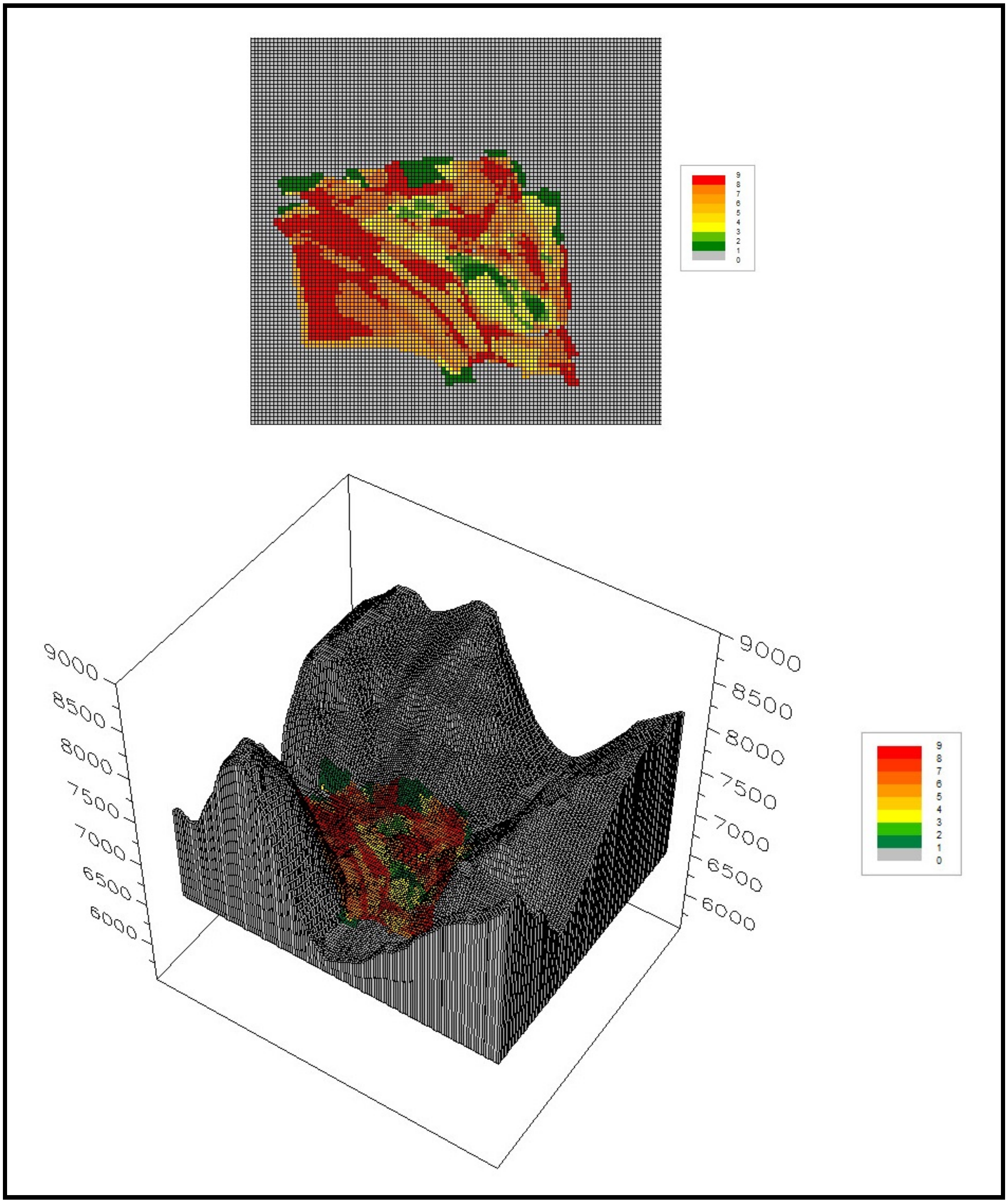
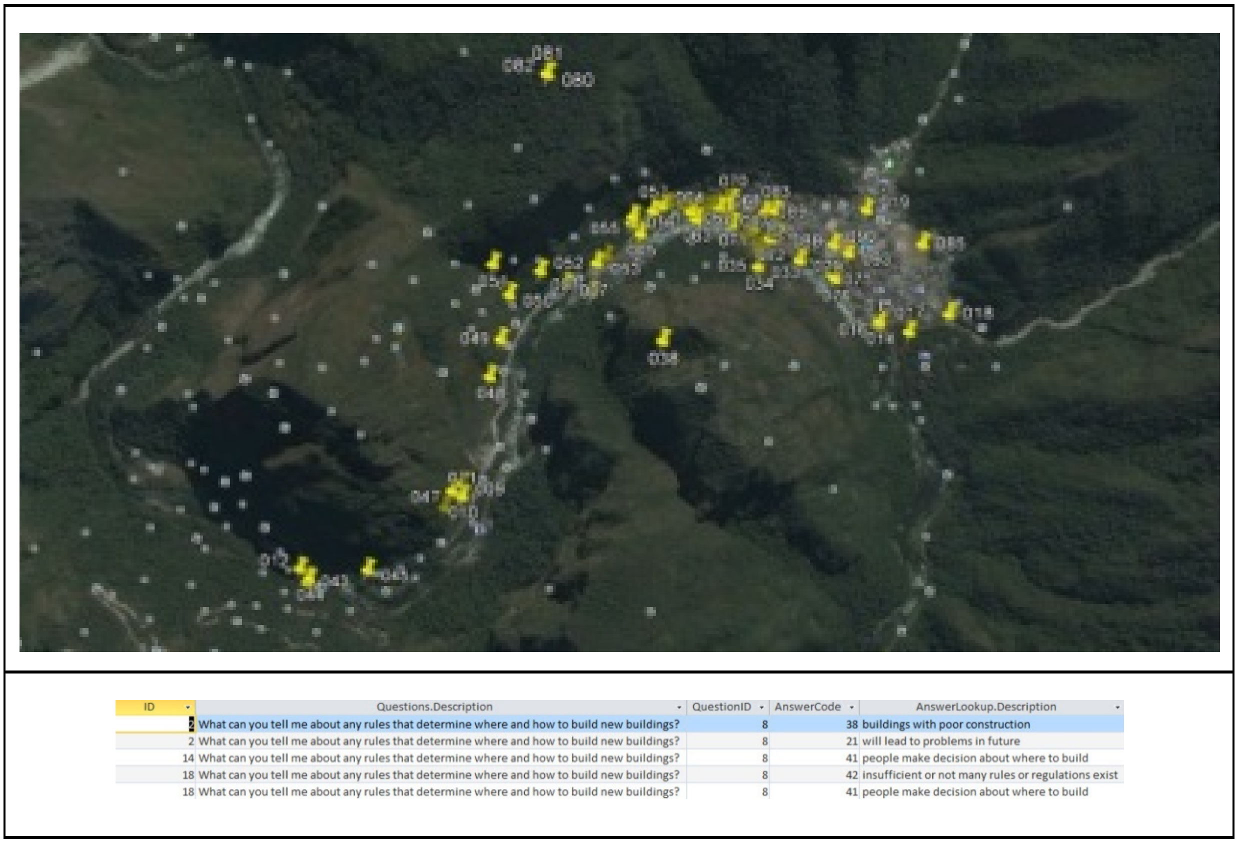


Figure 10. The rated landslide susceptibility map for Aguas Calientes is shown first without visual change with respect to topography (top) and then is draped over the DEM (bottom).

As a means of exploring these areas of note, we might imagine the following example. Two respondents may have identified an area as carrying a high risk rating while 23 respondents did not acknowledge the area as containing high risk or did not acknowledge it at all. This is still an important aspect of the results as it reveals a lack of understanding or knowledge as to the realities of the physical processes at work in the given area, particularly if the modeled results identified the area as high risk. The lack of identification of an area as containing high, medium or low risk signifies that that area does not, in the opinion of the respondent, carry any risk. Therefore, for two of the 25 respondents, an area carried high risk and although 23 respondents did not agree, their lack of identification of risk is telling and bears further study.

The results of performing queries on the interview data will vary. An example of a result of a simple query about local perceptions regarding building codes and construction is provided below (Figure 11). In another sample query of the 25 participants interviewed, 10 participants identified the Urubamba River as carrying the most risk for huaycos followed by the Alcamayu and, then, Aguas Calientes. Three people identified a combination of rivers, replying that it was not possible to identify one that carried more risk than the others. Those that identified the Alcamayu as carrying the most risk either lived or worked within what would be considered the affected area should the river reach bankfull and/or a debris flow rip through the channel causing damage such as the debris flows experienced in 2005. Since the banks of the segment of the Aguas Calientes River that runs through the town are enforced with concrete, it is not surprising that the fewest number of people cited that river as the most dangerous or posing the most risk.



ID	Questions.Description	QuestionID	AnswerCode	AnswerLookup.Description
2	What can you tell me about any rules that determine where and how to build new buildings?	8	38	buildings with poor construction
2	What can you tell me about any rules that determine where and how to build new buildings?	8	21	will lead to problems in future
14	What can you tell me about any rules that determine where and how to build new buildings?	8	41	people make decision about where to build
18	What can you tell me about any rules that determine where and how to build new buildings?	8	42	insufficient or not many rules or regulations exist
18	What can you tell me about any rules that determine where and how to build new buildings?	8	41	people make decision about where to build

Figure 11. The results of a spatial query of the interview data. Each participant is also correlated with a GPS point.

Incorporating actual responses to questions can also add a rich tapestry to the results of the spatial queries. For example, in response to the question about where it is safe to build and whether there are sufficient regulations, one of the participants, the female owner of a juice bar in the local market, provided the following comment:

- *"..todo lo quiero construir"* ("… all I want to build")
- *"no hay respeto por la autoridad de Municipio… ellos estan preocupado con dinero"* ("there is no respect for the authority of the Municipal government… they are preoccupied with money")

In response to the question about whether there is a difference between landslides and rockfalls, the same participant responded with:

- *"no hay diferencias; son igual; si, ocurren aqui; si, empiezan en lo mismo lugar"* ("there are no differences; they are the same; yes, they occur here; yes, they begin in the same place")

In addition, a majority of the participants, regardless of the length of time spent in Aguas Calientes, were able to recall, with riveting detail, the degree of damage and short-term and long-term impact to the town both structurally and economically resulting from the recent natural disasters in 2007 and 2010.

In summary, with the creation of the query-ready database and using the corresponding GPS points, it is possible to identify whether any correlation exists between the selection of one river over another is affected by their proximity to that river. A full compilation of salient comments along with a full summary of the responses will be provided in the final report to the Mayor of Aguas Calientes and the Ministry of Culture in Cuzco and Aguas Calientes.

Discussion

To address the central question regarding the comparison between perception and modeled results, it is necessary to also compare the modeled results with previous findings, particularly the areas of risk identified by Bulmer & Farquhar (2010). In addition, a vital assertion of this study is that the evaluation of the spatial distribution of risk perceptions is imperative to understanding the readiness and knowledge base of a population living in a high risk zone for natural disasters such as slides, flooding, debris flows, and rockfalls. Therefore, a comparison of the results of the model and the mapped perceptions provides a useful component to the analysis by identifying points of discrepancy and agreement.

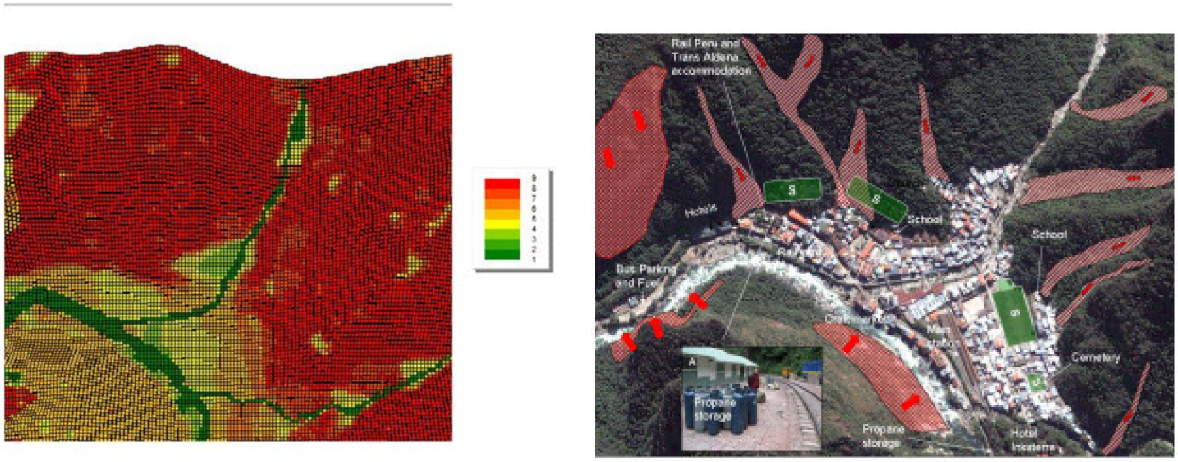


Figure 12. Results of landslide susceptibility model and hazard zones identified by Bulmer and Farquhar (2010).

To begin then, a visual comparison between the results of the landslide model and those published by Bulmer & Farquhar (2010) are shown above (Figure 12). In the image to the right, Bulmer & Farquhar (2010) identified areas prone to rockfalls, topples and slides (shown with a red stipple pattern). Areas of concern for floods and debris flows are shown with a red stripped pattern (Figure 12).

All of the areas demarcated are contained within the highly susceptible regions (“7”-“9” susceptibility rating). However, there are areas around the perimeter of the town that, based on the results of the prototype landslide susceptibility model, still carry a moderate level of susceptibility that are not identified by Bulmer & Farquhar (2010). It is interesting to note the degree of overlap between the results of the flow accumulation map and the some of the flow paths previously identified (See Figure 12; Bulmer & Farquhar 2010), particularly in the NW corner of town where there may be a developing area of concern.

Figure 13. Photos taken from author's hostel showing proximity of town to Urubamba River.

Further underlying the complexities of the hazard situation in this unique setting is the overall response by participants in illustrating areas of high risk. The vast majority of the town is seen to be at moderate to high risk for landslides alone. Only a select few areas on the perimeter of the town are seen as relatively low to no risk. This should be an important result for land use planners and managers for the region as this suggests that there is a relatively low awareness of the impact of continued development up the hillside with respect to landslide susceptibility.

In addition, participants viewed the hillside to the east of the town bordering the east bank of the Urubamba as moderately to highly susceptible to landslides (Figure 13). Given the relative stability of this largely granite rock face, this, along with the relatively dispersed nature of responses suggests that an opportunity exists to provide clarification as to the processes involved in slides and the associated risk. A major finding of this study also includes the discovery that the term "risk" carries not only varying connotations from person to person based on prior personal experience, but also can vary from culture to culture. Perspectives tend to be aligned more with the positioning of the individual within the landscape relative to where they lived or work rather than by gender or length of time as a resident in Aguas Calientes. However, those who had spent years, or on the rare occasion, their life, in Aguas Calientes were able to provide more detail with regard to past events and seemed to have a deeper understanding of the underlying causes of landslides, rockfalls and huaycos and the impact of people on the environment.

Furthermore, this type of analysis offered the opportunity to empower an under-represented group (indigenous Andean peoples) and improve collaboration between agencies (international and regional) and the affected community (Vilímek et al. 2010). For the first time, the perception of the people of Aguas Calientes was considered in a spatial analysis of landslide susceptibility. As a result, the study may provide useful and previously unaddressed information for the development of urban growth management plans. In addition, the improved growth management plans for Aguas Calientes offer the potential to enhance conservation and protection of the world-cultural value of Machu Picchu Sanctuary.

Areas for Further Research

One possible extension of the methods introduced in this study is an exposure analysis using a variable with buffer. Such an analysis allows for identification of structures that lie within a buffer and carries socio-economic weight or represent a loss or consequence to the occurrence of a hazard in the area defined by the susceptibility model. First, a buffer is established surrounding the road that leads out of the town to Machu Picchu Sanctuary as well as along the railroad that enters town. The purpose of establishing this buffer is to highlight areas that would be affected should a slide occur along this transportation corridor. The project area size is 135 x 117 cells. Each cell size is approximately 32.8ft. Therefore, the buffer that is up to seven cell sizes away extends a buffer out to ~230ft.

Second, a variable width buffer up to 50m away or ~164ft is established along the Urubamba, Aguas Calientes, and Alcamayu rivers. This is the equivalent to setting the buffer up to five cells away. The buffer enables visual interpretation of the threat and resulting impact of a debris flow within that proximity to the river. The results of these buffer maps can be displayed over satellite imagery in order to view affected areas. In particular, land use planners and resource managers will be able to identify and assess the financial impact to built features such as high-end hotels, schools, medical facilities, the police stations, restaurants, and housing.

A flow accumulation analysis could also provide land use planners with additional data to support resource allocation and the findings of the landslide susceptibility modeling. Using the Drain tool in MapCalc, a map is produced that simply uses the input of an Elevation basemap to identify points of flow. The steepest paths and thus the paths of greatest flow are illustrated in the resulting output map. This process can aid in the verification of landslide susceptibility maps and help to highlight any developing flow paths or weaknesses in the landscape previously not accounted for in urban planning and emergency preparedness and response plans.

Though it is presented in the context of future developments of the methods presented in this paper, the results of the flow accumulation analysis are presented here. The resulting map illustrates both expected (the river channels) and previously identified areas at risk for a slide or debris flows (Bulmer &

Farquhar 2010; Figure 14; Figure 12).

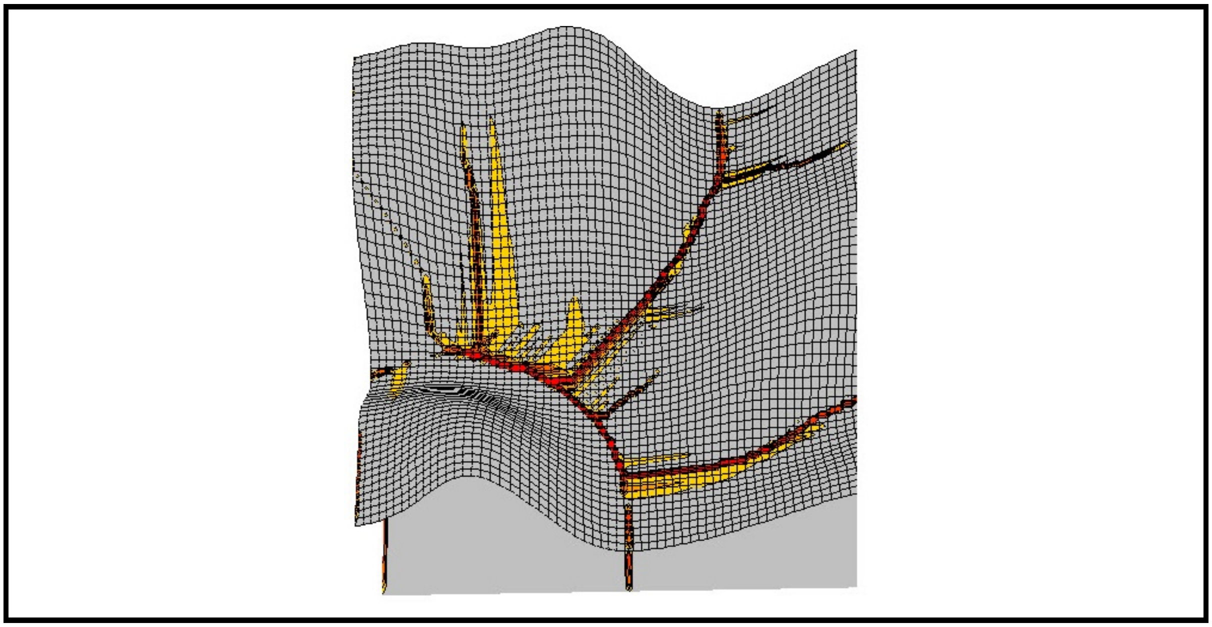


Figure 14. Results of a flow accumulation analysis highlighting areas of highest flow within the project area

Areas of flow within the town correspond with areas of susceptibility for landslides, but also highlight significant flow paths that carry a low landslide susceptibility rating. This may be due to the fact that land cover type reduces the susceptibility of a landslide, but not overland flooding. The area of extended flow to the south of the flow path that corresponds with the Alcamayu River, could suggest a potential hazard threat for structures and people within that designated path. In addition, a high and medium flow path exist at the northern end of town may signify a developing gulley or area of unique susceptibility. Areas of moderate flow to the northwest of the flow path along the Aguas Calientes River correspond with the central plaza, main food market, a school, and the municipal building. This area was perceived to be associated with relatively low risk. In addition, it is demarcated with signage as one of the safe zones within the town. This analysis then can provide an interesting comparison to both landslide susceptibility model results and to risk perceptions.

There is great potential for application of a GIS analysis of the sediment control and erosion issues facing Cuzco Valley and the Urubamba Valley. Refinement of the model is needed and this will come with creation and inclusion of better and better data, really more data, and also with the results of presentations and discussions with the local municipality and Ministry of Culture. Several data collection challenges must be overcome in order to successfully apply the results of such an analysis. These challenges are beyond the scope of this project. For example, it was not possible to conduct a thorough soil sample study or slope stability assessment within time, financial, or resource constraints.

One of the limitations of this study also includes the accessibility and use of remote sensing data. Usable image are difficult to obtain, in part due to the severity of the terrain along with the variability of the weather/cloud cover. As Gonzales Inca notes, long-term monitoring of the key watersheds is necessary to obtain sufficient data for analysis (2009). Currently, there is a shortage of reliable, long-term data regarding the history of sediment erosion and resulting events. Furthermore, application of GIS, whether in modeling ecosystem services or assessing landslide vulnerability, will necessarily entail efforts to communicate findings and suggested plans of action to the non-expert community, particularly with respect to the prevention of hazards where loss of life and property is imminent. This is an identified area of growth and of concern and within the scope of this project. The results of this study will be compiled, translated and presented in a public forum to the people of Aguas Calientes as well as to the Ministry of Culture in Cuzco and in Machu Picchu.

In future applications of the model and the data derived from the interviews, I intend to adapt the model to include debris flow modeling that would include rather than exclude the role the rivers play in providing pathways. In addition, I am in discussions now to bring this methodology to bear in other locations such as Cusco.

Not to be overlooked is the ability of this novel method to provide a voice to a people who otherwise do not have an outlet or means to participate in creating sustainable management plans. It is my hope the results of my analysis can be used to enhance dialogue and the development of sustainable growth management and hazards management plans/

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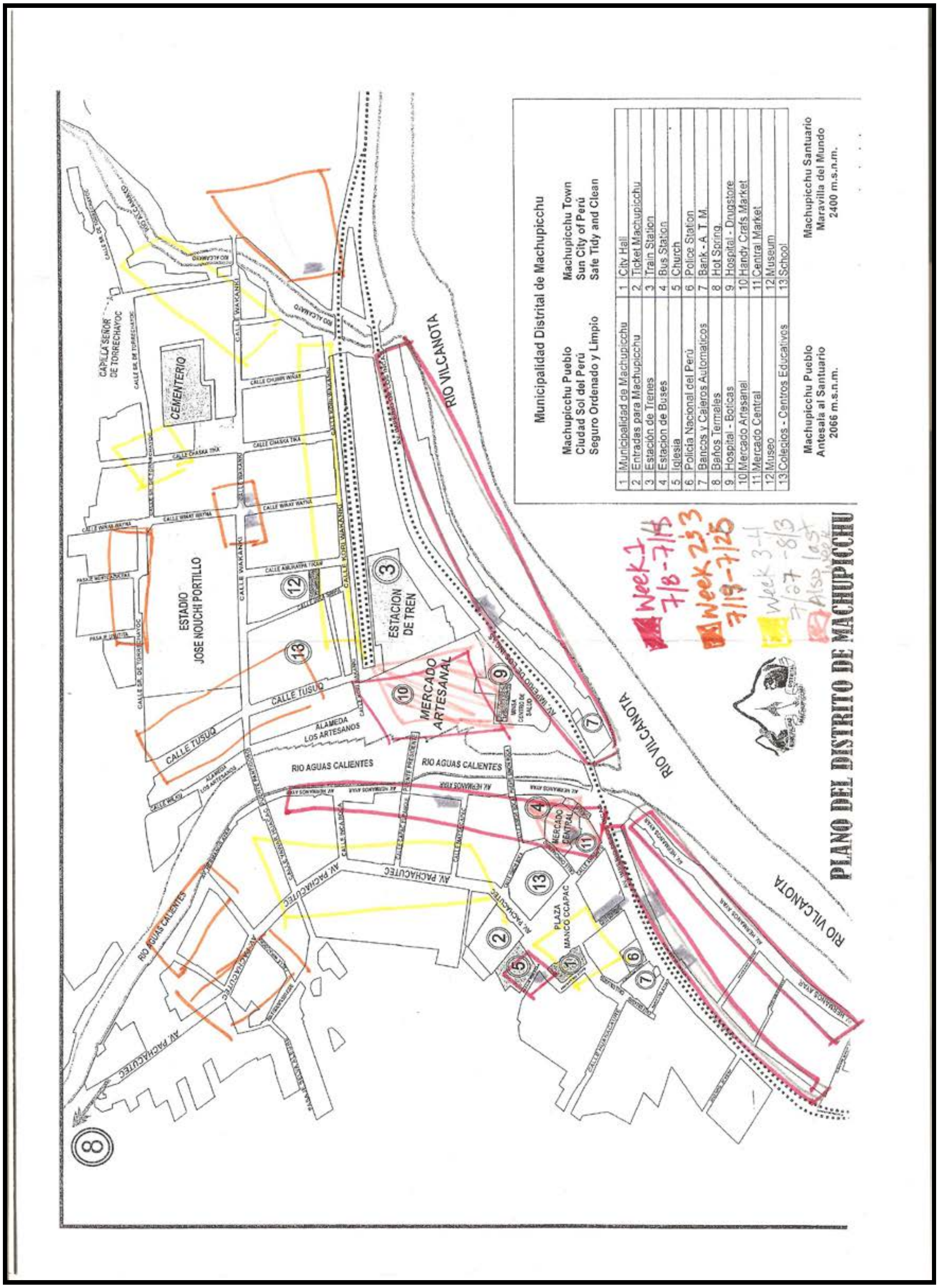
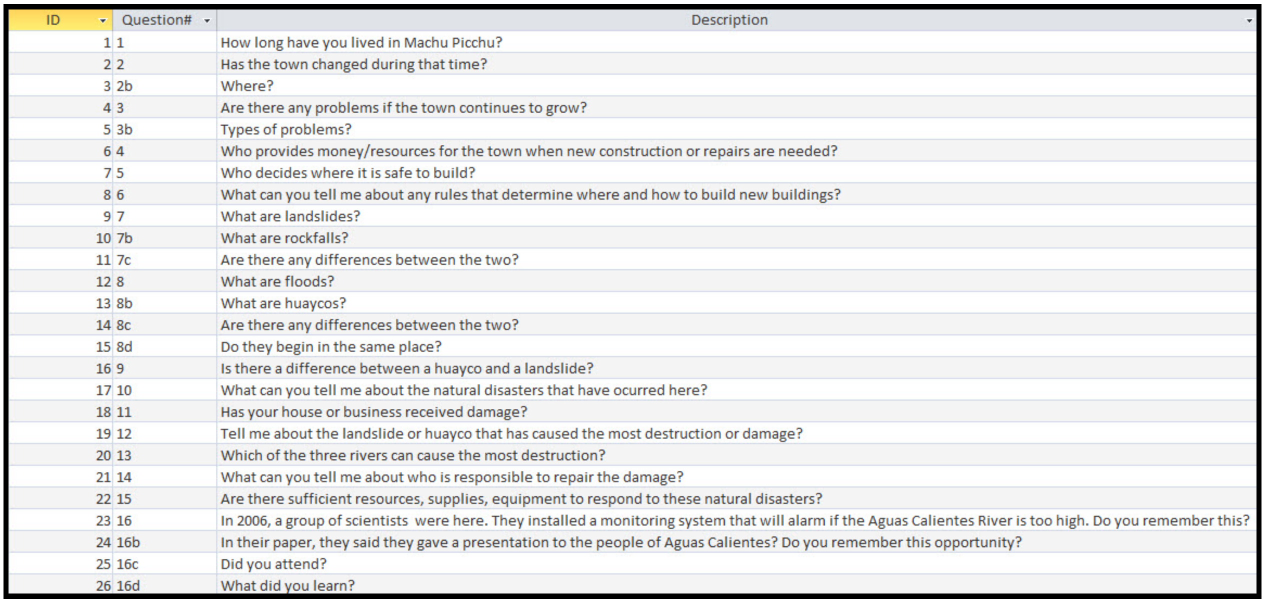
APPENDIX A

Schedule for identifying participants.



APPENDIX B

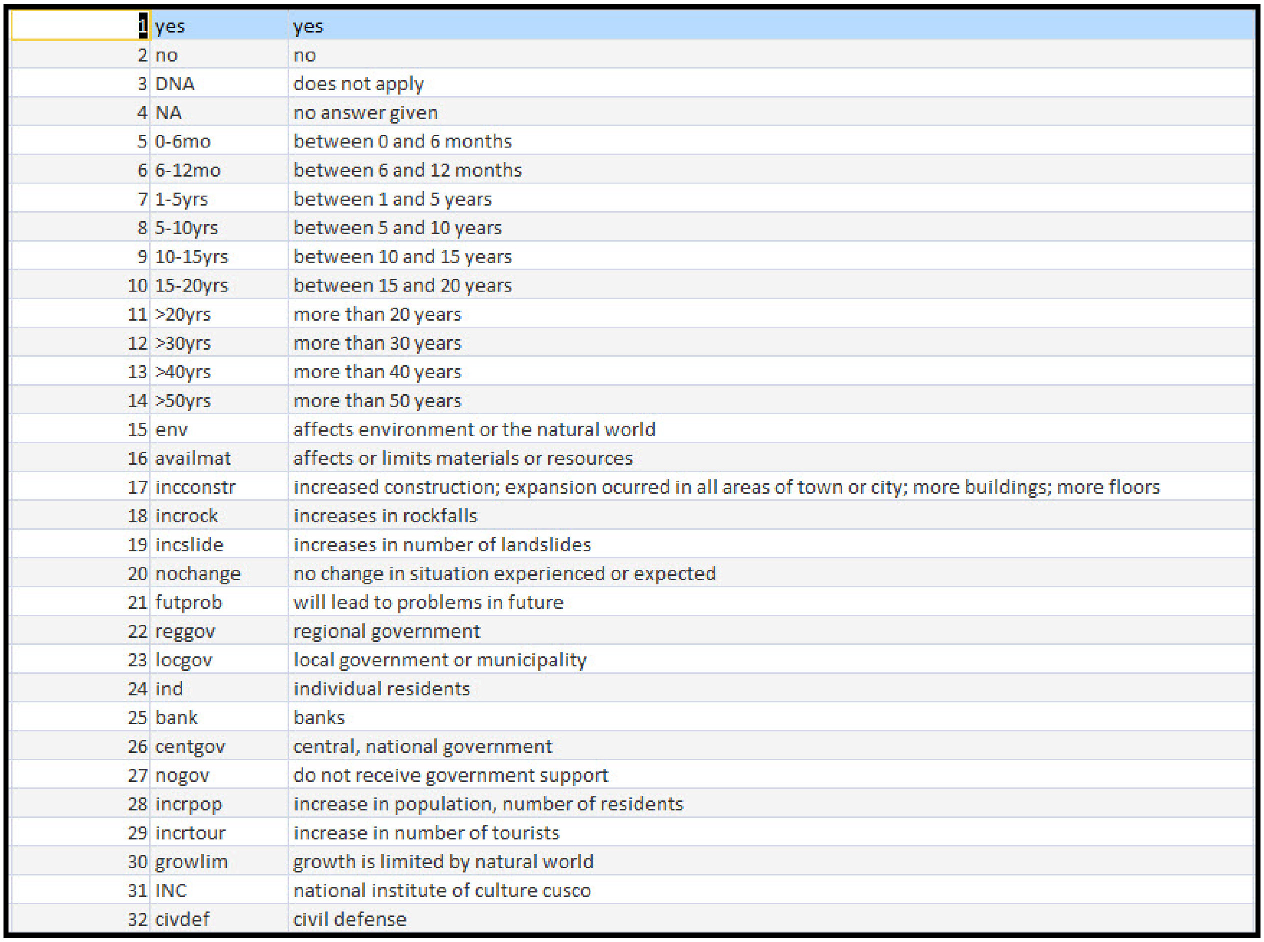
Interview questions.



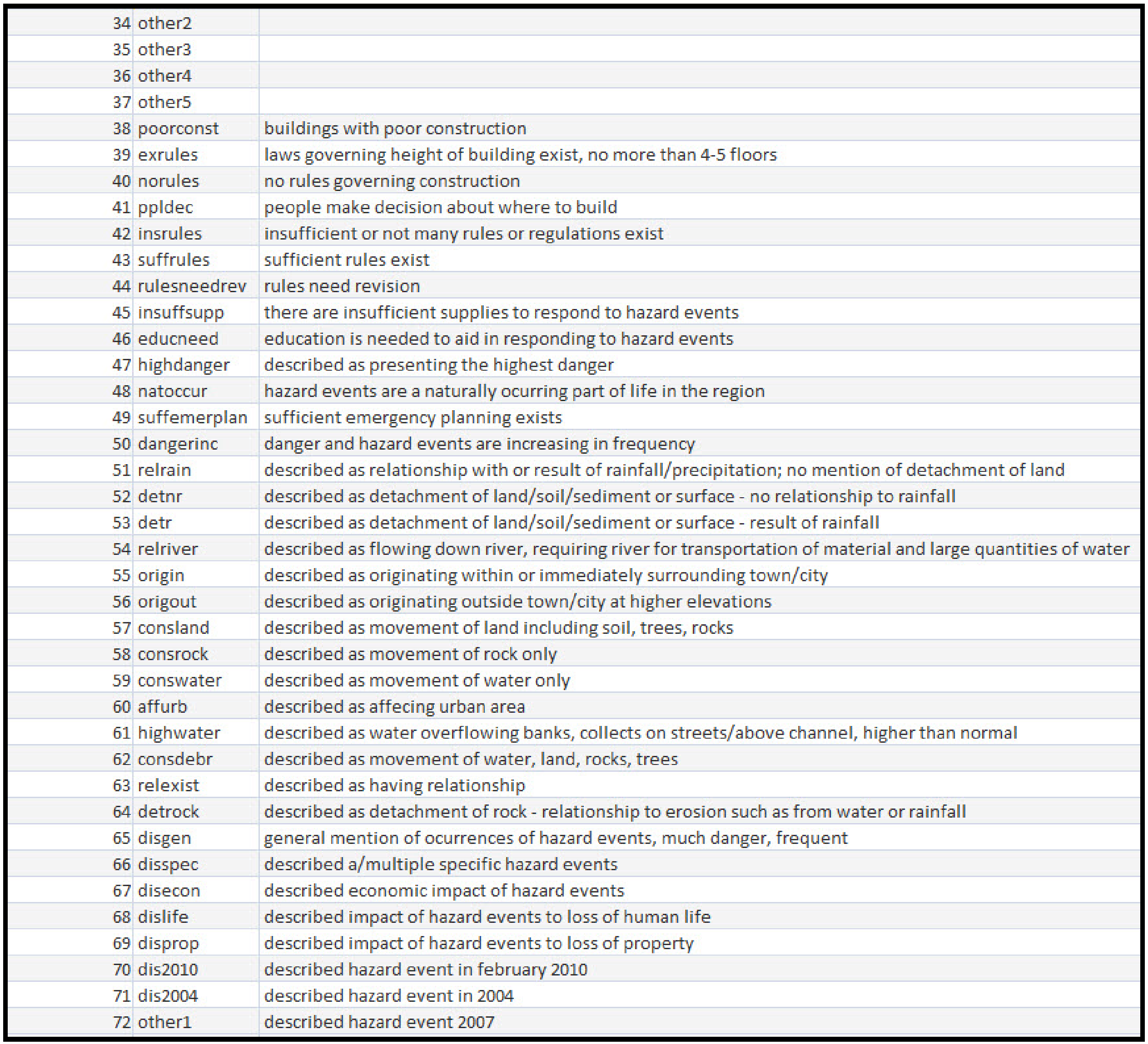
ID	Question#	Description
1	1	How long have you lived in Machu Picchu?
2	2	Has the town changed during that time?
3	2b	Where?
4	3	Are there any problems if the town continues to grow?
5	3b	Types of problems?
6	4	Who provides money/resources for the town when new construction or repairs are needed?
7	5	Who decides where it is safe to build?
8	6	What can you tell me about any rules that determine where and how to build new buildings?
9	7	What are landslides?
10	7b	What are rockfalls?
11	7c	Are there any differences between the two?
12	8	What are floods?
13	8b	What are huaycos?
14	8c	Are there any differences between the two?
15	8d	Do they begin in the same place?
16	9	Is there a difference between a huayco and a landslide?
17	10	What can you tell me about the natural disasters that have ocurred here?
18	11	Has your house or business received damage?
19	12	Tell me about the landslide or huayco that has caused the most destruction or damage?
20	13	Which of the three rivers can cause the most destruction?
21	14	What can you tell me about who is responsible to repair the damage?
22	15	Are there sufficient resources, supplies, equipment to respond to these natural disasters?
23	16	In 2006, a group of scientists were here. They installed a monitoring system that will alarm if the Aguas Calientes River is too high. Do you remember this?
24	16b	In their paper, they said they gave a presentation to the people of Aguas Calientes? Do you remember this opportunity?
25	16c	Did you attend?
26	16d	What did you learn?

APPENDIX C

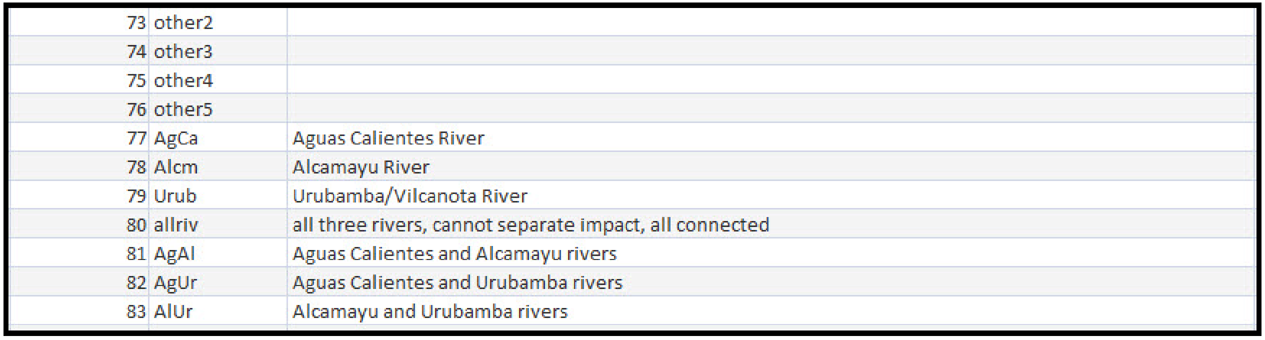
Answer Lookup Table



1	yes	yes
2	no	no
3	DNA	does not apply
4	NA	no answer given
5	0-6mo	between 0 and 6 months
6	6-12mo	between 6 and 12 months
7	1-5yrs	between 1 and 5 years
8	5-10yrs	between 5 and 10 years
9	10-15yrs	between 10 and 15 years
10	15-20yrs	between 15 and 20 years
11	>20yrs	more than 20 years
12	>30yrs	more than 30 years
13	>40yrs	more than 40 years
14	>50yrs	more than 50 years
15	env	affects environment or the natural world
16	availmat	affects or limits materials or resources
17	incconstr	increased construction; expansion ocurred in all areas of town or city; more buildings; more floors
18	incrock	increases in rockfalls
19	incslide	increases in number of landslides
20	nochange	no change in situation experienced or expected
21	futprob	will lead to problems in future
22	reggov	regional government
23	locgov	local government or municipality
24	ind	individual residents
25	bank	banks
26	centgov	central, national government
27	nogov	do not receive government support
28	incrpop	increase in population, number of residents
29	incrtour	increase in number of tourists
30	growlim	growth is limited by natural world
31	INC	national institute of culture cusco
32	civdef	civil defense



34	other2	
35	other3	
36	other4	
37	other5	
38	poorconst	buildings with poor construction
39	exrules	laws governing height of building exist, no more than 4-5 floors
40	norules	no rules governing construction
41	ppldec	people make decision about where to build
42	insrules	insufficient or not many rules or regulations exist
43	suffrules	sufficient rules exist
44	rulesneedrev	rules need revision
45	insuffsupp	there are insufficient supplies to respond to hazard events
46	educneed	education is needed to aid in responding to hazard events
47	highdanger	described as presenting the highest danger
48	natoccur	hazard events are a naturally ocurring part of life in the region
49	suffemerplan	sufficient emergency planning exists
50	dangerinc	danger and hazard events are increasing in frequency
51	relrain	described as relationship with or result of rainfall/precipitation; no mention of detachment of land
52	detnr	described as detachment of land/soil/sediment or surface - no relationship to rainfall
53	detr	described as detachment of land/soil/sediment or surface - result of rainfall
54	relriver	described as flowing down river, requiring river for transportation of material and large quantities of water
55	origin	described as originating within or immediately surrounding town/city
56	origout	described as originating outside town/city at higher elevations
57	consland	described as movement of land including soil, trees, rocks
58	consrock	described as movement of rock only
59	conswater	described as movement of water only
60	affurb	described as affecing urban area
61	highwater	described as water overflowing banks, collects on streets/above channel, higher than normal
62	consdebr	described as movement of water, land, rocks, trees
63	relexist	described as having relationship
64	detrock	described as detachment of rock - relationship to erosion such as from water or rainfall
65	disgen	general mention of ocurrences of hazard events, much danger, frequent
66	disspec	described a/multiple specific hazard events
67	disecon	described economic impact of hazard events
68	dislife	described impact of hazard events to loss of human life
69	disprop	described impact of hazard events to loss of property
70	dis2010	described hazard event in february 2010
71	dis2004	described hazard event in 2004
72	other1	described hazard event 2007



73	other2	
74	other3	
75	other4	
76	other5	
77	AgCa	Aguas Calientes River
78	Alcm	Alcamayu River
79	Urub	Urubamba/Vilcanota River
80	allriv	all three rivers, cannot separate impact, all connected
81	AgAl	Aguas Calientes and Alcamayu rivers
82	AgUr	Aguas Calientes and Urubamba rivers
83	AlUr	Alcamayu and Urubamba rivers

APPENDIX D

IRB Statement to participants

INFORMED CONSENT FORM

University of Denver Master's Research Project

Title of Research Project: Assessment of Perceptions of Landslides (in Aguas Calientes, Peru)

You are invited to participate in a research project that is analyzing the perceptions of the threat and impact of landslides in Aguas Calientes, Peru. This survey (consent, study, etc.) was approved by the University of Denver's Institutional Review Board for the Protection of Human Subjects in Research on _______________.

Participation in this survey should take about 20 minutes of your time. Participants will be asked 5-10 questions about their knowledge of the history of the development of the town of Aguas Calientes and understanding about how landslides affect the region and the impact of possible future landslides. Participants will also be asked to identify and rank areas of concern on a map of the town and the surrounding region.

Your responses will be anonymous. That means that no one will be able to connect your identity with the information you give. Participation in this project is strictly voluntary. The risks associated with this project are minimal. If, however, you experience discomfort you may discontinue the survey at any time. We respect your right to choose not to answer any questions that may make you feel uncomfortable. Refusal to participate or withdrawal from participation will involve no penalty or loss of benefits to which you are otherwise entitled.

If you have any concerns or complaints about how you were treated during the interview, please contact Paul Olk, Chair, Institutional Review Board for the Protection of Human Subjects, at 303-871-4531, or email du-irb@du.edu, or call Office of Research and Sponsored Programs at 303-871-4050 or write to either at the University of Denver, Office of Research and Sponsored Programs, 2199 S. University Blvd., Denver, CO 80208-4820. Sample: http://www.du.edu/orsp/forms.html

Signature of Principal Researcher:

(Alicia F. Green, M.A., Graduate Student, University of Denver, alicia.green@du.edu)

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[i] Selby (1982) defines debris flows as "slurries of viscous soil and boulders which can move at high velocities over rough surfaces. The primary conditions contributing to suitable conditions for a debris flows include: availability of water from intense rainfall, deposits of unconsolidated soil such as alluvium, a mechanism for mixing soil and water (landslide), a channel for the debris flow to follow, deposits of transported weathered or shattered bedrock, unstable slopes that be experiencing undercutting by a stream channel". These debris flows may originate as landslides that develop into debris flows near the base of a slope (Selby 1982; Varnes 1958).

[ii] And as: "the group of processes whereby debris or rock material is loosened or dissolved and removed from any part of the earth's surface." It is a function of erosivity and erodibility, factors that must be taken into account when evaluating the weighting of variables in a landslide model. Soil characteristics, rainfall amounts and durations, and presence, extent and type of vegetation all play a role in increasing or decreasing the erodibility and erosivity. (Thomas & Goudie 2000).

[iii] Erodibility in this use of the word is defined as the vulnerability of the soil to erosion (Thomas & Goudie 2000).