Floods, Vulnerability, and the US-Mexico Border: A Case Study of Ambos Nogales

by

Bernardo J. Márquez Reyes

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Graduate Supervisory Committee:

Hallie Eakin, Co-Chair
Francisco Lara-Valencia, Co-Chair
Rimjhim Aggarwal

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ABSTRACT

Environmental change and natural hazards represent a challenge for sustainable development. By disrupting livelihoods and causing billions of dollars in damages, disasters can undo many decades of development. Development, on the other hand, can actually increase vulnerability to disasters by depleting environmental resources and marginalizing the poorest. Big disasters and big cities get the most attention from the media and academia. The vulnerabilities and capabilities of small cities have not been explored adequately in academic research, and while some cities in developed countries have begun to initiate mitigation and adaptation responses to environmental change, most cities in developing countries have not.

In this thesis I explore the vulnerability to flooding of the US-Mexico border by using the cities of Nogales, Arizona, USA and Nogales, Sonora, Mexico as a case study. I ask the following questions: What is the spatial distribution of vulnerability, and what is the role of the border in increasing or decreasing vulnerability? What kind of coordination should occur among local institutions to address flooding in the cities? I use a Geographic Information System to analyze the spatial distribution of flood events and the socio-economic characteristics of both cities. The result is an index that estimates flood vulnerability using a set of indicators that are comparable between cities on both sides of the border. I interviewed planners and local government officials to validate the vulnerability model and to assess collaboration efforts between the cities. This research contributes to our understanding of vulnerability and sustainability in two ways: (1) it provides a framework for assessing and comparing vulnerabilities at the city level between nations, overcoming issues of data incompatibility, and (2) it highlights the institutional arrangements of border cities and how they affect vulnerability.

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Chapter 1

INTRODUCTION

On July 12 of 2008, a brief period of heavy rain hit Nogales, Sonora. As on almost any other rainy day, people expected moderate flooding along the arroyos. However, to everyone's surprise, a large section of the downtown area was suddenly under six-foot-deep waters. Entire shops and houses were flooded, and the economic damage was estimated at 8 million dollars, prompting the government to declare Nogales a disaster zone (McCombs, 2008). The flood was caused by two walls, both built by the US Border Patrol (USBP), meant to control another type of "flood": the undocumented entry of immigrants into the United States.

To prevent people from crossing the border undocumented, the USBP built a gate and a three-foot wall inside a tunnel that drains stormwaters from Mexico to the United States. With the conveying capacity of the tunnel reduced, the tunnel collapsed on the Mexican side, directing all water to the streets. The international border wall prevented the stormwater from flowing north, so all of it accumulated on the Mexican side. Trash dragged by the storm water blocked the permeable parts of the border wall, exacerbating the flood on the Mexican side and making the border wall a dam inside the city. Ironically, part of the wall built by USBP inside the tunnel to stop the flow of illegal aliens, was built *illegally* in Mexican territory. Before the 2008 disaster, nobody except the USBP knew about the construction of this wall.

Here, at the US-Mexico border, people live in the middle of complex environmental and social hazards. Because solving border issues requires cross-border collaboration, solutions are hard to implement. Central governments are often detached from the reality of border communities, leaving the people and local governments to fend for themselves. Meanwhile, climate, political, economic, and social changes create new risks for people who live on the border. The place where the two countries meet is marked by contradictions: globalization and nationalism, diplomacy and armed violence, natural abundance and degradation, the richest and the poorest. In spite of efforts to resolve these contradictions and increased awareness of border problems on the part of the media, NGOs, government, and academia, border cities are still behind in terms of environmental stewardship and quality of life. The complexities of the contradictions that occur at the border deserve attention from sustainability scientists.

Sustainability science integrates several perspectives to study the relationship between human and natural systems, diagnose root problems in the relationship, and prescribe solutions for a healthier relationship. We can advance knowledge of complex human-nature systems by looking at the vulnerability of a system to change (Turner et al., 2003a; Kates et al., 2001). Using the vulnerability concept, researchers are trying to understand why some people, cities, and ecosystems are more susceptible to harm than others. Vulnerability research has evolved to include the capacity of a system to adapt to change, the scales on which vulnerability changes, the interaction of multiple stressors on a system, and the diversity of disciplinary perspectives that enrich the concept, thus making vulnerability a useful lens through which to look at sustainability problems.

In this thesis I describe vulnerability as a system of people, institutions, policy, infrastructure, and environment that combine to increase vulnerability at the US-Mexico border. By taking a historical account of Ambos Nogales, I look at how economic development at the border is intertwined with the creation of vulnerability, and how understanding the creation of vulnerability can help local officials rethink development and growth of their cities. I focus on the hazard of flooding and its effects on the border cities of Nogales, Arizona and Nogales, Sonora—together known as Ambos Nogales. I assess the vulnerability to floods in Ambos Nogales using a quantitative model and examine the capacity of local, state, and border institutions to reduce vulnerability.

In Chapter 2 I review the main concepts of vulnerability and how they relate to development and disaster studies. I describe the origins of the study of vulnerability, and how vulnerability is measured and mapped. I also explain the links between institutions and vulnerability.

Chapter 3 explains the methods and data used in the study. I describe the indicators and spatial analysis used to measure vulnerability, as well as the qualitative method used to understand and assess flood management on the border.

In Chapter 4 I present a case study of Ambos Nogales. I describe the geography, demography, economic development, and flooding history of Ambos Nogales, and the local and national institutions that play a role in flood management and mitigation.

Chapter 5 presents the analysis and results from the vulnerability assessment. In Chapter 6 I discuss and provide the results of the interviews with local officials from both sides of the border.

Finally, in Chapter 7 I present the major findings and conclusions of the study. I also recommend policy to address the flood problem at an institutional level, and suggest ways this research can be expanded.

Chapter 2

LITERATURE REVIEW

"If there could be such a thing as sustainable development, disasters would represent a major threat to it, or a sign of its failure" (Hewitt, 1995, p155).

Sustainable development, a term first introduced in the late 1980s, is now shaping most of the discussion on what a healthy relationship between human and environmental systems should look like. While many scholars have pointed to the weakness and vagueness of the term, the concept is what is important. The concept of sustainable development encompasses human values of peace, justice, and well-being that we can agree are worth striving for. Disasters act in opposition to sustainable development, by disrupting peace and well-being, and increasing injustices. Disasters impact all aspects of life: economic, environmental, and social. Often, material losses are considered to be the principal disaster impact: how much infrastructure was damaged, how many crops were lost, how many houses were destroyed (Pelling, 2003). But disasters can also reduce natural capital, adding stress on the people who depend on natural resources for their livelihoods (Wisner et al., 2004). The structure and organization of society can be fundamentally altered after a disaster, giving rise to conflict and loss of social bonds (Oliver-Smith, 1996). Most importantly, disasters take human lives. According to the United Nations Development Programme (2006), 53 percent of the deaths caused by natural hazards occur in countries with low human-development indicators.

Unfortunately, disasters have increased considerably during the past 50 years. The number of disasters has increased by a factor of 15 since the 1960s over 200 million people in 2009 were left without basic necessities (i.e., water, food, shelter, medical assistance) as a result of natural disaster, compared to 5 million in the 1960s (see Figure 1). This increase is not due only to better disaster reporting or an increase in population;

it is also caused “by the growing vulnerability of population to extreme physical events” (O’Keefe et al., 1976). Though more people are now affected by disasters, development has clearly provided benefits (e.g., better protection, early-warning systems) that have significantly reduced the number of deaths caused by disasters.

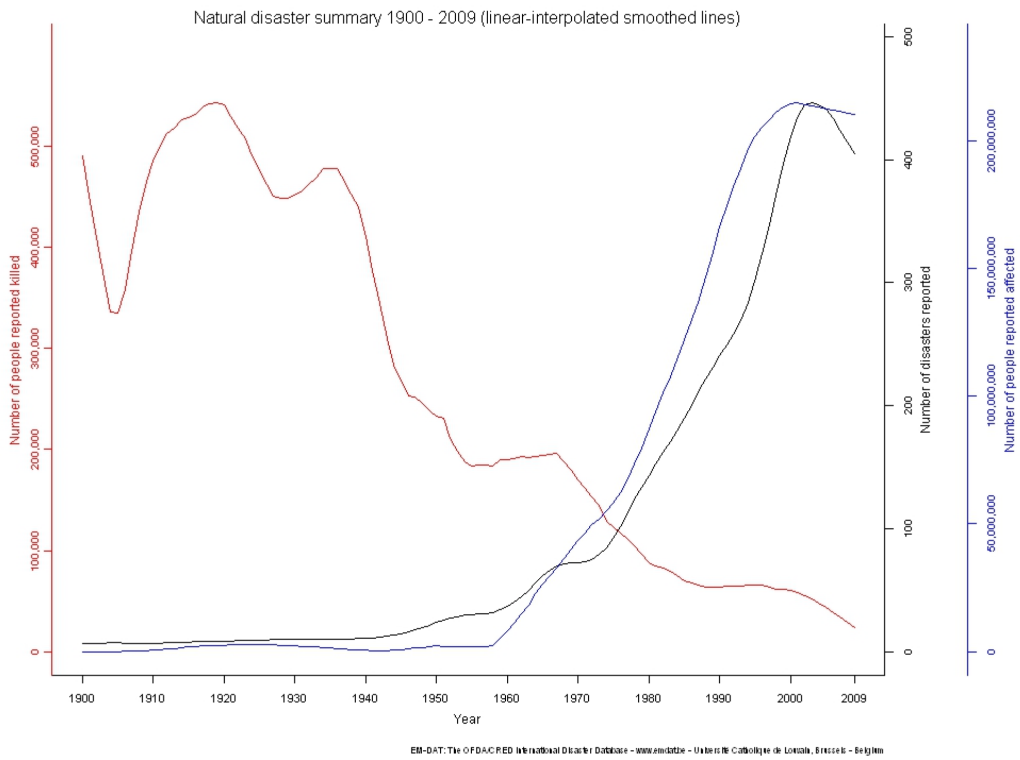

Figure 1. Natural disasters from 1900-2009. The trend line shows an increase in the number of disasters and people affected by disasters, and a decrease in the number of people killed by disasters. (Source: http://www.emdat.be/natural-disasters-trends)

Even though development and disaster studies are rooted in similar concerns about human well-being, it is only recently that we have started to understand the links between development and disasters (Susman, O’Keefe & Wisner, 1983; Hoffman & Oliver-Smith, 2002; Pelling, 2003; Collins, 2009). Most of our understanding converges on the idea of vulnerability. Because the terms risk, hazard, disaster, vulnerability, and resilience are used in many disciplinary contexts, it is important to define them for the purposes of this study. Definitions are provided in Table 1.

Table 1
Key definitions

Risk	The likelihood of being harmed (Pelling, 2003).
Hazard	An extreme natural event with the potential to harm society.*
Vulnerability	The degree to which a system is likely to experience harm due to exposure to a hazard (Turner et al., 2003a).
Social Vulnerability	The attributes of people or communities that can increase damage from a hazard (Hewitt, 1983).
Physical Vulnerability	The attributes of the built environment that can increase damage from a hazard
Disaster	The outcome of a hazard and vulnerability coinciding (Pelling, 2003).

*Hazards can be either natural or technological, but I only look at natural hazards in this study.

VULNERABILITY: CONCEPTS AND THEORY

Vulnerability has been increasingly valuable as a concept for understanding human-nature relationships, in part because it has been enriched by the disciplines of geography, psychology, anthropology, development studies, and most recently, ecology. But, researchers have conceptualized vulnerability in different ways. These conceptual differences have in turn led researchers to generate different frameworks with which to analyze and assess the vulnerability of systems. For example, the literature on vulnerability characterizes vulnerability in two ways: *vulnerability as an outcome*—with a focus on the impacts and consequences of a stressor on a system—or *vulnerability as a context* of conditions that determine the impacts of a stressor in a system (O'Brien et al., 2004). Based on case studies in Norway and Mozambique, O'Brien et al. (2004) argue that the interpretations have different implications for policy and produce different types of knowledge. The methods and research questions I use in this study align with the *vulnerability as a context* interpretation by emphasizing the social, physical, and institutional characteristics that determine vulnerability to flooding on the US-Mexico border.

While there is neither a universally accepted definition of vulnerability nor or a unified theory of vulnerability, because these diverge according to the theoretical traditions of each discipline, there are many points that do converge and allow us to make some generalizations about vulnerability (Adger, 2006; Eakin and Luers, 2006).

Most conceptualizations of vulnerability, including that of the Intergovernmental Panel on Climate Change (IPCC), explain vulnerability as a function of three attributes or dimensions: exposure, sensitivity, and adaptive capacity. *Exposure* refers to the level of stress or shock experienced by an environmental or human system (Adger, 2006). Exposure could be the physical impact of an environmental hazard such as a hurricane, flood, or earthquake, or it could be an economic or social stress such as market instability, pollution, or war. Exposure is usually measured by calculating the magnitude, frequency, and spatial coverage of a hazard (Burton et al., 1978; Tobin & Montz, 1997).

Early scholars of disaster and hazard studies focused on the exposure component of vulnerability. They were mainly interested in identifying who is exposed and what they are exposed to. In theory, if there is no exposed population, then there is no vulnerability. In the 1940s, the physical and engineering sciences defined our approach to dealing with natural hazards (Mileti, 1999). The work of White (1942) was some of the firsts to look at disasters from a social science perspective. White challenged the “bigger and stronger” technological approach to flood control, and focused on what makes people settle in dangerous areas in the first place. His work, along with that of Burton et al. (1978) led to the risk-hazard approach for understanding vulnerability (Figure 2).

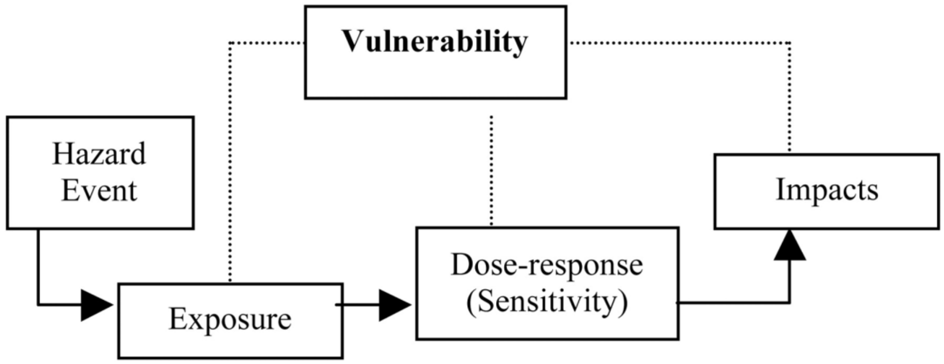

Figure 2. Risk hazard model (Source: Turner et al., 2003a)

The risk-hazard approach focuses on understanding the impacts of natural hazards on an exposed system. Vulnerability, in terms of the risk-hazard approach, is defined as the outcome of the combination of hazard risk and the potential for loss to the people that are exposed to the risk. This approach has been criticized for its focus on impacts of the hazards instead of on the causal links that lead to the impacts, and for ignoring the role of institutions and politics in shaping vulnerability (Liverman, 2001; Turner et al., 2003a).

The second ingredient of vulnerability is *Sensitivity*. Sensitivity is the degree to which a system can be harmed by a hazard. Sensitivity to a hazard is determined by the human and environmental conditions of a system (Turner et al., 2003a). In theory, a system with poor human conditions like poverty and unemployment, and poor environmental conditions like degraded soils and deforestation will be more sensitive to any particular hazard than a system with good human and environmental conditions. The sensitivity of a system can vary according to the characteristics of its population like economic position, social class, family structure, occupation, and race.

Political economists and political ecologists have been interested in the social and political conditions that made communities sensitive to disaster. Hewitt (1983) and Susman et al. (1983) integrated development theory into disasters studies. They claimed that economic development policies, based on the control and exploitation of local resources, actually increased the vulnerability of people to disasters (Susman et al., 1983). By increasing social inequity, development and economic policy can worsen the socio-economic status of some groups, which creates the conditions for disaster when a natural event hits. Revi (2008) accurately summarizes the differential risk that the poor face by using an example from India:

"the urban residents most vulnerable […] are the poor slum and squatter settlement dwellers and those who suffer from the multiple insecurities that poor governance, the lack of serious investment in the commons and a strong nexus between the political class, real estate developers and public agencies bring to cities. Through a long process of loss accumulation, they are multiply challenged by even small events that impact their livelihoods, income, property, assets and sometimes their lives. Because of systematic exclusion from the formal economy of the city – basic services and entitlements and the impossibly high entry barrier into legal land and housing markets – most poor people live in hazardous sites and are exposed to multiple environmental health risks via poor sanitation and water supply, little or no drainage and solid waste services, air and water pollution and the recurrent threat of being evicted."(Revi, 2008, p. 219)

In an effort to understand the linkages between development and the creation of vulnerability, Blaikie et al. (1994) proposed the Pressure and Release (PAR) framework. The PAR framework emerged as a response to criticisms of the risk-hazard approach. In the PAR framework, risk is defined as a function of a natural hazard and social vulnerability. The natural hazard acting on a vulnerable population is just the trigger event that causes a disaster. Thus, the PAR framework does not emphasize the hazard itself, but the social, political, historical, and cultural processes that create unsafe conditions for people (Figure 3). While the risk-hazard approach views vulnerability as an outcome, the PAR framework views vulnerability as a dynamic process controlled by socio-economic forces.

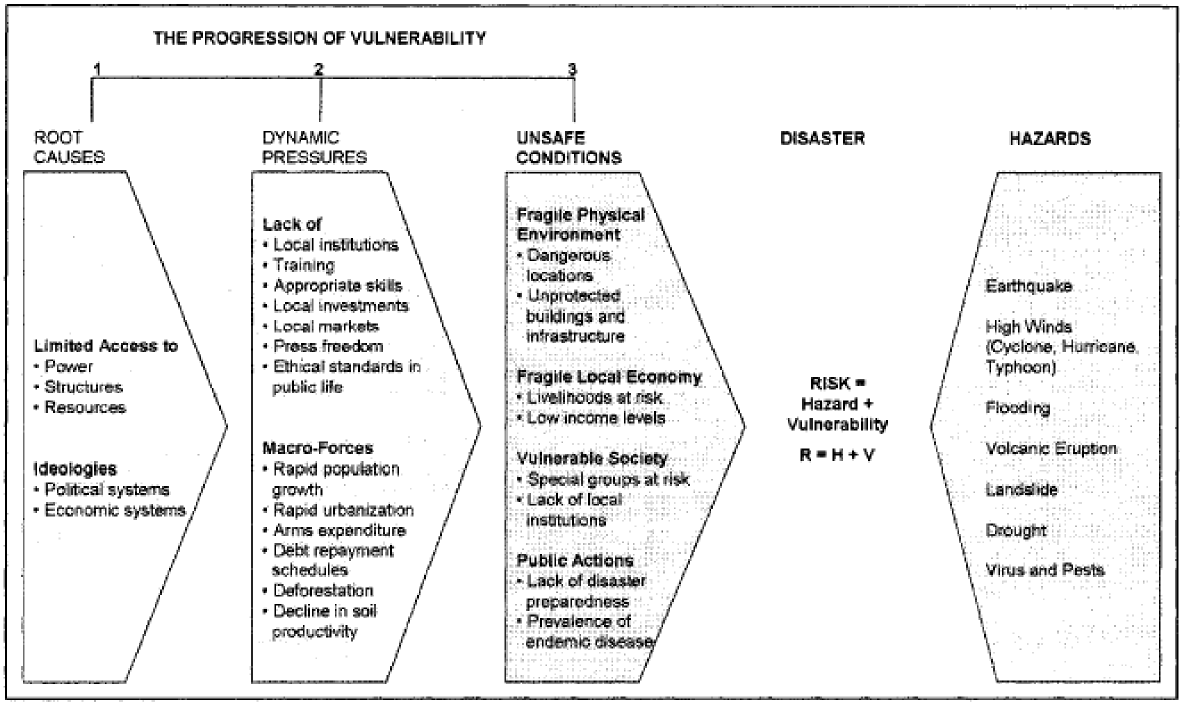

Figure 3. Pressure and Release Framework. Focuses on the social conditions of the system. (Wisner et al., 2004)

The PAR framework has been criticized as being insufficient to address the concerns of sustainability science, which lie not just in the vulnerability of people, but in the vulnerability of the environment as well (Turner et al., 2003a). PAR has also been criticized for ignoring the hazards themselves (Cutter et al., 2009), and for being a descriptive approach that in some cases provides a too generic description of vulnerability (Eakin & Luers, 2006).

Cutter (1996) tries to supplement the risk-hazard approach and its focus on hazards with the PAR framework and its focus on social conditions. Her hazard-of-place approach also provides an empirical approach to the measurement of vulnerability. The hazard-of-place approach focuses on the spatial interaction between natural hazards and people. With the development of Geographic Information Systems, this approach became popular for mapping vulnerability to multiple hazards. This approach emphasizes the proximity of people to a hazard, and the demographic variables that characterize vulnerability. However, the hazard-of-place approach fails to identify the drivers of vulnerability, which the PAR framework does identify, and if limited to mapping biophysical and demographic variables, the approach fails to account for the dynamic nature of vulnerability.

A third agreed-upon ingredient of vulnerability is *Adaptive Capacity.* Adaptive capacity is the ability of a system to maintain functionality and recover from a shock or stress caused by a hazard (IPCC, 2007). People are not just helpless victims at the mercy of environmental hazards: they can adapt to change, take advantage of opportunities, and learn from experience (Gallopín, 2006). What is of interest about adaptive capacity is the processes that either constrain or enhance the ability of a community to adapt to environmental change. A system with high levels of adaptive capacity is less vulnerable to hazards. Yohe and Tol (2002) state that adaptive capacity can reduce a system's sensitivity and exposure to hazards. They consider key determinants of adaptive capacity in a system to be its technological options, economic and physical resources, institutions, human capital, social capital, and risk-spreading processes.

The most recent framework for conceptualizing vulnerability comes from sustainability science (Figure 4). The SUST framework combines elements of the PAR framework with elements of ecological theory, particularly resilience theory. The idea behind resilience is that ecosystems, when faced with a stressor, have the capacity to absorb change and maintain functionality (Holling, 1973). The aim of the SUST framework is to analyze the resilience of the human-nature system. The SUST framework emphasizes that vulnerability operates at multiple scales: local, regional, and global. The SUST framework has been criticized mainly for its lack of utility in empirical research (Cutter et al., 2009), although Turner et al. (2003b) show how the framework can be applied to a real case study.

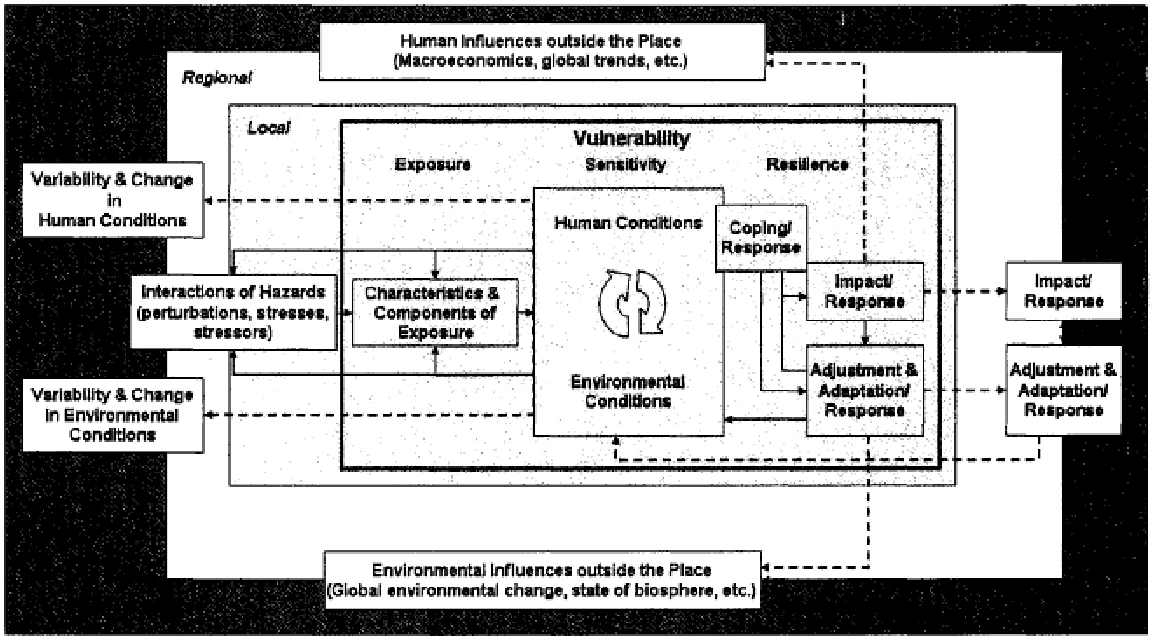

Figure 4. SUST Framework (Turner et al., 2003a)

Sustainability science emphasizes the importance of understanding institutions and their influence on vulnerability (Turner et al., 2003a; Costanza et al., 2001). If society has to adapt to quick and unpredictable changes like disasters, then institutions, as the structures, norms, rules, and values that organize human activity (Turner, 1997), need to be prepared to respond to these changes (Yohe & Tol, 2001; Eakin & Luers, 2006). Institutions can be either formal or informal (North, 1981). Formal intuitions are characterized by rules, laws, and organizational structures like government agencies. Informal institutions are based on social norms and networks. The interaction of human-nature systems is influenced by a complex set of formal and informal institutions. That institutions can improve or damage components of the human-nature system is evident in the case of urban flooding and disaster (Naess et al., 2005; Raschky, 2008; Tompkins et al. 2008). Thus institutions are drivers of vulnerability (or resilience) in the human-nature system.

Research on adaptation to climate change has focused on the characteristics of institutions that make them effective, or not, in responding to environmental change. Institutions that are not flexible and cannot adjust quickly to external changes are ineffective (Folke et al., 2005). Yet so are institutions that are too easy to modify when responding to changing environmental and social conditions, because they lack credibility and influence (Young, 2010). Effective institutions, then, are those rigid enough to maintain influence over other actors, but flexible enough to adjust and reconfigure with new environmental and social conditions. What are some of the characteristics that make institutions good at adapting? The literature highlights many attributes, among them learning capacity, trust, leadership, financial and human resources, and participation.

An institution with learning capacity is an institution that learns from past experiences and improves its performance, stores and transfers knowledge, and monitors and evaluates its processes (Ostrom, 2005). Trust among organizations helps them build adaptive capacity because they are able to share and rely on information from one another. Effective institutions have strong leaders. Leadership can come from the individual initiative of a visionary leader (Pielke, 1998), or from the collaboration of actors from different institutions (Folke et al., 2005). Institutions that include citizen participation can, in theory, respond better to the needs of society (Pelling, 1998). The open governance of institutions can also help establish trust between the public and the institution, increasing the credibility and influence of the institution. A resilient institution is one that establishes tight links within the institution and with the community at large (Berke et al., 1993). Finally, human and financial resources can determine the effectiveness of institutions (Nelson et al., 2010). Without them, institutions do not have the capacity (or have a very limited capacity) to deal with any type of problem.

Institutions face a paradox when dealing with disasters (Waugh & Streib, 2006). They must be able to plan meticulously and be spontaneous at the same time. To resolve this paradox, institutions must collaborate in a model that facilitates cooperation beyond an organization's boundaries (Waugh and Streib, 2006). A hybrid approach, one that combines command and control from central government and close collaboration with local governments, may provide the best resolution (Burby & May, 2009).

Global environmental research puts local government at the center of where most adaptation initiatives will take place (IPCC, 2007). However, local governments are constrained by regional, national, and international institutions that dictate major policy and distribute resources. The capacity of state and federal governments to manage and allocate resources is also constrained by new challenges like globalization, decentralization of government, and a larger set of problems of public concern (e.g., climate change) (Eakin & Lemos, 2006). If the state fails to acquire the social, political, human, and financial resources needed to meet these new challenges, then it is unlikely it will be able to provide the policy instruments and resources needed at local levels (Eakin & Lemos, 2006).

Understanding the nested scales of institutional structures is essential for understanding decision-making and capacity at the local level. The fact that cities on the US-Mexico border are governed by local, national, international, and border institutions increases complexity, especially because these institutions sometimes have conflicting goals. Border cities find themselves in a predicament: they are host to number of national policies (e.g., border security, immigration, trade) over which they have little or no control. The immediate concerns of border cities, like land use planning, urbanization, and quality of life are overlooked by national governments. This situation makes resilient institutions very hard to establish in the border context, but even more necessary than in other contexts.

In this thesis I adopt the PAR framework to analyze vulnerability to floods in Ambos Nogales. The PAR framework focuses on explaining the process of vulnerability; its theory is based on the processes of development (i.e., root causes and dynamic pressures) that lead to vulnerability. I find this framework particularly useful for the US-Mexico border region because it emphasizes vulnerability at the local level while still taking into consideration macro-level scales. The framework is also simple to understand and applicable for empirical studies. To complement the PAR framework, I elaborate on the interaction between unsafe conditions in a community and a natural hazard, using interview data and multi-criteria decision analysis. Further, I characterized the interaction between unsafe conditions and natural hazards as a relationship between exposure, sensitivity, and adaptive capacity, which together creates vulnerability (see Figure 5). In this way, I try to address some of the criticism that the PAR framework receives for being an oversimplified approach.

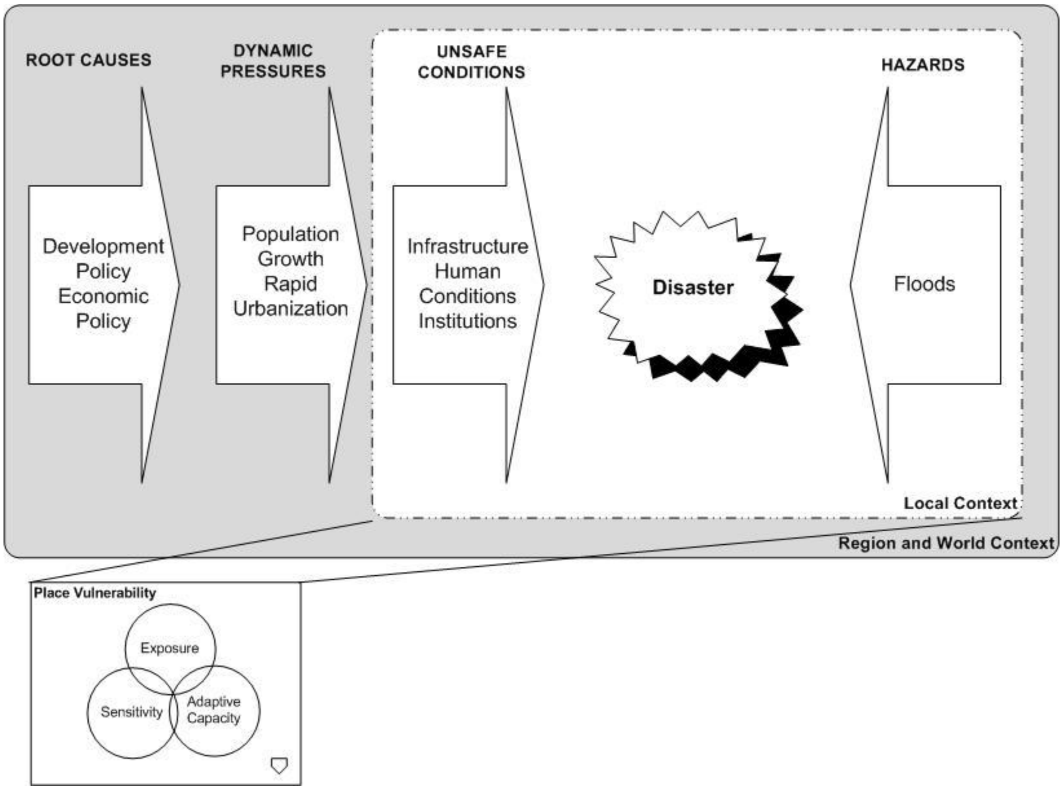

Figure 5. PAR Framework: The Progression of Vulnerability. (Adapted from Wisner et al., 2004)

MEASURING VULNERABILITY

The frameworks discussed above help us understand vulnerability. But exactly how do we measure vulnerability? One way to do so is through the use of indicators and indices. An indicator is a numerical measure that represents a characteristic of a system (Cutter et al., 2008). An index is a combination of indicators into a single metric. In vulnerability research, indicators provide researchers the means to test relationships between the characteristics of a system and the outcome of vulnerability (Eakin & Luers, 2006). In theory, by measuring the characteristics of a system through a set of indicators, one could predict changes in the system.

However, using indicators has it challenges. First, indicators simplify the complex interactions of a human-nature system into single variables (Cutter et al., 2009). And more importantly, how do we know that an indicator measures what we claim it measures? Adger (2006) states that selecting variables that measure vulnerability requires a “leap of faith,” If the links between the indicators and vulnerability are not well-established, then the analysis is of questionable value (Adger, 2006). In spite of these challenges, many researchers have conducted empirical research linking indicators with vulnerability outcomes (Chakraborty, 2005; Luers et al., 2003; Cutter et al, 2000). Some of the vulnerability indicators, common to these studies are described below.

Exposure Indicators

Exposure indicators quantify the physical characteristics of a hazard. Measures of exposure include the magnitude, frequency, duration, spatial extent, and seasonality of a hazard (Burton et al., 1978; Tobin & Montz, 1993). In case studies of floods, the extent of floodplains has been used as a proxy for exposure (Collins et al., 2008; Tiefebacher, 2006).

Sensitivity Indicators

Sensitivity indicators quantify the social and environmental conditions of a system. Many researchers agree on the social variables that increase the sensitivity of a system to a hazard. For example, economic condition plays an important role in determining sensitivity. Poor people are more vulnerable to hazards because they do not have resources to spend on reducing their risk (e.g., not being able to afford a safe location for their houses), and recovering after the hazard (e.g., not being able to get insurance for their property) (Fothergill & Peek, 2004). While the rich may lose more things (in terms of economic loss), the poor may lose their only things. The poor also tend to live in houses built with inadequate materials that do not provide protection from floods or hurricanes (Long, 2007).

Another indicator of sensitivity to hazards is the number of people with a physical or mental disability who need special attention during an emergency (Morrow, 1999). Chakraborty et al. (2005) state that evacuation planners should not only concentrate on high-risk areas, but on providing early warning and mobility assistance to special-needs populations regardless of their physical risks. Children and elders are also population groups that, with no physical or mental disability, may still be incapable of dealing with a hazard without help (Anderson, 2005).

Adaptive Capacity Indicators

Adaptive capacity indicators quantify the ability of system to recover from an external shock. They measure the access that people have to different resources. For example, people who have access to social networks can get access to information and material resources that can help them during an emergency. Hazard studies have used an individual's length of residence in a community as a proxy for social capital (Lara-Valencia et al., 2008), and social capital has a positive influence on adaptive capacity. The assumption is that the longer a person lives in a community, the tighter the links he or she is able to establish with community members.

Education is also used as an indicator of adaptive capacity, and is closely linked with income. People with high levels of education are able to earn higher incomes, thus increasing their access to resources that may help during an emergency (Cutter et al., 2003). Education can also play a role in people's ability to understand key information like forecasts, early warnings, and recovery procedures (Heinz, 2000).

Indicators of adaptive capacity and sensitivity are closely linked, and separating them can be an arbitrary process. Take income for example: a person with high income has the capacity to access many resources that can aide during disaster, which increases his adaptive capacity and reduces his sensitivity. In contrast, a person with low income has very limited access to resources, so his adaptive capacity is reduced and his sensitivity increased.

MAPPING

Geographic Information Systems (GIS) and Geographic Information Science have played an important role in measuring vulnerability. In an important study of GIS in vulnerability research, Cutter et al. (2000) layered a physical risk map with a social vulnerability map to determine the overall vulnerability of Georgetown County in South Carolina, and found that the places most exposed to hazards are not necessarily the most vulnerable. Many studies are now using this overlay approach to determine the spatial distribution of hazards (Chakraborty et al., 2005; Azar & Rain, 2007; Collins et al., 2008). As a result, researchers are now better able to communicate vulnerability to decision-makers, academics, and the public (Eakin & Luers, 2006). Mapping has also allowed for the analysis of multiple hazards. For example, Collins et al. (2008) measures hazard exposure on the US-Mexico border by layering environmental and technological hazards. He creates an index of bio-physical risks using proximity to floodplain, Toxic Release Inventory sites, industrial sites, and transportation routes. O'Brien et al. (2004) demonstrate the double exposure experienced by populations in India, by mapping vulnerability to climate change and to globalization.

Scale is very important to consider in mapping exercises, because results from vulnerability research are scale dependent (Turner et al., 2003a). The problem of scale is also known as the Modifiable Areal Unit Problem (MAUP). Studies that use aggregated census data have to take into consideration the differences that result from changes in the spatial scale (e.g., moving from census block to census tract) and the artificial boundaries that are used to aggregate data (Goodchild et al., 1993). To demonstrate the importance of scale, O'Brien et al. (2004) analyzed vulnerability to climate change in Norway at different spatial scales. They found that exposure and the socio-economic factors that affect adaptive capacity changed according to the scale of the analysis. Comparing vulnerability between countries can be problematic because of scale issues. For example, some studies of US-Mexico border cities use the census block group of the US and the *área geo-estadística básica* (AGEB) of Mexico as a unit of analysis for comparison (Collins et al., 2008; Tiefenbacher, 2006), but other studies use census blocks (a smaller unit than the block group) and AGEBs for comparison (Lara-Valencia et al., 2008). Determining which scale is better for analyzing vulnerability and providing meaningful comparisons between cities will depend on where the study takes place and on the purpose of the vulnerability analysis.

Chapter 3

METHODOLOGY

I developed quantitative indicators using census and geographical data to assess the vulnerability to flooding in Ambos Nogales. I used indicators as proxies to determine the exposure, sensitivity, and adaptive capacity of communities in Ambos Nogales. I also conducted fieldwork in Ambos Nogales that included interviews with public officials in charge of some aspect of flood management, site visits to communities affected by flooding, and analysis of documents from government agencies and periodical reports. The expert interviews served two purposes: (1) to evaluate the selection of the indicators (e.g., is car ownership important in Nogales, Sonora for someone that is affected by a flood), and (2) to learn about flood management in both cities. In this chapter, I will describe in detail the indicator and interview methods, where the data came from, and some limitations of the methods.

INDICATORS

There is extensive literature on vulnerability indicators (for a review see Cutter et al., 2009). Some of studies use census data to extract indicators of vulnerability. Following this line of work, I obtained demographic information relevant to vulnerability from the 2000 censuses of Mexico and the United States (e.g., education, employment, disabilities, etc.). Then I compared the data between Mexico and the United States to see if it was compatible or if it could be transformed into a comparable unit.

Each indicator represents a hypothesis—in selecting an indicator I hypothesized that it is relevant to explaining exposure, sensitivity, or adaptive capacity. The interviews, described later in the chapter, helped to validate the hypothesis implied with each indicator. Of course, the process of indicator selection is hindered by the data that is available from and comparable between the United States and Mexico. For example, household assets, like a radio or a computer, play an important role in a person's ability to access information (Wisner et al., 2004). The Mexican census has detailed information on household assets, but unfortunately the American census does not, so I use a reduced version of household assets (with car and telephone data) as an indicator.

The unit of analysis I chose for the indicator assessment is the census block group in the United States and the *área geo-estadística básica* (AGEBs) in Mexico. The census block group is the smallest geographical unit for which detailed socio-economic census data can be obtained in the United States (i.e., Summary File 3). It is also a unit comparable to the Mexican AGEB in terms of size and population density. In total, there are 11 census block groups in Nogales, Arizona and 88 AGEBs in Nogales, Sonora. The rest of this paper refers to both census block groups and AGEBs as the "block group."

SELECTING EXPOSURE INDICATORS

Exposure is the external factor that triggers a disaster, in our case floods in Ambos Nogales. I calculated exposure using three variables: (1) the percent of a block group that lies within the floodplain, (2) the percent of the block group at high risk of runoff, and (3) the population density in the block group. To calculate the first variable, I used floodplain maps for the city of Nogales, Arizona, and Nogales, Sonora, which I obtained from Santa Cruz County, and the *Instituto Municipal de Investigación y Planeación* (IMIP).[1] The maps differ in scale. The United States floodplain map measures the area covered by a 100-year flood event, while the Mexico map represents a 25-year event. This difference speaks to the lack of collaboration between American and Mexican agencies, and to the difficulties of planning for a border region. The second

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[1] IMIP translated to English is Municipal Institute for Research and Planning. IMIPs are a new model that Mexican cities are using to provide continuity to planning visions and projects in the city. IMIPs work as a semi-independent government agencies.

indicator—runoff—compensates for the limitations of the floodplain indicator. I extracted the runoff indicator from a hydrological model developed by Norman et al. (2010) for the Santa Cruz River watershed. Using geophysical and hydrological data, this model breaks the Santa Cruz watershed (covering both sides of the border) into several basins and calculates runoff risk under a 100-year flood scenario. I used GIS to overlay the map developed by Norman et al. (2010) with the block groups, of Ambos Nogales, and assigned a risk value to each of them. Figure 6 depicts the floodplain and runoff-risk maps used in the study. Population densities for each block group were derived from the censuses.

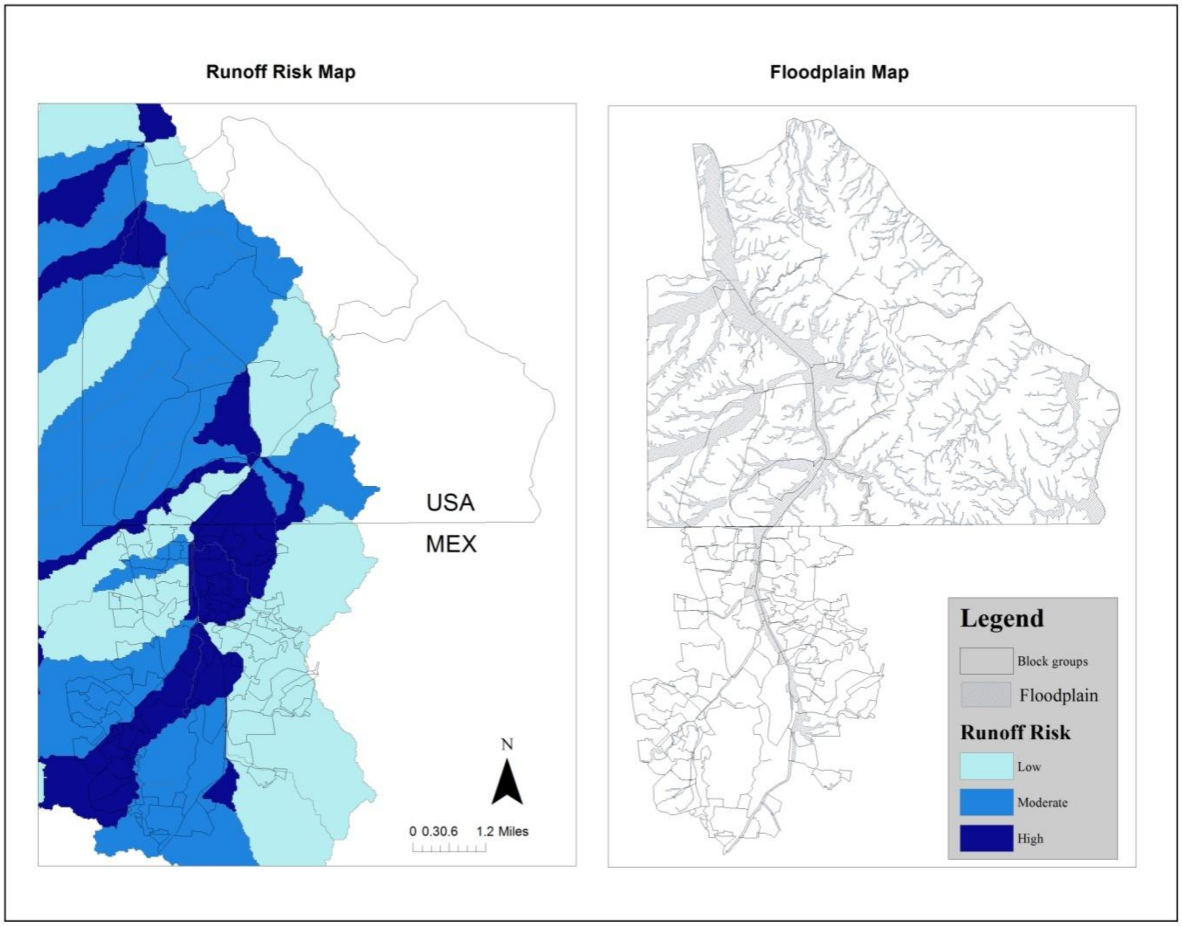

Figure 6. Runoff risk and floodplain layers. Runoff-risk map developed by Normal et al. 2010.

SELECTING SENSITIVITY INDICATORS

Sensitivity refers to the likelihood of being harmed by flooding. In this assessment, sensitivity at the block-group level refers to the degree that both population and infrastructure can be harmed by a flood. Indicators of sensitivity include: the percent of special-needs population, the percent of renters, the percent of nuclear families (i.e., families with both parents), the dependency ratio, and the percent of houses with poor construction. Blocks groups with higher percentages of special-needs populations and higher dependency ratios, for example, would be more sensitive to flooding because they would require increased efforts from agencies to assist and evacuate the disabled, elders, and children. Block groups with many houses in poor conditions (measured as the number of houses without a kitchen and without complete plumbing) are more likely to suffer damages from a flood, and thus are more sensitive. The percent of nuclear families and renters in a block group are indicators that can measure both sensitivity and adaptive capacity. A block group with a high concentration of single-parent families would be more sensitive to floods because family care and household income is the responsibility of only one person. At the same time, single-parent families have a reduced capacity to cope with floods because the family depends on one source of income. Female householders, particularly, are more sensitive (and have less adaptive capacity) than men because they tend to have fewer employment opportunities and lower wages, all while having the responsibility of being the primary caretaker of the family (Laska et al., 2008). I consider the percent of nuclear families and renters to be important in determining sensitivity rather than adaptive capacity because of the border context. Cities of the US-Mexico border are characterized as having a "floating population" (Arreola, 1996). This is particularly true on the Mexican side, where people constantly moving in and out of the city. They move in because they are looking for better jobs opportunities in the *maquiladoras* or because they need a temporary place to live as they make their move into the United States. Sometimes they succeed and are able to cross the border (legally or illegally), and sometimes they fail and have to return to their original home. The percent of nuclear families and renters are meant to capture this border dynamic. People that move to the border often do so without their nuclear families. A family member who has to move alone or is left behind, I hypothesize, is more sensitive to hazards because he or she does not have the support system that a nuclear family provides. Similarly, I assume that renters are part of the "floating population", and consequently, have weaker links to the community than homeowners.

SELECTING ADAPTIVE CAPACITY INDICATORS

Adaptive capacity allows a person to act, learn, and access resources in ways that reduce their sensitivity and exposure to floods. To measure adaptive capacity I use indicators of education, social capital, transportation, communication, and income. Income is one of the most important indicators of adaptive capacity. The more income people have, the more they are able to adjust to changes in their livelihood. Because comparing income between the United States and Mexico using census data is problematic, I decided not to use this indicator. Instead, I used other indicators that are highly correlated with income, like level of education (percent of population without a high school education), employment (percent of population with a full-time job), and asset ownership (percent of population with a car, and percent of population with landline telephone). But these variables are not just proxies for income; they can also tell us something about other components of adaptive capacity. For example, people with a car are not dependent on public transportation, where routes and vehicles may be inoperative after a flood. The length of residency of the population is used a proxy for social capital.

The assumption is that the more years a person has lived in the same house, the more and stronger social ties he establishes with neighbors and governmental officials, which could be useful during, and after a flood event. Table 2 provides a summary of all indicators.

Table 2
Indicators with definition and relation its vulnerability dimension

Indicator Name	How it is measured	Represents	Relationship[a]
Exposure			↑
Floodplain	Percent of block group within floodplain	Area affected by flooding	↑
Runoff	Percent of block group within high runoff risk	Area affected by flooding	↑
Population Density	Ratio between population and block group area	People that could be affected by floods	↑
Sensitivity			↑
Dependency	Ratio between dependents and independents	Dependency of family on few individuals	↑
Special Needs	Percent people with disability	Need for assistance	↑
Housing Construction	Percent of houses without kitchen and complete plumbing	Concern for the stability of housing	↑
House Age	Average year of construction	Concern for the stability of housing	↑
Family Structure	Percent of families with both parents	Concern for stress of single care giver	↓
Renter	Percent of people that rent their house	Concern for 'floating population'	↑
Adaptive Capacity			↓
Education	Percent of people without high school education	Access to resources useful for adaptation	↓
Residency	Percent of people with 5 years or more living in the same house	Opportunity to build social capital	↑
Transportation	Percent of people that own a car	Ability to quickly evacuate on an emergency	↑
Communication	Percent of people with landline telephone	Ability to get information	↑
Employment	Percent of population employed	Access to resources useful for adaptation	↑

[a] The↑symbol represents a positive relationship with the vulnerability dimension, e.g. as the percent of a block group within a floodplain increases, so does Exposure. The ↓symbol represents a negative relationship, e.g., as the percent of people without a car increases, Adaptive Capacity decreases.

RANKS AND WEIGHTS

With the indicators of exposure, sensitivity, and adaptive capacity determined, I used the Analytical Hierarchical Process (AHP) to assign weights to each indicator. The AHP is a multicriteria decision-analysis (MCDA) tool that allows you to compare and evaluate the different choices of a decision (Saaty, 1980). The criteria used to evaluate the choices of a decision can be prioritized and weighted using AHP. That way we can identify which criteria are more relevant than others. The AHP is an adequate tool for weighting variables because it is transparent and relatively easy to understand (see Appendix A). Eakin and Bojórquez (2008) applied the AHP to analyze vulnerability at the household level in rural Mexico.

The hierarchical structure of the AHP for this study is depicted in Figure 7. The top level, Vulnerability, represents the goal of the study which is to quantify vulnerability. The next two levels represent the criteria used to measure vulnerability: the dimensions of vulnerability (exposure, sensitivity, and adaptive capacity) and the indicators associated with each dimension. The bottom level represents the 99 block groups for which I measure vulnerability.

The weights developed through this process refer to the level of importance that each indicator has with respect to the dimension (e.g., the floodplain indicator is more important than population density for measuring exposure). Then, the same is true for the dimensions (e.g., Exposure is more important than Sensitivity and Adaptive Capacity for measuring vulnerability).

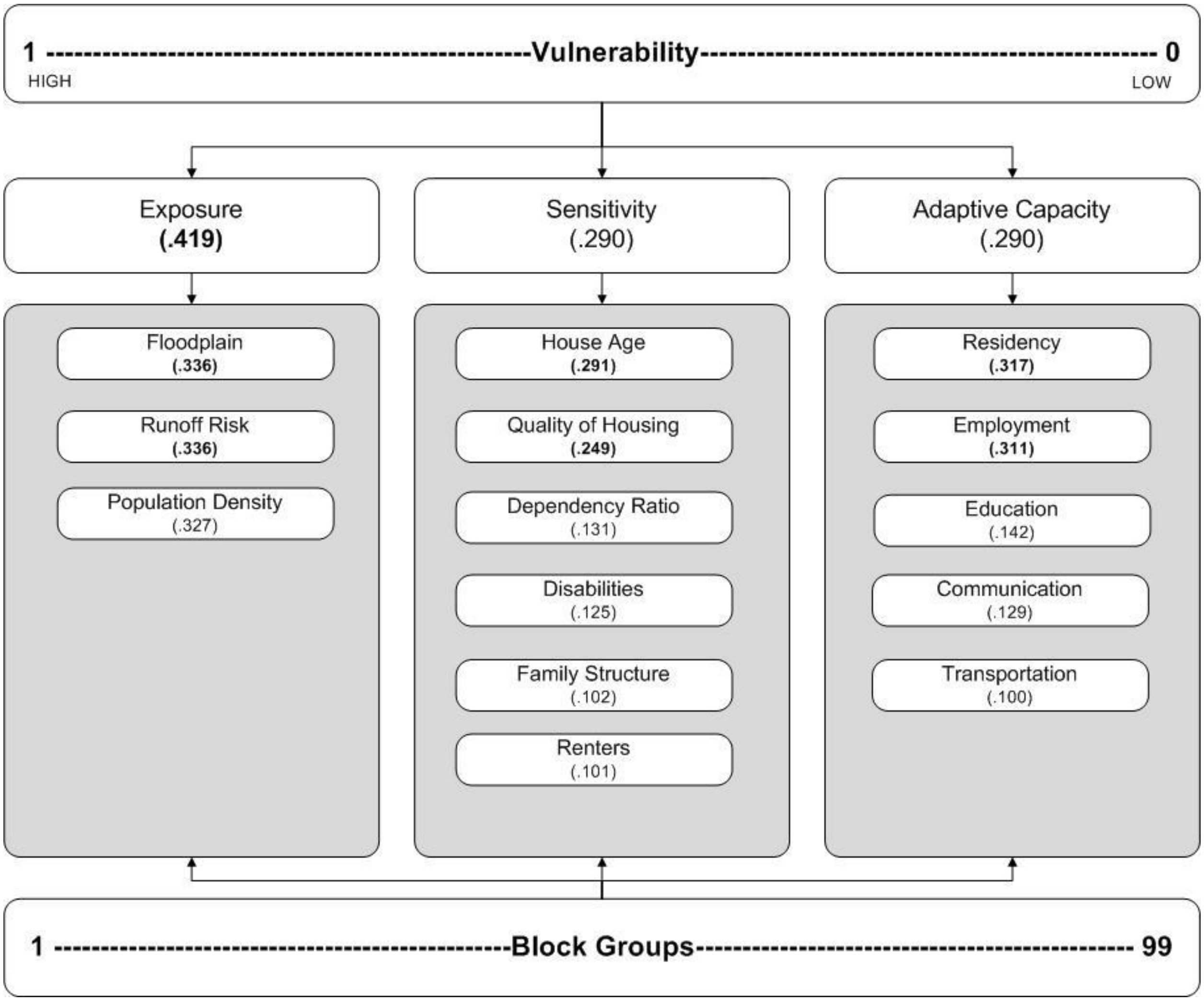

Figure 7. Hierarchical structure of indicators with assigned weights. Highest weights appear boldfaced.

The weights in Figure 7 were calculated through AHP using an ordinal ranking of indicators given by six professionals involved in flood management in Ambos Nogales (three from Nogales, Arizona, and three from Nogales, Sonora). Appendix B includes the survey used to obtain a ranking of indicators from most to least important. The weights are meant to represent the informed opinion and experience of these six individuals with flood management in their cities.

While many criticize the subjective nature of weights (Cutter et al., 2003, Collins et al., 2008), all indicator-based assessments include weights, even if only implicitly. By not assigning weights, the researcher makes a decision that all indicators are equally important (Eakin & Bojórquez, 2008). The irony of it is that the decision that all indicators are equally important is just as subjective as weighting indicators. Further, the importance of an indicator is context dependent, and should be evaluate according to specific contexts. By using AHP, I allow local actors to define what is important, because they know more about the local context than I do. This adds value and meaning to the research through the use of local knowledge and feedback.

CREATING AN INDEX

For vulnerability to be comparable among block groups, indicators need to be transformed from different units into a common unit. All indicators were normalized using two simple functions:

$$\delta_{ij} = \frac{X_{ij} - X_i^{min}}{X_i^{max} - X_i^{min}} \qquad (1)$$

$$\delta_{ij} = \frac{X_i^{max} - X_{ij}}{X_i^{max} - X_i^{min}} \qquad (2)$$

where δ_{ij} is the standardized observation of the i^{th} indicator for block group j^{th}, X_{ij} is the value of the i^{th} indicator for block group j^{th}, and X_{ij}^{max} and X_{ij}^{min} are the maximum and minimum values of the i^{th} indicator for all block groups. Equation (1) was used for indicators with a positive influence on vulnerability (i.e., as the value of the indicator increases so does vulnerability), and Equation (2) was used for indicators with a negative influence on vulnerability (i.e., as the value of the indicator increases, vulnerability decreases). In Equation (1) when $X_{ij} = X_i^{min}$, $\delta_{ij} = 0$; when $X_{ij} = X_i^{max}$, $\delta_{ij} = 1$. Conversely, in Equation (2) $\delta_{ij} = 0$ when $X_{ij} = X_i^{max}$, and) $\delta_{ij} = 1$ when $X_{ij} = X_i^{min}$. The value δ_{ij} always ranges between 0 and 1, where 0 is ideal (no vulnerability) and 1 is non ideal (max vulnerability). Once all indicators were standardized, they were combined with the weights as follows:

$$VD_{hj} = \sum_{i}^{n} w_i \delta_{ij} \,, \tag{3}$$

where VD_{hj} is the value of the h^{th} vulnerability dimension (i.e., exposure, sensitivity, or adaptive capacity) of block group j^{th}, w_i is the weight assigned to the i^{th} indicator, and δ_{ij} is the standardized observation of the i^{th} indicator for block group j^{th}.

Finally, exposure, sensitivity, and adaptive capacity are aggregated to obtain the vulnerability index:

$$V_j = \sum_{i}^{n} W_h VD_{hj} \,, \tag{4}$$

where $Vulnerability_j$ is the degree of vulnerability of block group j^{th}, W_h is the weight assigned to the h^{th} vulnerability dimension, and VD_{hj} is the h^{th} vulnerability dimension of block group j^{th}.

CREATING VULNERABILITY CLASSES

The next step is to divide the vulnerability index, V_j, into classes of vulnerability (i.e., low, medium, and high vulnerability). This step is important because it transforms a continuous index into discrete numbers (i.e., 1, 2, and 3), which I use to create maps of vulnerability in a GIS. The visualization of data in GIS is often overlooked by researchers, and results in them choosing algorithms without thinking about how the data is classified into different classes. Common methods of classification include quintiles, and natural breaks. But these methods ignore the ability of humans to understand and analyze information (Bojórquez et al., 2009). To consider human perception of visual data, I employ the Weber-Fechner law (Saaty & Vargas, 2001). According to the Weber-Fechner law, human perception is proportional to an increase in visual stimulus—a visual stimulus can only be perceived once it has been increased by a constant. Mathematically, Weber-Fechner law is described as follows:

$$S_n = S^* + (1 + r)^n S_0 \quad (5)$$

where S_n is the vulnerability class threshold, S^* is the block group with the worst case vulnerability (i.e., the worst case of a stimulus), (1+*r*) is the progression factor of visual perception and visual stimulus, *n* is the number of categories in which vulnerability is classified, and S_0 is the smallest stimulus that can be perceived. In this study, I tested map visualization with different parameters of *n* and (1+*r*). In summary, the Weber-Fechner law allows to divide the vulnerability index into vulnerability classes according to how humans can perceive changes in the intensity of the vulnerability index. Bojórquez et al. (2009) used the Weber-Fechner law to classify an index of groundwater vulnerability into four classes. When compared against other classifications methods, their approach proved to be the most helpful to policy makers.

INTERVIEWS AND FIELDWORK

I conducted 22 interviews with public officials during a two-month stay in Nogales, Sonora from July to August of 2010. Most interviews involved respondents from local agencies, and a few from state agencies (see Table 3 for a list of organizations). I selected participants based on their role of leadership in municipal agencies related to urban planning, and water and disaster management. My initial interview list was narrowed down with suggestions from key informants. Interviews include city planners, engineers, emergency respondents, fire-fighters, policemen, and social workers. I tried to balance the interviews between Arizona and Sonora by finding the appropriate counterpart across the border for each person I interviewed, but this was not always possible. I also included some interviews from non-government actors, like businessmen and local residents, who provided their own perspectives of flooding issues in Ambos Nogales. Interviews were semi-structured and designed to last about 30 minutes. The interview focused on two areas of flood management: (1) perspectives on the problems and solutions associated with flooding, and (2) perspectives on collaboration between border cities to solve the flooding problem (see Appendix C for a sample of the interview protocol). I used NVIVO, a software for qualitative analysis, to code and analyze the interviews (Table 4). The qualitative data from the interviews served to test and validate the indicators, and complemented the indicator assessment with information of institutional capacity and collaboration in flood management.

Table 3
List of interview participants with their position and organization

Nogales, Arizona	Nogales, Sonora
Director, Planning and Zoning	Director, IMIP
City Engineer	Engineer, IMIP
Director, Public Works	Director, Infraestructura Urbana y Obras Publicas
Floodplain Coordinator, Santa Cruz County	Director, OOMAPAS
Former Emergency Coordinator of Santa Cruz County)	Director, Desarrollo Urbano
Emergency Management Specialist, Santa Cruz County	Director, Planeación y Control Urbano
Environmental Engineer, International Boundary Water Commission	Director, Protección Civil
Director, Emergency Management, State of Arizona	Director, Comisión Internacional de Limites y Aguas
Hydrologist, Office of Border Environmental Protection	Director, Departamento Integral de la Familia
Member of Board of Directors, Friends of Santa Cruz River	Director, Centro de Comando, Control, Comunicación y Computo
Owner, La Cinderella & Kory's	City Historian
Owner, Bracker's	Resident, Colonia La Colosio

Table 4
List of codes used in interviews

Code Category	Sub Categories
Causes of Flooding	Topography, Urbanization, Extreme Precipitation, Urbanization (Run-off), Poor Infrastructure, Planning Decisions, Poor Maintenance of Canals
Flood Damage	Infrastructure, Housing, Health Concerns, River Contamination, Erosion, Deaths
Constraints to Collaboration	Local Initiative, Funding, Language, Politics (State and Federal) , Personnel Turnover, Increased Border Security, Technical Standards, State Policies, Technical Expertise, Time
Opportunities for Collaboration	Emergency Planning, International, State, Local
Limitations of Institutions	Funding, Personnel, Technical Knowledge, Leadership, Communication, Trust, Relationships
Solutions	Technological (Dams vs. *Gaviones*), Better Data (watershed, precipitation, peak volumes, runoff), Maintenance, Applying for funds, Regulation

In addition to the interviews, I conducted fieldwork in Ambos Nogales during the monsoon season, where in July 31st, 2010 the region was hit with rains equivalent to a 10-year flood event. During my two-month stay in Ambos Nogales, I was able to visit communities affected by flooding and infrastructure sites associated with flood mitigation, and to experience first hand flood responses in both cities.

Chapter 4

BACKGROUND

Ambos Nogales forms an urban region at the border of the United States and Mexico. Located 65 miles south of Tucson, Arizona and 160 miles north of Hermosillo, Sonora (see Figure 8), Ambos Nogales shares a common geography, history, economy, and culture. Today, while still intertwined in every aspect of daily life, the two cities look very different. In this section, I will provide a historical background of Ambos Nogales, and describe what the cities look like today. I will start with the economic development of border cities along the US-Mexico political boundary. Then I will describe the Ambos Nogales region by taking a look at the geography, demography, and historical flooding problems in the region.

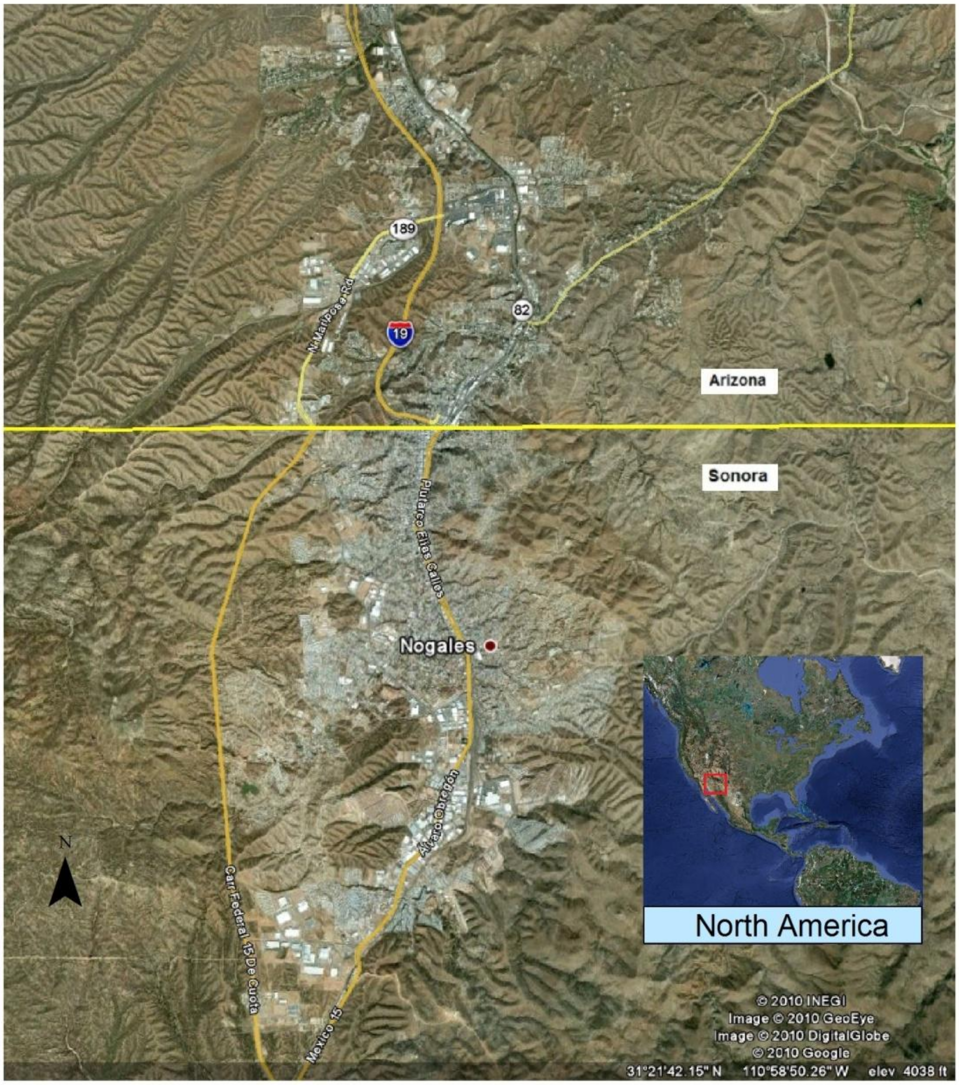

Figure 8. Location of Ambos Nogales.

ECONOMIC DEVELOPMENT ON THE US-MEXICO BORDER

US-Mexico border cities developed along the frontier of two countries with very different politics, economies, and cultures. While the US has been the poster child for open-market economies, Mexico was known for its protectionism and high level of centralization. Today, border cities are fraught with contradictions; for example, the income gap between the US and Mexico is one of the largest income disparities between two countries sharing a border.[2] In spite of the stark differences, cities on both side of the border developed as a result of policy choices meant to promote growth and prosperity in the region.

The Treaty of Guadalupe Hidalgo in 1848, which ended the Mexican-American War, and the Gadsden Purchase in 1853 determined the US-Mexico borderline (Esparza & Donelson, 2009). From 1850 to 1880, the Arizona-Sonora border remained a sparsely settled region. A combination of factors led to the establishment of the first border towns: strategic location, US customs posts, and the railroad industry. The Ambos Nogales valley was a strategic location for transportation of goods between Mexico and the United States. The Santa Cruz River served as a trade and communication route for travelers in both countries. Smuggling between the US and Mexico spurred the US to create a customs post in what is now Nogales, Arizona. The competition of railroad companies for trade routes resulted in the completion of a rail line in Ambos Nogales in 1882. The new rail line connected Ambos Nogales to major commercial markets in Tucson, Arizona and Guaymas, Sonora. Many travelers, particularly men on their way to the copper mines in southern Arizona and northern Sonora, found shelter and bought supplies in Ambos Nogales. The towns were officially founded after the completion of the rail lines: Nogales, Arizona in 1883, and Nogales, Sonora in 1884. While Ambos Nogales continued to grow due to increased commerce along border trade routes, it was the effect of major policy agreements between Mexico and the United States that made the area boom.

The promotion of border cities as tourist spots was one of the first policies to attract people to the border. Border cities were marketed to Americans as the “Old

[2] According to the World Bank, GDP per capita for the United State is US $46,715, and US $10,211 for Mexico (World Development Indicators Database)

Mexico" (Suarez-Barnett, 2002). The border became popular for American tourists who could not visit Europe because of World War I. Red light districts and *cantinas* also became very popular forms of entertainment in border cities. More companies moved business to the border to take advantage of both the American and Mexican markets.

The Bracero Program also directed many Mexican workers to the border region. Established in 1942, the Bracero Program was a binational policy that allowed Mexican workers to legally enter the United States to work on farms left unattended during World War II (Anderson & Gerber, 2008). The program ended in 1964, in part due to strong criticism of the low wages paid to Mexican workers, and reports of their mistreatment at the hands of their employers. But many workers remained in border cities.

To deal with the unemployment that resulted from terminating the Bracero Program, the Mexican government implemented the Border Industrialization Program (BIP) in 1965. The BIP promoted clustering of *maquiladoras* along the border—factories which allowed firms to import product parts into Mexico, use Mexican labor to assemble the parts into a finished product, and export the final product to other markets. Initially the goal was to provide jobs, but *maquiladoras* soon turned into a major economic development strategy to increase worker skills, transfer technological knowledge, and train Mexican managers (Anderson & Gerber, 2008). However, as Kopinak (1996) suggests, *maquiladoras* did not provide the human capital as hoped. Many researchers still debate whether a transition is under way from the old *maquiladoras*, founded on cheap labor, to "new wave" *maquiladoras* that are highly technological and require skilled labor.

Maquiladoras quickly became the most important economic sector in the border region (Kopinak, 1996). Devaluation of the Mexican peso in the early 1980s made Mexican wages even more attractive for foreign companies (Harrell & Fischer, 1985). To stabilize the economy, the government was forced to make two significant policy changes: reduce government spending and incentivize foreign direct investment in Mexico, particularly along the US-Mexico border.

The North American Free Trade Agreement (NAFTA) had immense impacts on border cities. NAFTA formalized the trade relationship between the United States and Mexico, and attracted more Foreign Direct Investment (FDI) along the border, thus boosting the already expanding *maquiladora* industry. By maximizing economic development along the border, Mexico hoped to integrate its economy with that of its developed neighbor.

Growth along the border resulted from three factors: transportation costs, agglomeration, and backward-forward linkages (Hanson, 1998). The new policies of trade liberalization encouraged firms to locate in border cities where the US market was more accessible, and where there was a closer connection between buyers and suppliers. Industry agglomeration encouraged more companies to move to the border. The breakup of the manufacturing belt in Mexico City and the new formation of clusters along the border can be attributed to trade reform between the US and Mexico (Hanson, 1998).

Looking at the history of Ambos Nogales gives us an idea of the processes that shaped the region to be what it is today. The economic development policies implemented at the US-Mexico are one of the root causes of vulnerability and in the region, as described by the PAR framework. The following section examines these dynamic pressures further by looking at the rapid growth of Ambos Nogales, and provides an overview of unsafe conditions in Ambos Nogales.

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ECONOMY AND POPULATION IN AMBOS NOGALES

The economy of Ambos Nogales is based on its status as a major international border crossing. *Maquila* jobs accounted for 60 percent of employment in 2000. In Nogales, Arizona, the retail and service sectors account for most of the city's employment. The city benefits from the daily flow of Mexican shoppers who cross the border to take advantage of products and services not available in Nogales, Sonora. Both cities also benefit from the import and export of products to American markets.

With a combined population of 215,000 people in 2005 (by official records)[3], Ambos Nogales is the largest binational region along the Arizona-Sonora border. Ninety percent of its population lives on the Mexican side, which also has a larger urban extent and a higher population density than its American counterpart. Over the last decades, Nogales, Sonora's population has grown by 4 percent annually, while Nogales, Arizona's population has not grown since the 1980s (see Figure 9). Although natural increase can explain some of the population growth in Nogales, Sonora, migration is a very important factor (Esparza & Donelson, 2009). Table 5 compares Nogales, Sonora's population with other Mexican border cities. Although the smallest of the seven major Mexican border cities, Nogales, Sonora added a third of it population in just ten years.

Thus Nogales, Arizona and Nogales, Sonora are faced with very different dynamic pressures. The Mexican city experiences rapid population growth, in which vulnerability increases because more people are exposed to floods and the capacity of the government to provide services is outmatched by growth. And even though the American side has a stable population, it is directly affected by the rapid growth of its counterpart. More people in Nogales, Sonora means more people and cars crossing the border and

[3] According to several interviews conducted in this study, the population in Nogales, Sonora is between 350,000 and half a million people.

using Nogales, Arizona's infrastructure. It also means more runoff generated from urbanization in Nogales, Sonora which damages infrastructure on the other side. The dynamic pressures in each city are closely interlinked.

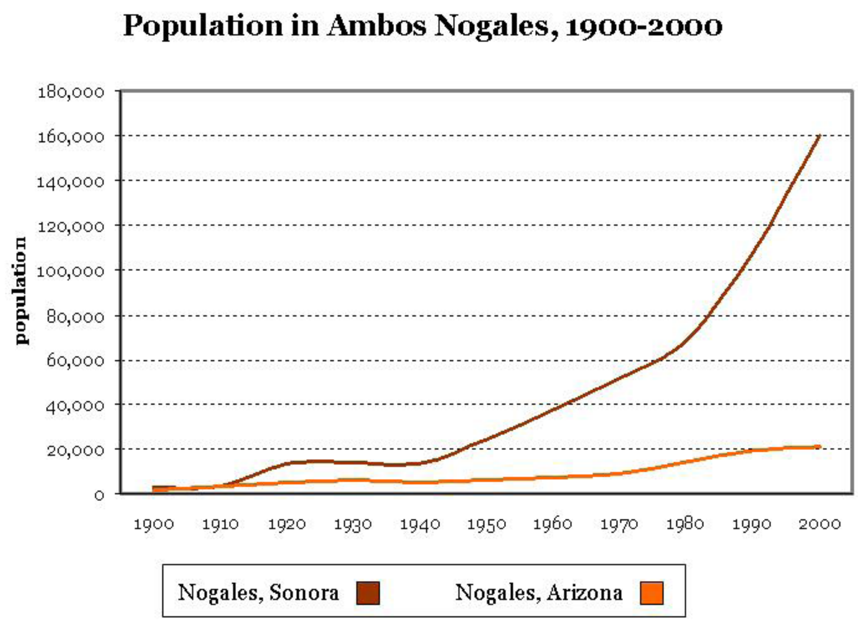

Figure 9. Population growth in Ambos Nogales (Source: US Census 2000; INEGI 200)

Table 5
Population in largest Mexican border cities, 1990 -2000

City	1990	2000	Percent Change	Net Increase
Tijuana	747,381	1,210,820	38%	463,439
Ciudad Juarez	798,499	1,218,817	34%	420,318
Reynosa	282,667	420,463	33%	137,796
Nogales	*107,936*	*156,854*	*31%*	*48,918*
Nuevo Laredo	219,468	310,915	29%	91,447
Matamoros	303,293	418,141	27%	114,848
Mexicali	601,938	764,302	21%	162,364

(Source: INEGI 2000)

Although both cities suffer from a lack of urban planning, we can observe serious deficiencies in infrastructure on the Mexican side (i.e., access to water, drainage and sewage systems, and transportation). Unregulated settlements, *invasiones*, are also commonplace in Nogales, Sonora. A lack of regulation has allowed many migrants to settle on the periphery of the city. This settlement pattern has been observed in other border cities (Arreola & Curtis, 1993), as well as in other Latin American cities. Because the very poor cannot afford to live in regulated settlements that provide urban services, they are forced to settle on the periphery of the city, on land exposed to natural hazards (e.g., landslides, floods). *Invasiones* are rarely regulated. The cost of bringing services to these areas is too high for local governments. In 2000, a third of the houses in Nogales, Sonora did not have in-door water connections, and 10 percent did not have sewage connections (see Table 6). Seventy percent of the houses had floors built with substandard materials (e.g., scraps, palm leaves, cardboard, and metal sheeting); twenty-two percent had walls built with substandard materials.

Nogales, Arizona does not have as many infrastructure deficiencies as Nogales, Sonora: the majority of houses have water, sewage, and electricity. In 2000, 87 percent of households owned at least one car and 97 percent had landline telephone (compared to 58 percent and 47 percent in Nogales, Sonora). However, some areas of the city (those closer to the east side of the border) show similar patterns of irregular settlements, that is, communities with no road access and substandard housing. While almost all of the sub-divisions in Nogales, Arizona are regulated, some houses were still built on steep slopes or located inside the floodplain.

Table 6
Comparing population and housing in Ambos Nogales, 2000

	Nogales, Arizona		Nogales, Sonora	
Population Characteristics	Total	Percent	Total	Percent
Population[a]	20,878	10%	193,517	90%
Age 0 – 14	6,009	29%	53,441	33%
Age 65 +	2,260	11%	4,383	3%
Residents	11,993	57%	111,117	71%
Female-household heads	757	11%	8,274	22%
Adults with no high school education	6,424	52%	62,510	66%
Car owner	5,548	87%	21,330	58%
Telephone owner	6,160	97%	17,245	47%
Renter	2,556	40%	7,263	20%
Average # of people per household	3.45		4.17	
Housing Characteristics				
Roof made of inadequate materials	-	-	26,760	72%
Walls made of inadequate materials	-	-	8,103	22%
Floor made of dirt	-	-	33,816	91%
Without kitchen	108	2%	3,868	10%
Without complete plumbing	103	2%	-	-
Without sewage	-	-	3,906	11%
Without water in house	-	-	25,745	31%
Without water, sewage, and electricity	-	-	1,192	3%

[a] As percent of Ambos Nogales population
[b] A resident is considered someone who has lived at least 5 years in the same house.
[c] Inadequate materials are defined by the Mexican Census as scraps, cardboard, palm, and sheet metal.

FLOODING PROBLEMS

Ambos Nogales sits on top of the Nogales Wash, which runs through the middle of both cities. The Nogales Wash originates in Sonora and flows north to Arizona where it connects to the Santa Cruz River. Ambos Nogales is located within a narrow valley with steep slopes surrounding the city on the east, south, and west (see Figure 10). At its southernmost end, the Ambos Nogales watershed peaks at 1,180 meters above sea level, and at the border the watersheds sits at 620 meters—a change of altitude of approximately 560 meters (or 1,800 feet). The Nogales Wash drains 66 out of the watershed's 72 square kilometers (US Army Corps of Engineers, 2005). Urbanization in the valley increases impervious surfaces and reduces flows channels, thus increasing the overall volume and velocity of runoff (Norman et al., 2010).

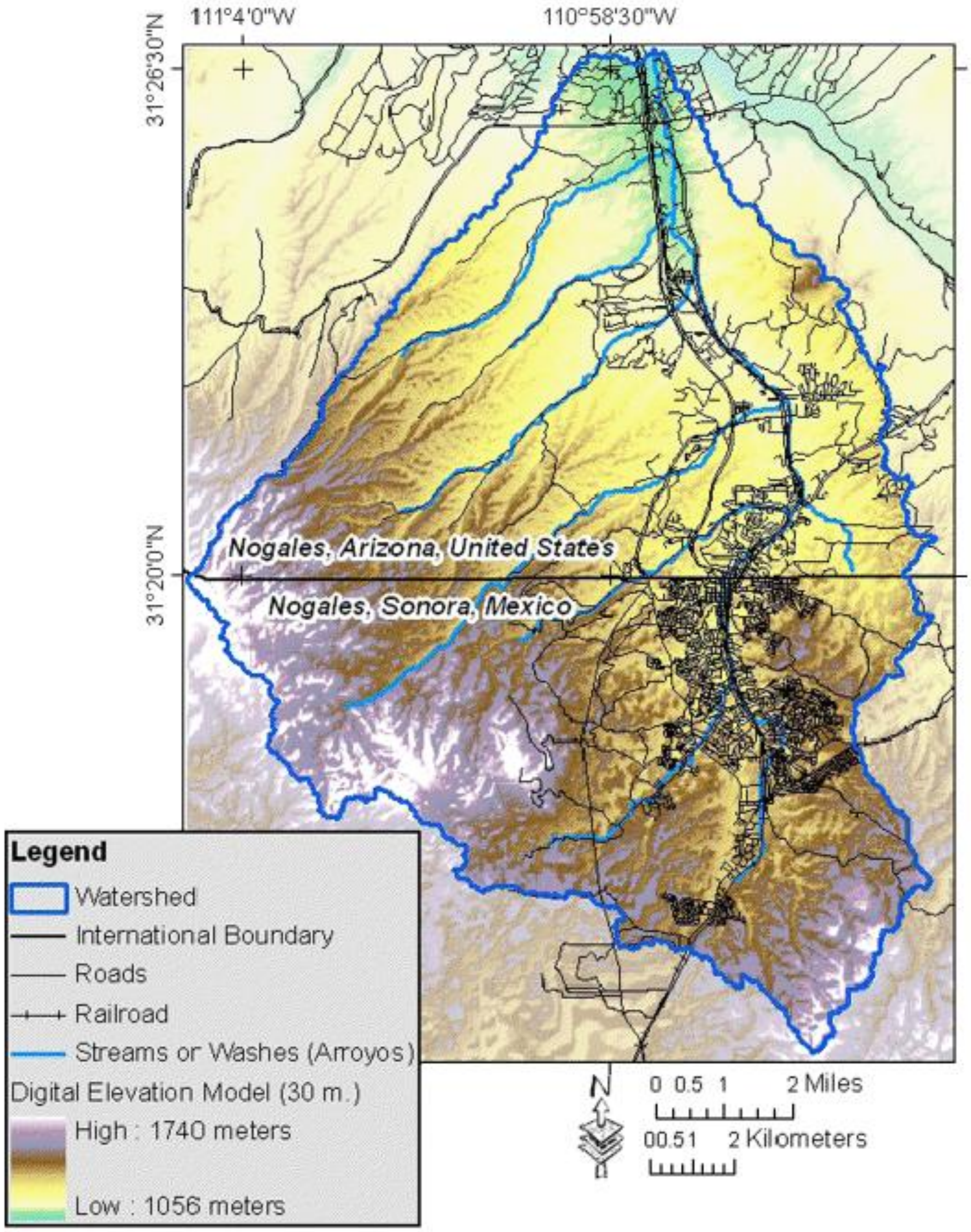

Figure 10. Ambos Nogales Watershed (from Norman et al., 2010)

While dry throughout most of the year, the Nogales Wash comes to life during the monsoon season. From July to September, Ambos Nogales receives up to 50 percent of its annual rainfall (i.e., ~20 inches). This creates major flooding in Ambos Nogales that affects both human health and commerce. Flood risk is intensified by a combination of narrow valleys, steep slopes, high elevations, poor soil filtration, and the fact that the cities are built on top of a wash. Even the most trivial rains can be a cause of concern; storms can result in millions of dollar in economic damages, and sometimes in the loss of lives. Appendix E provides a historical account of flooding in Nogales based on data from periodicals and government reports.

Floods in the 1930s prompted the channelization of the Nogales Wash. When finished in the 1940s, the channel drained the extent of both cities. But today, because of urban growth, the canal only drains a small portion of the Mexican city. On the Mexican side, four kilometers of the canal run underground, through a 4m by 8m tunnel designed to handle the runoff of a 10-year flood event.[4] However, experience has demonstrated that the tunnel can barely handle a 5-year flood event because urbanization has modified the watershed. Waters that cannot be accommodated by the tunnel overflow onto the streets, creating (literally) urban rivers. Landslides, residential flooding, debris accumulation, road and infrastructure damage, and water contamination are some of the recurrent problems caused by flooding.

Nogales, Arizona has also suffered much flood damage to infrastructure. In 2007 and again in 2010, floodwaters lifted two of the cement plaques that make up the floors of the channel, putting at risk the integrity of the whole structure. Underneath the channel runs the International Outfall Interceptor (IOI). The IOI transports the sewage of both

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[4] A 10-year flood event has a 10-percent probability of occurring in any given year. A 5-year flood has a 20-percent probability of occurring in any given year.

cities to a wastewater treatment plant further north. When a plaque fails, the main priority of the city is to protect the IOI. If damaged, the IOI would send 12 million gallons of raw sewage per day into the Nogales Wash and the Santa Cruz River, causing a major environmental disaster.

Figure 11. Flooding in Ambos Nogales, July 2010 (a) Middle-income neighborhood affected by flood. (b) Urban river (c) Runoff going through high income neighborhoods. (d) House with a foundation of tires. (Source: *Protección Civil*)

The unsafe conditions that we now see in Ambos Nogales are the result of the factors discussed above: economic policies to rapidly industrialize the border, the inability of governments to provide services and infrastructure in proportion to the growth border cities were experiencing, and inadequate management of an uneven topography prone to flooding. Figure 11 collects some of the images from floods during the summer of 2010.

Chapter 5

RESULTS

In this chapter, I present the results of calculating the vulnerability of block groups in Ambos Nogales by disaggregating the index into its main components: exposure, sensitivity, and adaptive capacity.

Out of the 99 block groups examined, 47 percent were classified as highly vulnerable, 30 percent as moderately vulnerable, and 22 percent as having low vulnerability. Block groups with highest vulnerability were those most exposed, sensitive, and lacking in capacity to adapt to flooding (Table 7). Exposure is the main factor that differentiates the highly vulnerable blocks groups from the moderately vulnerable block groups. Block groups with low and moderate vulnerability scored similarly on exposure and sensitivity; their adaptive capacity is what divides the two groups. I used Weber-Fechner's Law to divide the vulnerability index into three different classes. The Law produced a robust classification with $p<.001$ using a non-parametric statistical test.

Vulnerability in Nogales, Sonora was slightly higher than in Nogales, Arizona (Table 8). Nogales, Arizona had higher exposure and sensitivity scores; however, these results were not significant ($p = .157$ and $p = .079$, respectively). What makes Nogales, Sonora different from Nogales, Arizona is its lack of adaptive capacity (Figure 12). Figure 13 shows the distribution of vulnerability in Ambos Nogales. Vulnerability is concentrated in the downtown area of Ambos Nogales and decreases as the distance from the border increases. The only exception is La Colosio, a large illegal settlement on the southwest side of Nogales, Sonora.

Table 7
Block groups classified into vulnerability categories

	Total	Exposure	Sensitivity	Adaptive Capacity	Vulnerability
Low	22	0.11	0.26	0.33	0.21
Moderate	30	0.12	0.31	0.47	0.42
High	47	0.30	0.41	0.53	0.78

Table 8
Block groups classified by country

	Total	Exposure	Sensitivity	Adaptive Capacity	Vulnerability
US	11	0.42	0.55	0.28	0.51
MEX	88	0.34	0.40	0.62	0.55

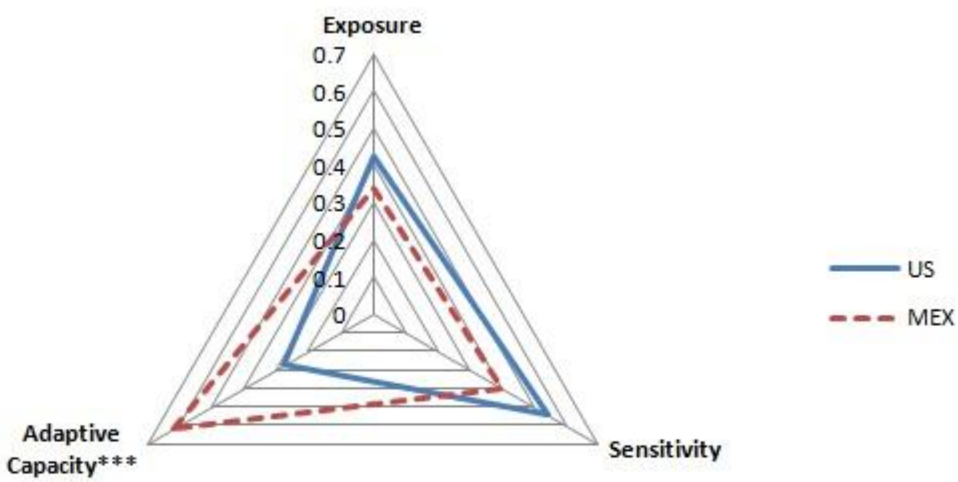

Figure 12. Nogales, Mexico and Nogales, US by vulnerability dimensions. The asterisks indicate significance of the vulnerability dimension in differentiating vulnerability in the two cities (*p<.0.05, **p<0.01, ***p<0.001).

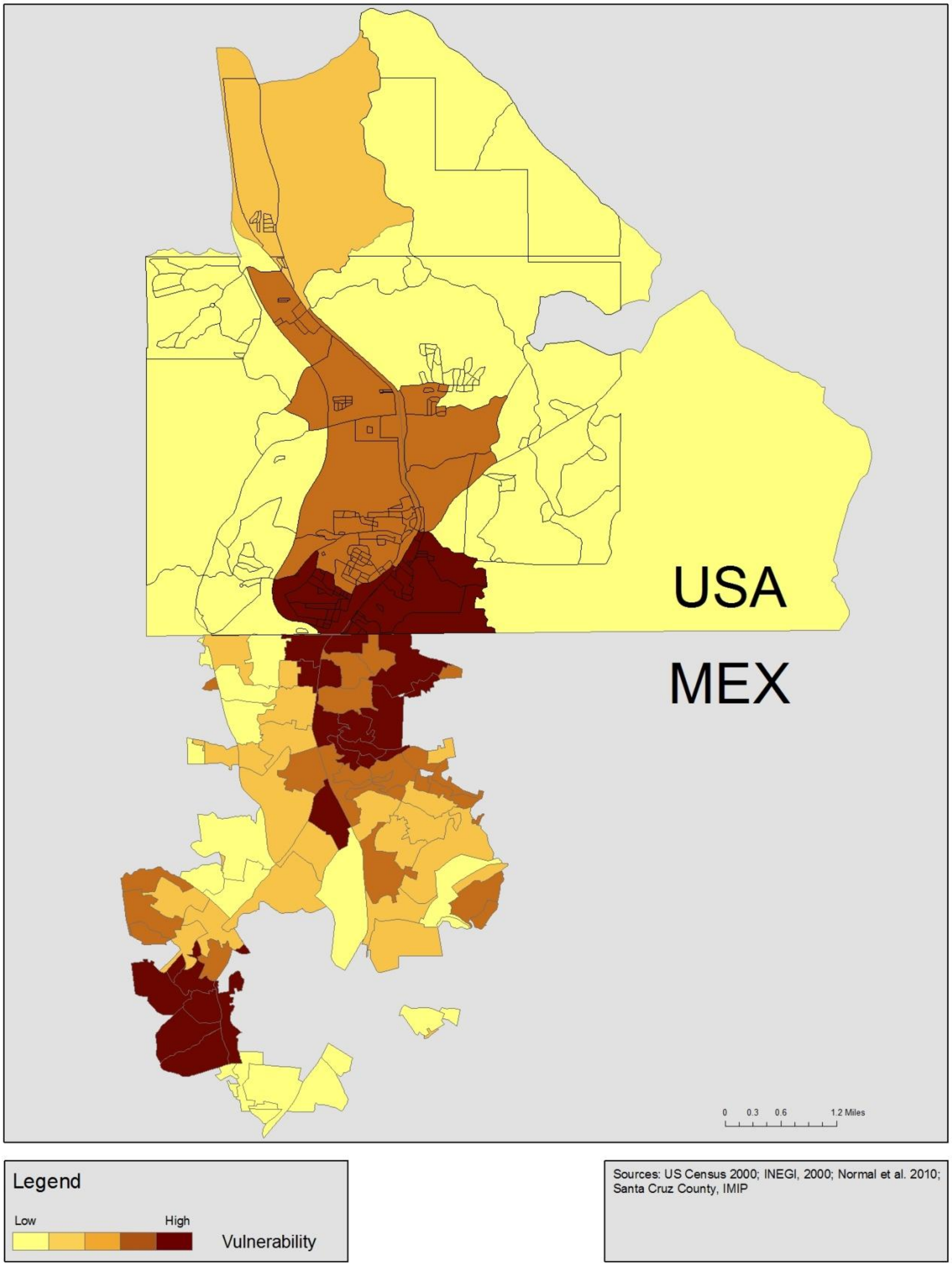

Figure 13. Distribution of vulnerability in Ambos Nogales.

EXPOSURE

Vulnerability Classes

Low and moderate vulnerability classifications had very similar exposure scores (0.11 and 0.12), while the high vulnerability classification had an exposure score of 0.30 (see Table 7). To explore the exposure dimension, I disaggregated the exposure index into its three indicators, percent of block group in floodplain, percent of block groups at high risk of runoff, and population density (see Figure 13). Runoff risk is what explains higher exposures; that is, block groups classified as being highly vulnerable are more likely to be exposed to runoff risk than block groups classified as having low or moderate vulnerability ($p < .001$).

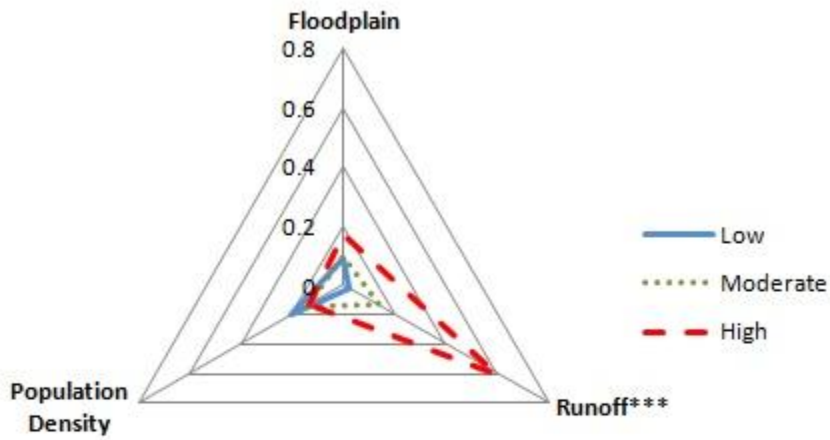

Figure 14. Vulnerability classification by exposure indicators. The asterisks indicate significance of exposure indicators in differentiating vulnerability between block groups (*p<.0.05, **p<0.01, ***p<0.001).

Nogales, Arizona vs. Nogales, Sonora

Exposure was slightly higher in Nogales, Arizona. However, this is attributable to the fact that the floodplains of the cities do not match: the American floodplain is for a 100-year flood and the Mexican floodplain for a 25-year flood. If the floodplains for both cities were similar, then exposure would likely be nearly identical for both cities. Higher population densities explain some of the increased risk of exposure on the Mexican side. Figure 15 shows the distribution of exposure in Ambos Nogales. Exposure is concentrated in the downtown sections of both cities, where the Nogales Wash crosses the international border. The map clearly shows that exposure decreases with distance from the downtown area. The only exception to this is the southwestern area of Nogales, Sonora, where the Las Chimeneas arroyo runs. This arroyo is the biggest tributary of the Nogales Wash, so when the Wash floods, the arroyo also floods.

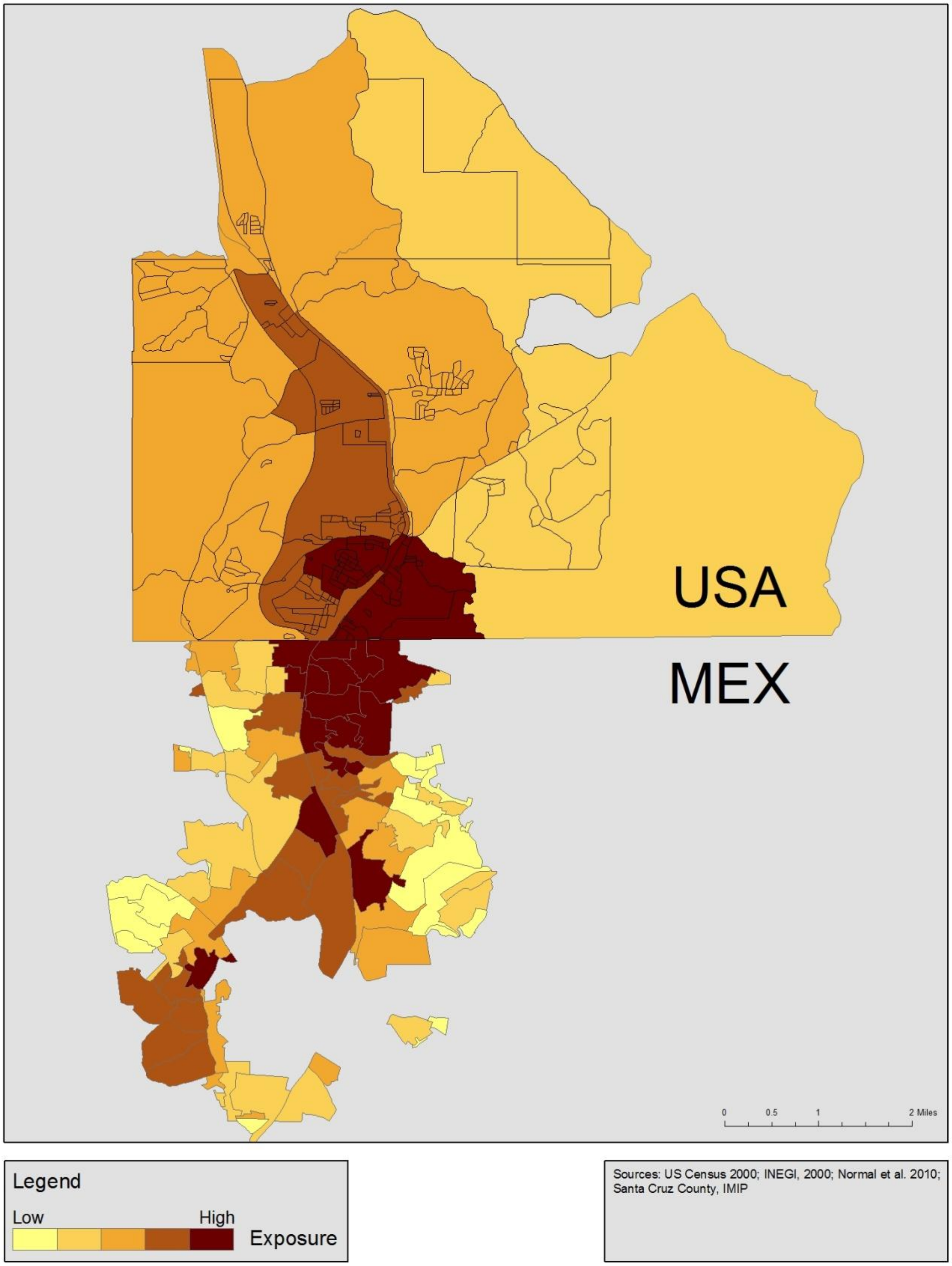

Figure 15. Distribution of exposure to floods in Ambos Nogales.

SENSITIVITY

Vulnerability Classes

Sensitivity–indicator scores were similar for the low and moderate vulnerability classes. Housing conditions was the only indicator that significantly differed among all three vulnerability classes; thus making it the most important indicator for determining sensitivity to floods (Figure 16).

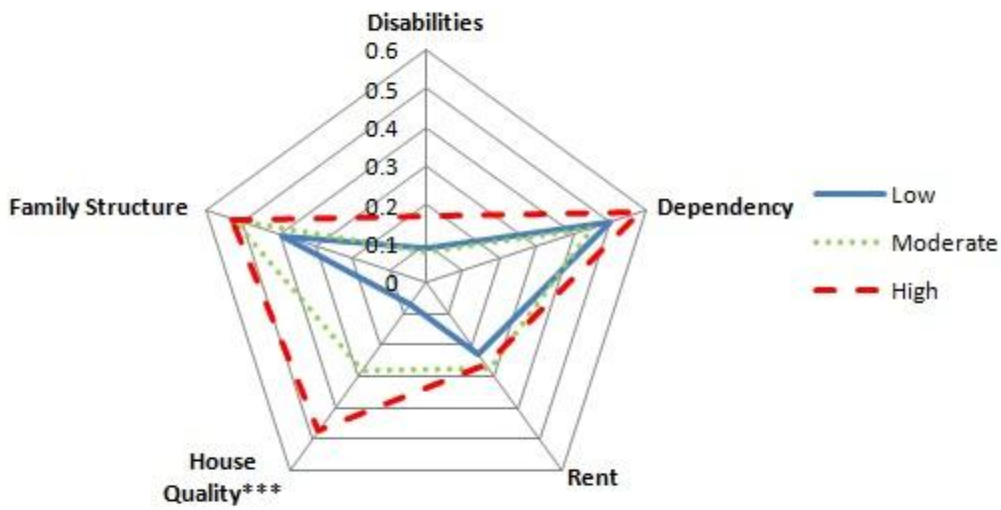

Figure 16. Vulnerability classification by sensitivity indicators. The asterisks indicate significance of sensitivity indicators in differentiating vulnerability between block groups (*p<.0.05, **p<0.01, ***p<0.001).

Nogales, Arizona vs. Nogales, Sonora

Nogales, Arizona is more sensitive to flooding than Nogales, Sonora (see Table 8). This seems counterintuitive because we expect that Nogales, Sonora, being the poorer city, will be more sensitive to floods. When we disaggregate the indicators (Figure 17), we see that the cities are sensitive to floods for very different reasons. Block groups in Nogales, Arizona are more likely to have people who need special attention during a flood, (i.e., children, elders, and people with disabilities). Block groups in Nogales, Sonora are more likely to have houses in poor condition that can be damaged during a flood. They are also more likely to have only one parent in the household. Interestingly, more people in Nogales, Arizona rent their house than in Nogales, Sonora. Figure 18 shows the block groups where sensitivity in Ambos Nogales is concentrated.

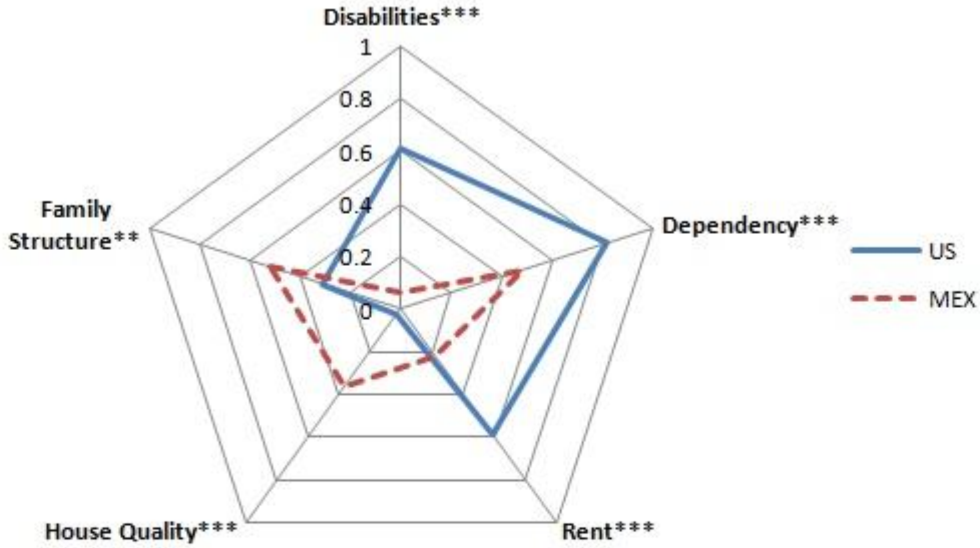

Figure 17. Nogales, MEX and Nogales, US by sensitivity indicators. The asterisks indicate significance of sensitivity indicators in differentiating vulnerability in the two cities (*p<.0.05, **p<0.01, ***p<0.001).

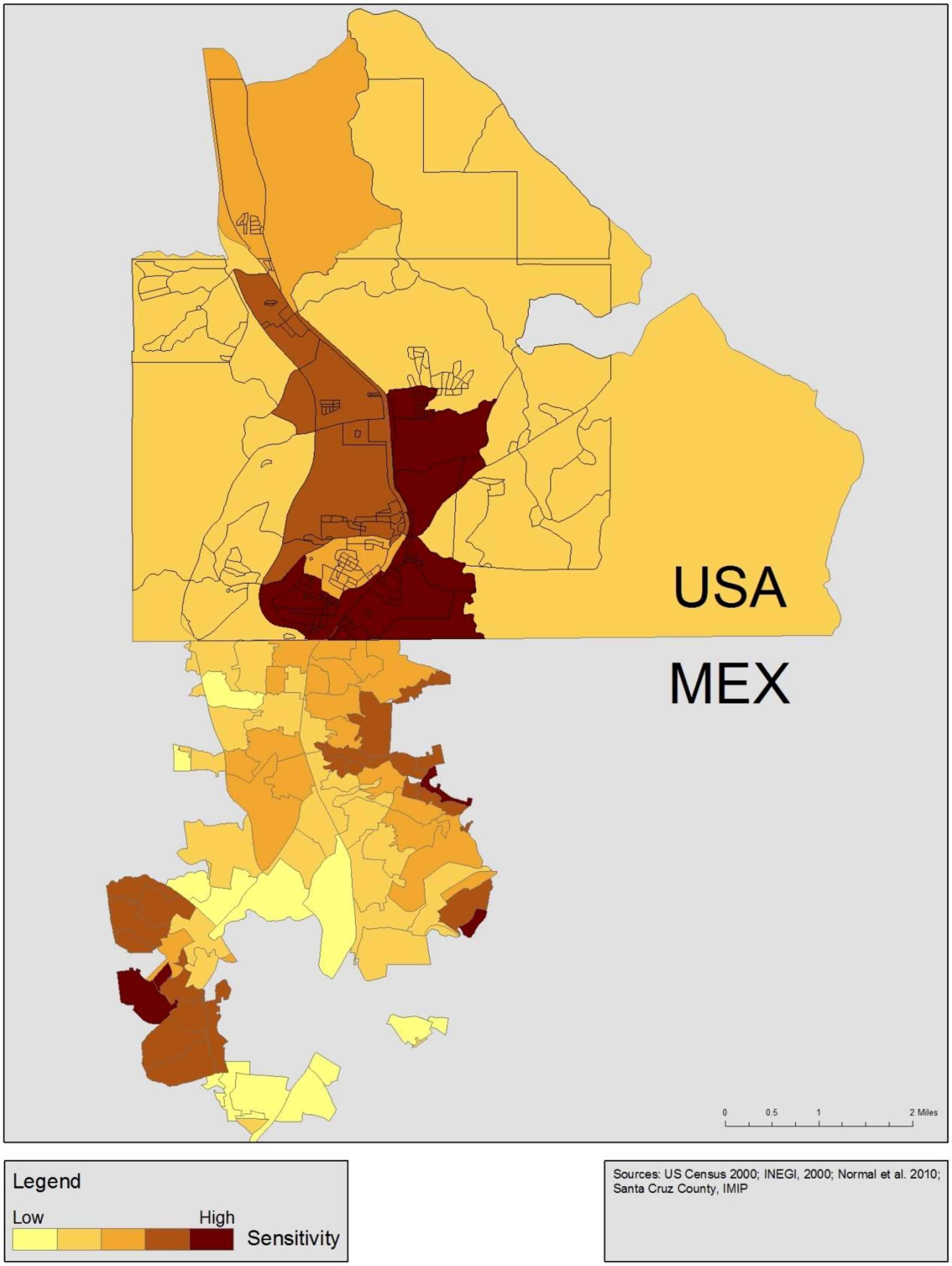

Figure 18. Distribution of sensitivity floods in Ambos Nogales.

ADAPTIVE CAPACITY

Vulnerability Classes

The low vulnerability class is most significantly different from the moderate and high classes in terms of adaptive capacity (Figure 19). Block groups classified as having low vulnerability are more likely to have residents who own a car and a telephone, have completed high school, and have a full time job. The most marked differences between the high and moderate vulnerability block groups are the car and education indicators. Block groups with high vulnerability are less likely to have residents who own a car or have completed high school.

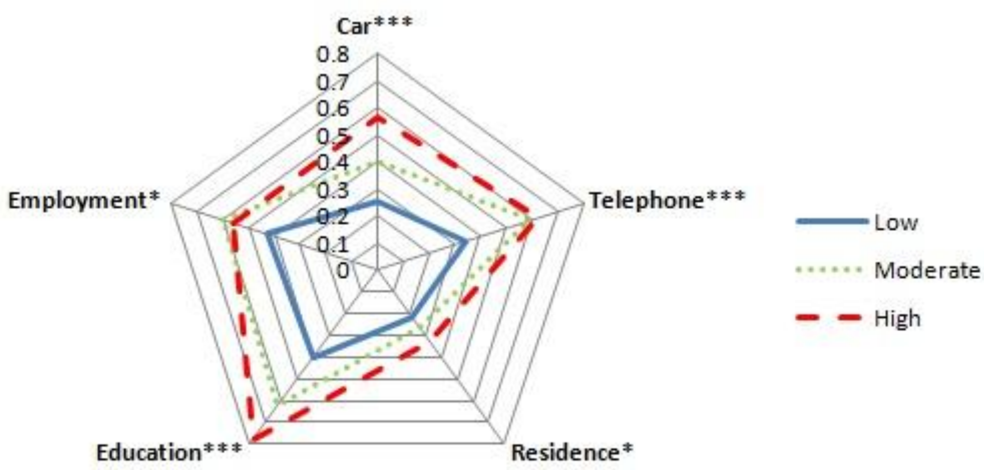

Figure 19. Vulnerability classification by adaptive capacity indicators. The asterisks indicate significance of adaptive capacity indicators in differentiating vulnerability between block groups (*p<.0.05, **p<0.01, ***p<0.001).

Nogales, Arizona vs. Nogales, Sonora

The biggest difference between Nogales, Sonora and Nogales, Arizona is in their adaptive capacities (Figure 20); thus, adaptive capacity is the most significant factor in differentiating vulnerability in Ambos Nogales. People in Nogales, Sonora are less likely to own a car and a telephone, have completed high school, or have a full time job. The only indicator in which the US side scored higher than the Mexican side is the residence indicator: people on the US side are less likely to have lived in the same house for at least five years than those on the Mexican side. I expected Nogales, Sonora to score higher in this indicator because of the "floating population" that characterizes the Mexican side of border cities. The residence indicator is congruent with the rent indicator (used to measure sensitivity), in which the US also scored higher (i.e., if a lot of people do not live in the same house for more than five years, then one would expect a higher percentage of renters in the city, and vice versa).

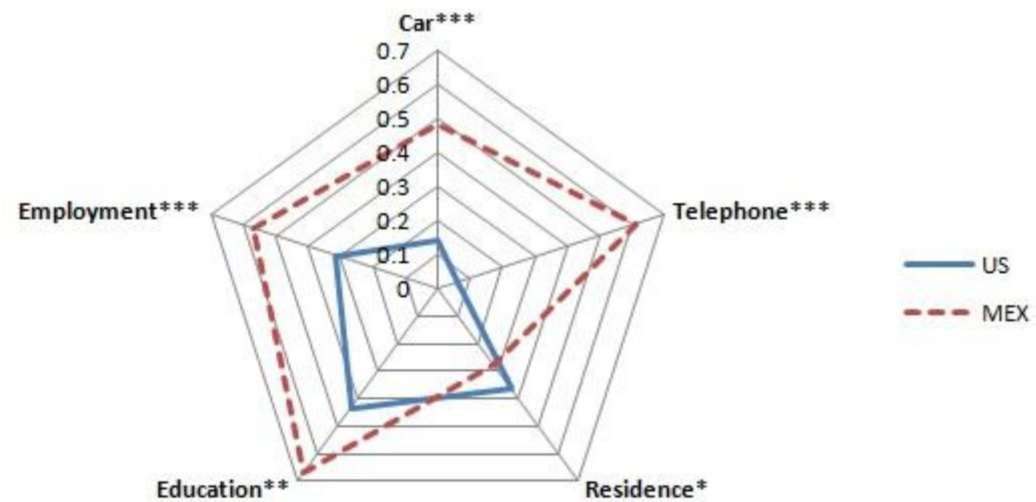

Figure 20. Nogales, MEX and Nogales, US by adaptive capacity indicators. The asterisks indicate significance of adaptive capacity indicators in differentiating vulnerability in the two cities (*p<.0.05, **p<0.01, ***p<0.001).

Figure 21 shows the distribution of adaptive capacity in Ambos Nogales, and here we can observe the stark differences between the two countries. Also, we can observe that block groups around the periphery of the city in Nogales, Sonora are low in adaptive capacity as compared to block groups in the center.

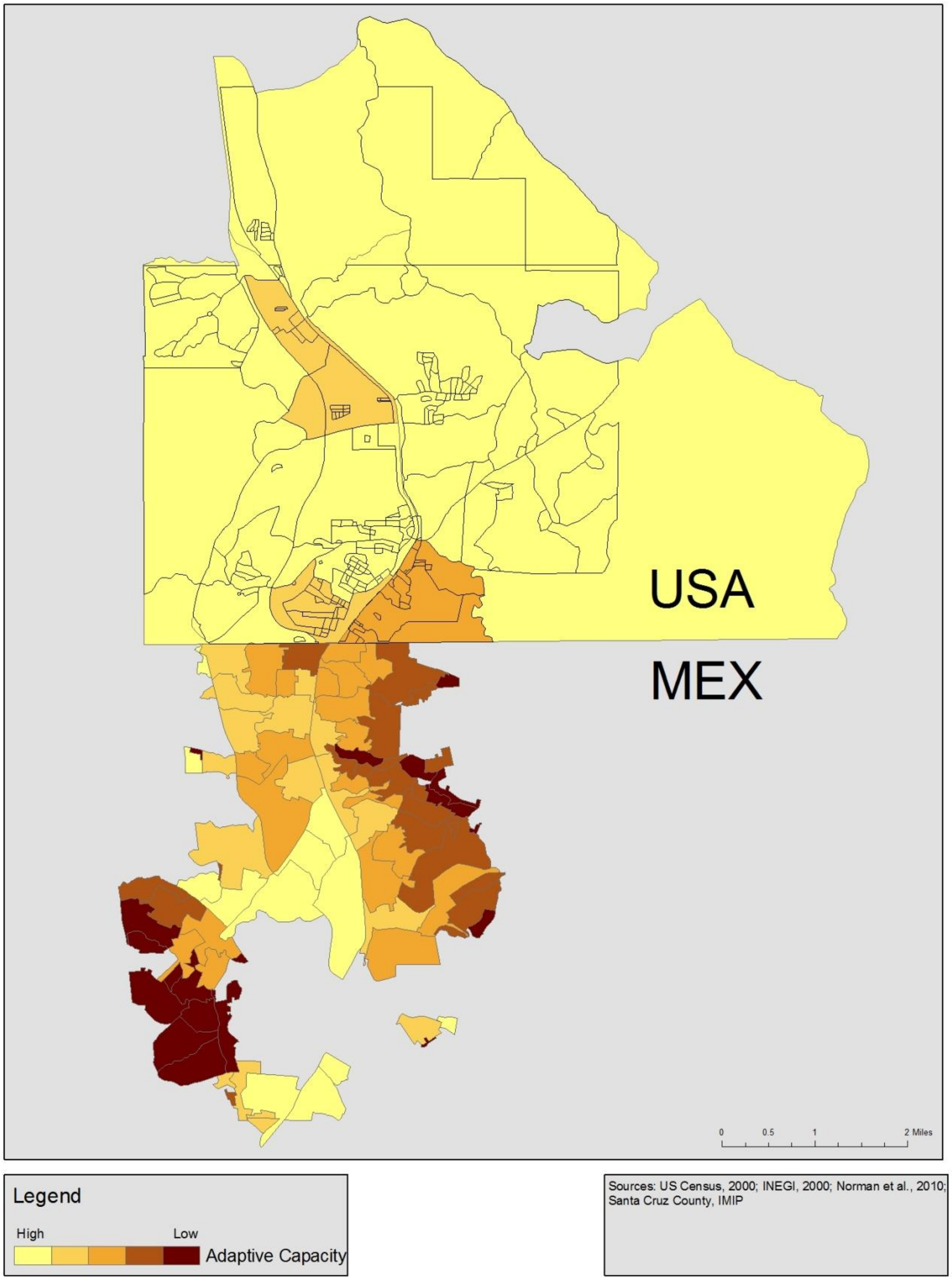

Figure 21. Distribution of adaptive capacity in Ambos Nogales.

COMPARING THE INDEX

To test the validity the vulnerability index, I compared it to a marginalization index developed by the *Consejo Nacional de Población* (CONAPO) in Mexico. CONAPO is an agency of the Mexican federal government whose mission it is to make sure that the benefits of social and economic development are fairly distributed among the population. The *Índice de Marginalización Urbana* uses census data at the block group level for all cities in Mexico. The index is composed of 11 indicators that include:

- mortality rate
- percent of women aged 12 to 17 with at least one child
- percent of population covered by healthcare
- percent of population living below the poverty line
- percent of population without a primary education
- percent of population without a refrigerator
- percent of population without a computer
- percent of population without a high school education
- percent of houses with dirt floors

Percent of population without a high school education is the only indicator that is measured exactly as I measure it. Unfortunately, because no similar index exists for the American block group, I only compared the Mexican block groups.

The correlation between the vulnerability index and the CONAPO index was high; $R^2 = 0.384$, and thus $R = 0.62$ ($p < 0.001$). This shows a strong positive relationship between the two indices. The classification of vulnerability classes (low, moderate, and high) also has a strong relationship with the classification of marginalization by CONAPO (very low, low, moderate, high, and very high). Since the data was ordinal, I used Spearman's rho to check for correlation (rho = .602, $p < .001$).

Finally, I wanted to see how well the vulnerability index could predict marginalization in Ambos Nogales by using a simple multi-variate regression equation:

$$CONAPO = ß_1 \text{(Sensitivity)} + ß_2 \text{(Adaptive Capacity)} + C_0 \qquad (6)$$

where CONAPO is the marginalization index, $ß_1$ and $ß_2$ are the predictor coefficients for Sensitivity and Adaptive Capacity, and C_0 is a constant. I decided to leave Exposure out of the equation because its indicators do not measure socio-economic data. This would, I expect, add a bit more prediction power to the equation.[5] Both Sensitivity and Adaptive Capacity had positive coefficients ß, which suggests that block groups with high sensitivity to floods and low adaptive capacity are also more likely to be marginalized block groups. The variables do a really good job of predicting marginalization (R^2 = .846, R= .920, $p < .001$). This result shows that marginalization is closely related to the indicators I selected to measure sensitivity and adaptive capacity (Figure 22).

[5] In a regression that did include Exposure, the value for its ß was -.016 which suggests that as Exposure increases marginalization decreases. This is the result of block groups in the middle of the city being highly exposed to floods but less marginalized than block groups in the periphery of the city. However, Exposure was not statistically significant when included in the model (p = .717).

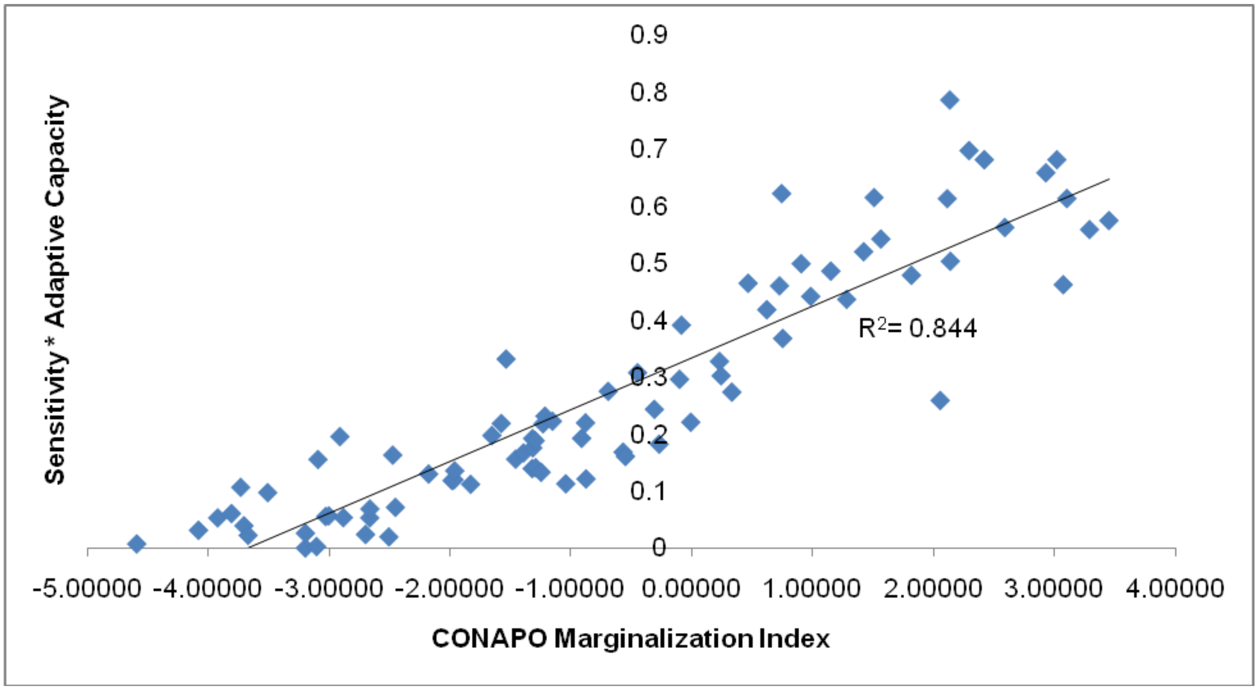

Figure 22. Correlation between CONAPO, Sensitivity, and Adaptive Capacity

Chapter 6

INSTITUTIONS

PERSPECTIVES ON FLOODING

Public officials from both sides of the border agree that exposure is the most important factor in vulnerability in the region. This is reflected not only in their weighting of vulnerability dimensions (see Figure 7), but in their individual interviews. All interviewees acknowledged that flooding in the city results from the topography of the region, the expanding urban footprint of Nogales, Sonora, and the fact that the infrastructure on both sides cannot handle the volume of water that the watershed creates. “Time to flood is getting shorter, and volume is increasing. This means that peak volumes are getting higher and more water goes to the streets and not the channel,” affirms the Floodplain Coordinator for Santa Cruz County. To make matters worse, rains seem to be more intense and frequent, as the Director of *Control Urbano* in Nogales, Sonora notes: “It has rained like no other year; I don’t know if it’s climate change or what, but I have never seen so much rain.” The risk of flooding is perceived to be increasing and expected to continue to increase. The interviewees in both municipalities underscored the very limited resources they have to deal with floods. State and federal governments have done little to solve the problem.

Perspectives on flooding from Nogales, Arizona

Public officials on the American side are very worried about two things: the growth of Nogales, Sonora, and the condition and capacity of the current canal. The city planner notes that, “The other side does not have city limits like we do; they continue to expand and develop more land. This creates a problem for us.” In fact Nogales, Sonora just developed its *Plan de Desarrollo Urbano* last year. This is the city’s first plan for growth and land-use in all of its history. The plan is still waiting for approval from the municipality. In spite of the new plan, the city engineer of Nogales, Arizona worries about the quality of infrastructure and public works on the other side, where he has observed structures built on top of *arroyos*, and hills that are cut into and left unprotected from erosion.

But the biggest worry for city officials in Nogales, Arizona is the condition of its own canal. The canal, built in the 1930s, is in dire need of repairs. City officials say that they do not have the resources necessary to maintain the canal. “Some point to the US Army Corps of Engineers, some to the County, some to the International Boundary Water Commission [because this is] … a binational issue, and some to the city,” reports the city engineer, “ but no one wants to take responsibility.” The IBWC paid part of the cost to repair damages that the canal suffered in the floods of 2007 and 2010. However, the main priority for the IBWC is the IOI, the sewage line that runs underneath the canal. So they only repair what is necessary to protect the IOI.

City officials have tried to bring state and federal attention to the condition of the canal, but their requests have not yielded any results. The US Army Corps of Engineers (ACE) has done no more than help the city with technical studies. The city engineer of Nogales, Arizona recently submitted the city’s application to a program that requires ACE to fix the canal if it is damaged during a flood. However, the application was denied because the canal is too old and the city cannot provide the maintenance required by ACE. The Arizona Department of Emergency Management (ADEM) and the Federal Emergency Management Association (FEMA) can only intervene after a disaster. “This is the dilemma we face. We have to wait for a disaster to get help,” the engineer concludes.

Perspectives on flooding from Nogales, Sonora

There is no official agency responsible for flooding in Nogales, Sonora. The planning and public works departments of the municipality, and the local branch of the state agency for emergency management (*Protección Civil*) take most of the responsibility. Mexican officials assert that, structurally, the canal is in great condition, but they acknowledge that the canal does not have the capacity to handle a 5-year flood event. Their biggest concern, as explained by the Director of Public Works, is the economic and material losses caused by the floods, "We cannot continue like this. We spent $1,600,000 MEX in preventatives measures. Now we estimate $70,000,000 MEX in damages from these past rains. The costs of repairing infrastructure and cleaning the streets are just too much for the city."

When hard rains hit, like they did in the month of July 2010, all of the municipal agency directors meet to develop a plan of recovery. Declaring the city a disaster zone is one of the top strategies. However, in 2010 they only got an emergency-zone declaration. The local director of *Protección Civil* explains that the federal government already had its hands full with all of the disasters caused by rain in Mexico during the summer.

The director of the *Departamento Integral de la Familia* gives another explanation. She notes that to be declared a disaster zone, a city needs to have a certain number of people in the *albergues* (shelters). She explains, "Even though we estimated that the number of affected people was high, they either stayed at a family or friend's house, moved to another place, or outright refused to abandon their homes during the flood." The city did not have enough people in the shelters; this weakened their petition to be declared a disaster zone.

Protección Civil, established in 2000, is the local branch of the state agency responsible for protecting people from disasters in Nogales, Sonora. Because the agency is new, it has few resources to do its work. The director in Nogales, Sonora explains what is expected of the agency, "The government thought we would have an immediate impact in reducing disasters in Mexico. As a newly formed organization they wanted us to run when we were barely learning to walk." Because of this, *Protección Civil* sees collaboration as extremely important for accomplishing its goals.

COLLABORATION

International collaboration between American and Mexican organizations is crucial to address problems at the border (Morehouse, 2003; Clough-Riquelme, 2005; Lara-Valencia et al., 2008). But local relationships between cities that share a border may be even more important to solving their problems (Rodríguez & Hagan, 2001).

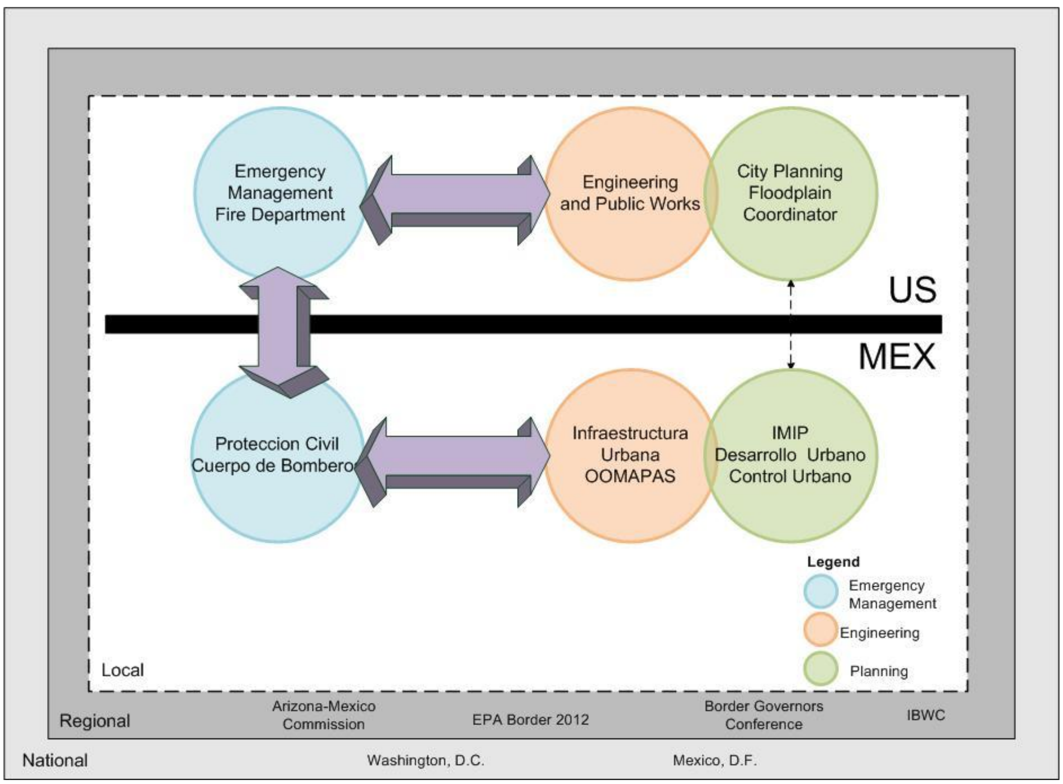

Figure 23. Collaboration in Ambos Nogales.

Figure 23 depicts current collaboration between government agencies in Ambos Nogales. Currently, there are strong links between emergency management, engineering, and planning agencies on each side of the border, but strong links only between emergency management *across* the border.

Collaboration on water and flood management occurs only during emergencies. Only those interviewees working in some aspect of emergency management (i.e., firefighters and police officers) were able to name their counterpart on the other side of the border.[6] In fact, collaboration during emergencies is something many local officials are very proud of. When the La Paz Agreement[7] was signed in 1983, it formalized the existing collaboration between Mexican and American local authorities. One of the first outcomes of the Agreement was a bi-national plan for the management of chemical substances along the border. This plan, which established the protocol for managing chemical spills, was implemented in all border cities with facilitation from the EPA. Local officials in Ambos Nogales wanted to extend the plan to include all hazards in their area, but the EPA refused to provide funding to do so. "We created the plan anyways. It was signed by the mayors and fire chiefs of both cities. The EPA eventually liked the idea and supported us. Our plan was the first all-hazards bi-national plan," stated the ex-director of Emergency Management in Santa Cruz County. The plan became a model of collaboration for other border cities and it has been widely recognized as an example of successful border collaboration by local, state, and federal officials. Even the US Department of Defense recognized the importance of Ambos Nogales's collaboration—the plan was featured in the magazine *Ágora*, a publication supported by the US Northern Command.

[6] Some respondents, from both sides of the border, refer to the Emergency Management on the American side, as *Protección Civil* of Nogales, Arizona.

[7] The La Paz Agreement, signed by the US and Mexican national governments, serves as the legal basis on which federal agencies can engage in collaboration initiatives for the protection and improvement of the environment on the border.

Despite Ambos Nogales's success with collaborative emergency management, collaboration has not made headway in city planning and engineering, functions that could reduce the risk of flooding in the first place. When asked about cross-border collaboration, the director of Public Works in Nogales, Sonora responded, "That is not my topic. That is a topic of *Protección Civil*." Similarly, his counterpart on the American side responded that, "We have been very timid about collaboration."

However, local Mexican agencies do collaborate across the border with organizations like the EPA, the University of Arizona, Arizona State University, the Border Environment Cooperation Commission (BECC), and the Arizona-Mexico Commission (see Figure 23), and this collaboration provides Nogales, Sonora with technical studies and tools that can help them manage their watershed (e.g., Norma et al., 2010; Lara-Valencia & Díaz-Sotomayor, 2010). Another product of collaboration is the retention dams currently being constructed in Mexico, jointly funded by the EPA through its Border 2012 program and *Consejo Nacional de Agua* (CONAGUA). Ironically, despite these collaborations that reduce the impact of flooding in Ambos Nogales, the US Border Patrol exacerbates flooding impacts by constructing a wall for security purposes—highlighting how the conflicting goals of institutions at state, regional, and national levels can increase vulnerability at the local level.

While emergency management officials have established a relationship across the border that significantly improves emergency-response outcomes, cross-border collaboration is the exception and not the rule in Ambos Nogales. In the following section, I discuss why planners and engineers have not emulated the success of emergency managers, and why even emergency managers are having trouble maintaining the relationships they have already established.

CONSTRAINTS TO COLLABORATION

Standards and procedures

All public officials talked about how the lack of shared standards makes collaboration difficult (see Table 9). The difference in how the floodplain is measured and defined is one example. But American officials also worry about standards for Mexican infrastructure. For example, the flood maps in Nogales, Arizona do not take into consideration water retained in basins on the Mexican side; this is because the basins do not meet the US ACE construction standards (G.L., personal communication, July, 2010). Even when conducting a collaborative study there are technical standards and processes that need to be addressed. "The question is how do we combine methods," as an official from Nogales, Sonora stated.

Table 9

Summary of interview responses regarding collaboration

	Constraints to Collaboration				
Nogales, Sonora	Resources[a]	Turnover[b]	International Relationship[c]	Language[d]	Standards[e]
Planning	x		x		
Emergency Management	x	x	x	x	
Infrastructure	x		x		x
Nogales, Arizona					
Planning		x	x	x	x
Emergency Management	x	x	x		
Infrastructure	x	x	x		x

[a] Refers to the financial and human resources available to city government
[b] Refers to changes in personnel
[c] Refers to the context of the cities being located at an international border
[d] Refers to the ability of city officials to speak another language (i.e., Spanish vs. English)
[e] Refers to the difference in technical standards between American and Mexican engineers and planners

Personnel Turnover

The constant turnover of government personnel in Nogales, Sonora was also identified as a major obstacle for collaboration. A planning official in Nogales, Arizona noted, “Not only is there a change in leadership, but sometimes the whole department is changed.” In Mexico, local government officials are reelected every three years, which creates a problem because there is no continuity to previously established projects. To attenuate this issue, the Mexican local governments are now establishing *Institutos Municipales de Investigación y Planeación* (IMIP). IMIPs work as consulting agencies to the local governments; they do the research and planning, and the local government is in charge of plan implementation. The directors of IMIPs are reelected every three years as well, but their reelection occurs during the midterm of the local governments, and they are elected by a board of citizens.

However, even though personnel turnover was identified as a constraint to collaboration in Nogales, Arizona, there is really no evidence that there would be more collaboration if this were not the case. For emergency management officials, however, personnel turnover actually has hampered collaboration between the cities. The ex-director of Emergency Management for Santa Cruz County stated that, “What we have been able to accomplish is because of the relationships that have been established throughout the years. Everything starts with personal relationships. When a new director comes […] we don’t know what to expect. But he is informed of the relationship that was previously established, and we have no problem.” In fact, this is not always the case. The director of *Protección Civil* explains that when a new fire chief came to Nogales, Arizona, he was not interested in any collaboration. “We have a bi-national plan for emergency situations, but if there is no communication between the parties we cannot use it. It was not until a fire broke in April 2010 that we received a call.” Officials in

Protección Civil pointed out that although collaboration still occurs, communication has changed since a new director took over the emergency management department in Santa Cruz County. The emergency management department went from five people to just one. Its new director oversees two departments, and he cannot speak Spanish.[8] New personnel who are not originally from Ambos Nogales or not familiar with border cities also represent a constraint to collaboration.

Lack of resources

Public officials also talked about the lack of personnel and finances to establish effective collaboration. Collaboration requires time and money, which local governments do not have. Participating in activities of the US-Mexico Environmental Program (Border 2012), the Arizona-Mexico Commission, and the Border Governor's Conference sometimes requires significant expenditures because the meetings are held in different cities along the border.

International relationship

Collaboration is also constrained by international policy that affects the border and over which local actors have no control. The most recent example is the passage of S.B. 1070—an Arizona law that makes it a crime for an alien to be without proper documentation of their legal residency in the US at any time. Many Mexican cities protested the law and refused to participate in cross-border activities (e.g., the Border Governor's Conference of 2010 was cancelled because of it).

Ambos Nogales's local government agencies have had very limited resources to deal with the planning and infrastructure that the region requires. Their lack of institutional capacity to administer and manage urbanization has contributed to the unsafe

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[8] Despite several attempts to contact the Director of Emergency Management, I was not able to get an interview with him.

conditions now present in Ambos Nogales. Even though local officials see collaboration across the border as a potential tool for increasing adaptive capacity, collaboration remains limited to disaster response. Institutions at the state and national levels implement policies at the border that not only increase unsafe conditions at the local level, but can actually increase the hazard itself, as demonstrated by security-driven policies that led to the construction of the flood-causing border wall. These findings support the assumption of the PAR framework that institutions are not neutral, but either diminish or increase unsafe system conditions.

Chapter 7

CONCLUSION

DISCUSSION

The relative importance of exposure, sensitivity, and adaptive capacity in determining vulnerability has been debated in environmental-change research. The risk-hazard approach emphasizes exposure as the most important determinant of vulnerability (Burton et al., 1978). Political-ecology and political-economy approaches assert that vulnerability varies according to the socio-economic characteristics of a system (Wisner et al., 2004), and emphasize studying the "pre-hazard" condition of a system. Most recent vulnerability frameworks emphasize the multiple scales at which a system is vulnerable, and the role of institutions in affecting vulnerability (Turner et al., 2003). This case study in Ambos Nogales does not challenge the assumptions built into each approach, but makes the case that vulnerability research can be enriched by combining approaches.

I found that when Ambos Nogales is analyzed as a region, exposure is the most important determinant of vulnerability, which supports the line of research of the risk-hazard approach. However, exposure is not just an external factor that acts on a system. Exposure can be created within the system. This is clearly evident in Ambos Nogales, where the international border wall has increased the risk of flooding in downtown Nogales, Sonora.

When vulnerability was compared between Nogales, Sonora and Nogales Arizona, we observed that even though exposure was constant between the two cities, adaptive capacity was not—making the Sonora side more vulnerable to floods than the Arizona side. Social and institutional characteristics of Nogales, Sonora lowered its adaptive capacity. This finding supports the political-ecological assumption that the poorest (in this case those living on the Mexican side) are also the most vulnerable because they have less access to resources (Pelling, 2003; Wisner et al., 2004).

Vulnerability to flooding in Ambos Nogales is explained by historical factors that created unsafe conditions (i.e., increased the natural runoff of the watershed) and limited the adaptive capacity of city governments. Capacity is limited not only by financial and human resources, but by the implementation of national policies that affect the border but over which border communities have no control of. Lack of adaptive capacity is particularly a problem for the local institutions charged with city management. Border cities are at the meeting point of multiple dynamic pressures—rapid urbanization, globalization, migration, and international security—that overwhelm their capabilities. Regional, national, and international organizations have vested interests in the border, and when higher-level policies ignore local needs the result is often an increase in local vulnerability. In Figure 24 I summarize the progression of vulnerability in Ambos Nogales through the PAR framework.

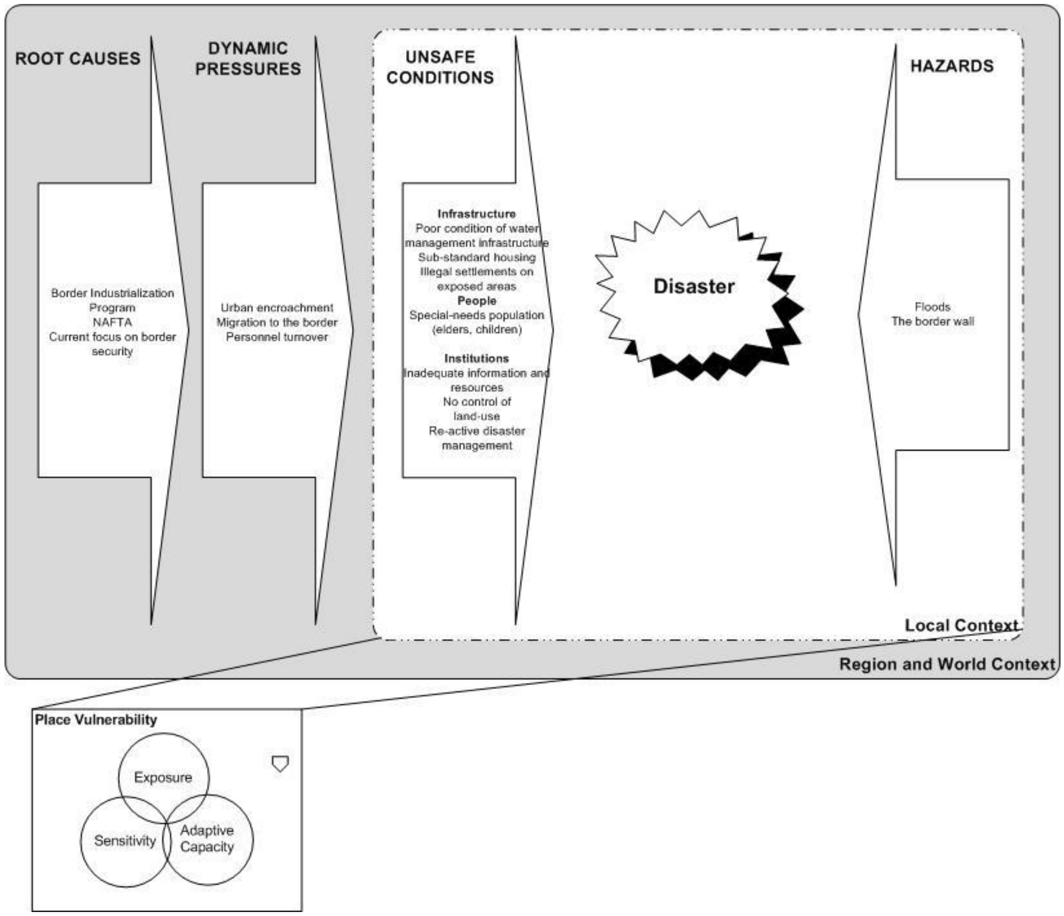

Figure 24. Progression of vulnerability in Ambos Nogales.

Nogales, Arizona and Nogales, Sonora are equally exposed to floods in the valley, with exposure concentrated in the downtown area of both cities. The downtowns of Ambos Nogales have suffered recurrent seasonal flooding, with most damages inflicted on businesses and infrastructure. The fact that this is the most exposed (and vulnerable) area to floods and also where the border wall was erected is not coincidence. The border wall has actually increased vulnerability to floods in downtown Ambos Nogales, particularly on the Mexican side. Since the natural flow of water goes north towards Nogales, Arizona, the border wall acts as a dam in the middle of the Ambos Nogales. In the flood of 2008, waters rose 8 feet in parts of downtown Nogales, Sonora.

The border wall acted as flood protection for the American side, even though their businesses also suffered a lot of damage.

Exposure to floods decreases with distance from the international border, with one exception. That exception is the largest illegal settlement in Nogales, Sonora. La Colosio is located inside the floodplain. Despite efforts from the government to move families to other parts of the city, La Colosio has continued to grow for more than 40 years.

While exposure is equal, sensitivity differs between the Mexican and American cities. Sensitivity to floods in Nogales, Arizona arises from the demographic characteristics of the city. The American side has a much older and more dependent population than the Mexican side. Nogales, Arizona also has a very large percentage of people with disabilities compared to Nogales, Sonora. (But this difference in percentage may be a result of better reporting in the United States, even though the definition of disability is nearly identical in both countries.) Contributing to the concentration of an elderly population in Nogales, Arizona is the migration of young people out of the city to attend college or look for better job opportunities.

Sensitivity in Nogales, Sonora is due not to demographics, but to the quality of housing. The fact that Nogales, Sonora has a higher percentage of houses built with sub-standard materials than its neighbor makes its population more likely to suffer damages from a flood. Most low-quality housing is located on the periphery of the city where exposure is lower, much of it in La Colosio. Colonia houses are often improvised with a combination of sub-standard materials like wood, metal sheets, cardboard, tires, and rocks. Even though *colonia* exposure might not be high, according to public officials on the Mexican side, the vulnerability of its residents is higher because they are more sensitive and lack adaptive capacity.

Adaptive capacity is the factor that differentiates the two sides of Ambos Nogales in terms of their vulnerability. In fact, adaptive capacity is spatially inverted (see Figure 21). In Nogales, Arizona, communities with higher percentages of people who are unemployed, have no high school education, and do not own a car or a telephone are more likely to be located in the downtown area; in Nogales, Sonora, they are located on the periphery. Regardless of location, adaptive capacity is significantly lower on the Mexican side—both its citizens and local institutions have fewer resources. Even though both cities are equally exposed to floods, it is the lack of adaptive capacity of Mexican communities that makes Nogales, Sonora more vulnerable.

Local organization and government agencies on the border are trapped in a cycle of disaster management that focuses on reactive responses. Thus, the institutional responses themselves are part of the factors that lead to unsafe conditions in Ambos Nogales. When a disaster hits, local governments do their best to provide temporal solutions (e.g., fixing, cleaning, reconstructing, rescuing). They have been successful in responding to disasters through close collaboration. But there is no collaboration on urban planning and infrastructure, even though such collaboration could prevent disaster or ameliorate its impacts. Consequently, disaster management fails to improve the situation in Ambos Nogales; the cities remain equally exposed to floods.

Like adaptive capacity, vulnerability to floods in both cities is unequally distributed. Vulnerability in Nogales, Sonora is unequally distributed across its spatial area and demographically. The outskirts of the city are the most socially vulnerable, while the center of the city is more physically vulnerable. Social vulnerability in Nogales, Arizona is concentrated in the urban core. This may be due to the fact that the city is very small and most of its population is concentrated in the urban core, while the periphery is mostly rural areas where we are more likely to find higher income populations than on the Mexican side.

RECOMMENDATIONS

How do we reduce vulnerability to floods in Ambos Nogales? To answer this question, I studied the interaction between unsafe conditions and flood hazard in both cities. I analyzed that interaction by looking at exposure, sensitivity, and adaptive capacity, and found that exposure—particularly runoff—was the most important factor for both cities. The sensitivity of housing infrastructure and the adaptive capacity of people were secondary contributors more important for communities in Nogales, Sonora than for those in Nogales, Arizona. I also found that the capacity of institutions to minimize the occurrence of floods and to help citizens recover from them is inadequate in both cities. While common sense says that increasing the capacity of the canal would solve the problem, there are economic and institutional constraints to such solution. It would cost millions of dollars for the Mexican government to enlarge the underground section of the canal. In addition, such a solution would require the canal to be enlarged on both sides of the border, otherwise it would not work. To reduce vulnerability to floods in Ambos Nogales I propose the following feasible solutions:

1. *Reduce exposure to floods by requiring that new developments produce no additional runoff.*

    The city of Nogales, Sonora is already built on top of a wash, and it has expanded through the valley without land-use planning or regulation. As a state official notes, "There is little we can do about past development." However, the city continues expand—new developments are planned to the east, south, and west of the city. The new *Plan de Desarrollo Urbano* should require that new developments do not increase the natural runoff rate of the land. A piece of undeveloped land creates a certain amount of runoff when it rains. New developments should maintain that level of runoff by providing water-retention features in the form of basins that serve as both green space and flood control. The *Plan de Desarrollo Urbano* already requires developers to allocate some land for recreational activities. Using this land for flood control would provide two benefits without adding too much to the cost of development.

Another option to reduce runoff in Nogales, Sonora is implementing a water harvesting program in industrial areas. Industrial parks cover an area of 356 hectares (Lara-Valencia et al., 2009), accounting for 11% of the total land extension of the city. Most, if not all, of this area is covered by non-porous surfaces (i.e., concrete and asphalt) that increase natural runoff levels. For example, a *maquiladora* with a roof area of 325,000 square feet will generate 200,000 gallons of water from just one inch of rain.[9] (Three *maquiladoras* with a similar square footage would generate enough water from a one-inch rain event to fill an Olympic-sized swimming pool.) With over 80 *maquiladoras* in Nogales, Sonora, the volume of water quickly adds up. The government could incentivize *maquiladora* water harvesting, and in combination with Nogales, Sonora's two universities (which focus on civil engineering), could help start a pilot harvesting project. Also, m*aquiladoras* already have budgets established for social causes (e.g., for food programs) that could be expanded to include water harvesting. Implementing water harvesting would provide a benefit to the city by reducing runoff and to *maquiladoras* by providing the water the factory requires for its processes.

[9] Multiplying surface area by height of water gives you the volume generated. A one-inch rain event is fairly common; it occurs every year.

2. *Provide housing alternatives that are affordable to low-income and middle-income families.*

Housing construction is an important determinant of sensitivity to floods. Poor house construction is characteristic of irregular settlements in Nogales, Sonora. Providing urban services and infrastructure in higher elevations of the city where the poor are located is too expensive for the municipality—these services are only available at lower elevations where high-income households and industry are located. Nogales, Sonora has no housing for low-income households. A program that provides affordable housing is essential to reduce the sensitivity to floods in irregular settlements. While it is not likely that by providing affordable housing the city will be able to remove people from irregular settlements, it is likely that by doing otherwise these settlements will continue to grow and emerge in other areas.

Removing people from irregular settlements is unpopular. In combination with the previous suggestion, the city should provide assistance to households already located in irregular settlements and exposed to floods. The Director of *Control Urbano* acknowledges that, "Now we call these settlements irregular, but back then, it was the normal thing to do. We need to respect that history." Since Hurricane Katrina, engineers and architects have made advancements in flood-resistant housing for the poor. These alternatives should be explored in irregular settlements already established in Nogales, Sonora. However, if such suggestions are implemented, the municipality needs to closely monitor *colonias* to prevent more settlement.

3. *Create a cross-border committee of local officials charged with finding solutions to flooding not just with a focus on infrastructure but also on land-use planning.*

Planners and engineers on both sides of the border stated that they do see a benefit in collaborating and sharing information; however, they do not do so. A local cross-border planning committee would benefit both cities and provide a forum for collaboration. Officials on the Arizona side worry about the urban processes that take place across the border and end up affecting their city, while officials from the Sonora side worry about the limited capability they have to handle growth. An opportunity exists to apply the experience and technical resources from Nogales, Arizona to the needs of Nogales, Sonora. For example, land-use and the floodplain are well-regulated in Nogales, Arizona but absent in Nogales, Sonora. A pilot project in which technical experts from the Arizona side provide consulting to the Sonora side on one major development project (at least as it relates to the control of run-off) would initiate collaboration while solving a problem. This project could be the basis for establishing ongoing collaboration in which major development projects in Nogales, Sonora are submitted for evaluation by and comments from officials in Nogales, Arizona. This is a common practice in the United States in cities that are closely located to one another.

A joint committee could develop plans and strategies for flood management in Ambos Nogales, and more effectively request funds from state and federal governments for the maintenance and repair of key water infrastructure. Said committee should include planners, engineers, emergency managers, and experts in law, grant seeking, and health and social issues to provide different approaches to problem-solving. The existing collaboration between emergency management officials can serve as a model for this new type of collaboration.

4. *Include vulnerability analysis into urban planning and flood management and continue to monitor it.*

This study demonstrates that vulnerability is not a product of exposure alone, but of the social and institutional characteristics that make cities susceptible to harm. While the study showed that exposure is indeed the most important factor in determining vulnerability in Ambos Nogales, public officials must not neglect the social and institutional characteristics that heighten vulnerability. That social and institutional characteristic actually do affect vulnerability is demonstrated by the fact that despite equal exposure to floods in both cities, the Mexican city is more vulnerability because its communities have less adaptive capacity.

The methods used in this study reveal how sensitivity and adaptive capacity contribute to vulnerability. Public officials need to be aware of these two variables, in addition to the variable of exposure, if they are to craft effective solutions to flooding. Large, expensive infrastructure projects designed to reduce exposure are unlikely to provide a comprehensive solution to a problem that has several contributing factors. Reducing exposure requires money that Ambos Nogales doesn’t have and has failed to acquire. Implementing solutions by addressing sensitivity and adaptive capacity may be more cost effective and easier to achieve, especially if the cities take advantage of cross-border collaboration and resources. The concept of vulnerability may serve as an education tool for planners, engineers, and emergency managers that helps them look at problems and solutions in their city from different perspectives than those they are accustomed to. By looking at the city as system where hazards, people, infrastructure, and institutions interact to determine the exposure, sensitivity, and adaptive capacity of the city, local officials can see how policy interventions will affect each component of the system.

One challenge to conducting a vulnerability assessment on the US-Mexico border was the lack of data compatibility between the cities. The difference in the standards used to define a floodplain, the units of classification used in the censuses, and the transformation of census data into agreeable units are some examples of this incompatibility. While it is unrealistic to expect cities to redefine census standards, it would be useful for border cities to at least go beyond the standards and definitions provided by their national governments and collaborate on the creation of new standards relevant to the border region (e.g., the creation of multiple floodplain maps or a border quality-of-life index based on census data). The Border Environmental Health Initiative (http://borderhealth.cr.usgs.gov) can serve as a model for this type of collaboration, one that could serve not just to monitor vulnerability in the future, but also provide a basis on which to request funds and assistance from central governments for the border region.

Finally, vulnerability should be continuously evaluated. Vulnerability is a dynamic process—as social, economic, and environmental conditions change, so does vulnerability. In this thesis I provide a method that could be used by public officials to track vulnerability in the future. With the new census coming out in 2011, the analysis can be easily replicated by combining exposure with the marginalization index that CONAPO maintains.[10] Such an analysis would provide public officials with a user-friendly approach that can be reapplied every 5 to 10 years.

5. *Reframe the debate about the US-Mexico border in terms of human and economic impacts on border cities.*

The policies established at higher levels of government are disconnected from the reality that people, businesses, and local governments experience on the border. The border wall goes beyond security concerns, environmental impacts, or even a moral debate about people putting their lives at risk to cross the border. All these concerns are legitimate, but the border wall affects tens of thousands of people directly and daily. The flood of 2008 is just one example of the unintended consequences that the border wall has on people, businesses, and life on the border (see Figure 25). Reframing the debate around the impacts of the wall on border citizens would help Washington D.C. and Mexico D.F. create policies that do not treat border cities as a homogenous, abstract entity, but as dynamic, living places that require individualized solutions crafted with input from local authorities.

[10] CONAPO's marginalization index would be used as a substitute for Sensitivity and Adaptive Capacity (refer to Comparing the Index in Chapter 6).

Figure 25. Unintended dam created by the border wall during the flood of July 2008 in Ambos Nogales. (Photo provided by City Planning, Nogales, Arizona)

SUMMARY

This research contributes to the vulnerability literature by showing how exposure to environmental hazards can be increased from within the system. The case study of Ambos Nogales showed how two cities in the same geographic location and with the same level of exposure can have different levels of vulnerability because of adaptive capacity deficiencies at the community and institutional levels. The case of Ambos Nogales is also a good case study to look at how regional, national, and international scales affect vulnerability at the local level. In Ambos Nogales, we can see the direct impacts of national policy increasing vulnerability of the region.

This study also makes methodological contributions to vulnerability research. It is possible to conduct spatially-detailed analysis between cities of different countries. The Analytical Hierarchical Process used in Eakin & Bojórquez (2008) is modified and applied to the border context using census and geographical data. While other methods have been used to analyze vulnerability in the US-Mexico border (e.g., see Collins et al., 2008), the method here proposed incorporates local knowledge into the weighting of indicators and expert knowledge through the incorporation of hydrological and geophysical models of the terrain in Ambos Nogales.

Finally, this study adheres to the principles of sustainability science by going beyond the scholarly requirements of academic work, and providing recommendations to local officials of how to reduce vulnerability in Ambos Nogales. The results of this research will provide decision-makers at the border with alternatives ways of thinking about disaster management, planning as a border region, and a user-friendly method to monitor vulnerability into the future.

FUTURE RESEARCH

Much research will be needed to improve our understanding of the components that contribute to up the vulnerability of the US-Mexico border region. I would like to start by suggesting ways in which the approach I used in this study can be improved.

The method could incorporate a more comprehensive weighting system to determine the importance of particular variables. A pair-wise comparison between variables (i.e., weighting variables against each other) instead of ranking variables in relation to a parent concept, as it was done in this study, could provide additional insights into the determinants of vulnerability. This research describes vulnerability in Ambos Nogales from the perspective of emergency managers, planners, and engineers. The study would be enriched by including other sectors (e.g., social-oriented agencies, NGOs, and neighborhoods) in interviews and the weighting of indicators. The method would also benefit by integrating scenarios of possible futures, so that it could be used not only to assess present vulnerability, but also to plan for future vulnerability (e.g., how much the watershed might be affected by global warming and future urban growth). The vulnerability assessment would be strengthened by quantifying the impacts and consequences of flooding in Ambos Nogales (e.g., economic losses, damaged structures, lives lost), and seeing if those impacts align spatially with the areas identified as most vulnerable in this study. If the data can be obtained, the opportunity to align outcomes with determinants may exist in the records of emergency calls placed during and after a flood disaster.

There are other lines of research in the border context that would be interesting to explore. For example, what is the role of non-governmental organizations (NGOs) on the border? While I did interview NGOs on the American side, it was very hard to find NGOs in Nogales, Sonora. Respondents on the American side said that while they collaborate with universities and government on the Mexican side, they rarely do so with Mexican NGOs because there are few and they disappear quickly.

Because climate change and environmental hazards are not constrained by political borders, transnational analyses are necessary to plan for mitigation, adaptation, and emergency response. More efforts are needed to collect data that are meaningful and relevant for both sides of the border.

It is important to understand the inherent vulnerabilities of a population to make inferences about vulnerabilities that may be present in the future. As suggested by Cutter et al. (2000), vulnerability research has a lot to learn from place-based spatial modeling of vulnerability. This paper contributes to vulnerability research in a transnational context, using data from both countries to explain and quantify vulnerability to floods in Ambos Nogales.

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APPENDIX A

ANALYTICAL HIERARCHICAL PROCESS

The AHP was developed by Thomas Saaty in the 1970s. AHP uses math and psychology to facilitate decision-making. A complex decision can be broken into smaller components that can be evaluated and compared to each other, allowing the decision maker to rank the importance of components according to his or her judgment. AHP is a three step process: (1) build a hierarchy of the problem, (2) establish priorities, and (3) calculate weights.

Build a hierarchy of the problem

To build a hierarchy in the AHP you need to define the goal of the study, the unit of evaluation (i.e., the alternatives), and the criteria that will be used to evaluate the alternatives. Figure 7 shows the hierarchy structure of this study. The goal is to measure vulnerability, the units of evaluation are the block groups, and the criteria I use to measure vulnerability are exposure, sensitivity, and adaptive capacity, and their associated indicators.

Establish priorities

Criteria and sub-criteria need to be prioritized according their relative importance to the decision-maker. To accomplish this, I developed a survey (see Appendix B) where decision-makers could rank the importance of each indicator with respect to exposure, sensitivity, and adaptive capacity. Participants were also asked to rank the importance of exposure, sensitivity, and adaptive capacity with respect to vulnerability. The result is an ordinal scale that can be transformed into weights.

Calculate weights

I used the following formula to translate ordinal numbers into weights:

$$w_i = \left(\frac{1}{n}\right) \sum_k^n 1/k \;, \qquad (5)$$

where k is the rank (ordinal number) assigned to the i^{th} indicator, n is the total number of indicators, and w_i is the resulting weight of the i^{th} indicator. Equation (5) is applied to the ranks given by each decision-maker, and w_i is averaged across all decision-makers. Finally, w_i is normalized so that the sum of all weights adds to one.

APPENDIX B

SURVEY TO DETERMINE WEIGHTS

The following survey was administered in person to the city planner of Nogales, Arizona, the Santa Cruz floodplain coordinator, the former emergency manager for Santa Cruz County, the director of the Municipal Institute for Planning and Research, the director of *Protección Civil* (equivalent to emergency management in the United States), and the director of *Departamento Integral de la Familia* (an agency that does social work and provides aid to families after a flood).

***2. Our research suggests that the impacts of flooding in Nogales result from a combination of three factors: Exposure, sensitivity, and adaptive capacity.**

Exposure is the physical risk of flooding in the community.

Sensitivity refers to the degree to which the well-being of a community changes as a results of flooding. We know that the same level of flooding affects some communities more tan others because of the social and economic conditions of the community (for example, some communities depend more on modes of transport that may be affected by flooding, or some communities have infrastructure that cannot withstand flood waters).

Adaptive Capacity refers to the ability of a community to maintain functionality and recover after a flood. Some communities may have access to resources that allow them to quickly recover, adapt their livelihoods and learn from experience.

So for example, if exposure was evenly distributed in an area (i.e. everyone has the same risk), a community that is highly sensitive would be worse off than a community that is less sensitive. A community with high adaptive capacity would be better off than a community with low adaptive capacity.

The worse case scenario would be a community that is highly exposed to flooding, highly sensitive, and has low adaptive capacity to deal with the situation.

Considering the different communities and Colonias of Nogales, which factor (Exposure, Sensitivity, or Adaptive Capacity) do you think is the most important in determining the impact a flood can have in a community or Colonia? You can assign the same rank if you think that two factors are equally important.

	Most Important	Important	Least Important
Exposure	○	○	○
Sensitivity	○	○	○
Adaptive Capacity	○	○	○

***3. Exposure. At the census tract level (or Colonia), what variables do you think are more important in determining how exposed a community is to flooding.**

	Most Important	Important	Less Important	Least Important
Percent of community in floodplain.				
Amount of runoff that the community can receive.				
Density of population.				
Density of housing units.				

Other (Is there another variable that you think is important?)

***1. Sensitivity. At the community level, what variables do you think are important in determining the degree to which the well-being of a community changes as a results of flooding.**

	1 (Most Important)	2	3 (Important)	4	5 (Less Important)	6	7 (Least Important)
Percent of community members with disabilities and special needs							
Percent of children and elders in the community							
Percent of houses that are poorly constructed							
Average year that the houses were built							
Percent of female head-households in community							
Percent of overcrowding in houses (hacinamiento)							
Percent of people that rent their house							
Amount of trash that obstructs water flow							

Other (Is there any other variable that you would consider important in measuring sensitivity?)

✱2. Adaptive Capacity. People have access to resources that could make then more able to deal with flooding in their community. What variables do you think are the most important in determining how a community can adapt and recover from flooding in their community?

	1 (Most Important)	2	3 (Important)	4	5 (Less Important)	6	7 (Least Important)
Percent of community members that own a car.	○	○	○	○	○	○	○
Percent of community members with a job.	○	○	○	○	○	○	○
Percent of the community members that completed a high school education.	○	○	○	○	○	○	○
Percent of community members that have a landline telephone.	○	○	○	○	○	○	○
Percent of community members that are economically stable.	○	○	○	○	○	○	○
Percent of houses with complete plumbing and drainage.	○	○	○	○	○	○	○
Percent of people with healthcare.	○	○	○	○	○	○	○
Percent of the community members that are longtime residents of the community.	○	○	○	○	○	○	○

Other (Is there any other variable that you would consider important in measuring adaptive capacity?)

APPENDIX C

SURVEY: INSTITUTIONAL COLLABORATION

Interviewee: ____________________________
Organization: ____________________________
Date: ____________________________
*Before beginning interview: summarize the research project and ask if the participant has any questions.

I. Background and Scope

1. Could you describe the organization that you work for? What is its mission and goal? How large is it?
2. Could you describe your job position? What kind of activities do you perform in this position?

II. Climate Hazards and Disasters

3. What do you think is the main cause of flooding in the city?
4. How has the flooding problem been addressed?
5. What are the areas most affected by floods?
6. Who is mostly affected by floods?
7. Do you think that flood risk has increased?
8. What happened in the floods of 2008? And how did the governments respond?
9. How does government prepare for the monsoon season?
10. Is the city prepared for a bigger flood?
11. What do you think needs to be done to reduce flooding in the city?

III. Sources of Information

12. What types of information do you need to do your job effectively?
13. Where do you get the information that you need?

IV. Collaboration

14. Do you collaborate with other organizations? Which organizations? How do you collaborate?

    For example:
    Other municipalities
    State agencies
    National agencies
    Universities
    Private industry
    Grassroots organizations

15. Do you collaborate with organizations or people on the other side of the border? Which organizations? What is the nature of this collaboration?
16. Do you work on flood mitigation or prevention projects with the planning department of the other city?

17. What is you experience with collaboration with the city of Nogales, Arizona (or Nogales, Sonora)?
18. What do you think are factors that have (and have not) allowed successful border collaboration?
19. If there was collaboration in flood management, where should it focus?
20. Do you share information with them? What type of information?

21. Do you meet regularly to discuss issues pertaining to both cities?
22. What types of meetings, conferences, or workshops to you participate in?
23. Do you feel that collaboration is useful? Why? Do you believe the collaboration leads to better decision-making?

APPENDIX D

INFORMATION LETTER

Study Title: Institutional Response and Collaboration to Climate Hazards

Dear *Name of Participant*:

My name is Bernardo J. Marquez and I am a graduate student under the direction of Dr. Hallie Eakin in the School of Sustainability at Arizona State University.

For my thesis project, I am researching the impact of environmental hazards (particularly flooding and drought) in the cities of Nogales, Arizona and Nogales, Sonora. I want to analyze the geographical distribution of environmental hazards in the two cities, and understand how institutions are responding and adapting to the hazards. The objectives of my research are to:

- Understand the historical developments (economic, social, and environmental) that have created vulnerable conditions in the US-Mexico border region
- Understand the role of collaboration among agencies (particularly the city governments) to address global environmental changes

I am inviting your participation, which will involve an interview of 45 to 60 minutes about your duties and activities as a public official, and your collaboration with other institutions to address flood hazards. You have the right not to answer any question, and to stop the interview at any time.

Your participation is voluntary. If you agree to be interviewed, you are free to withdraw your consent and discontinue participation at any time. The interview will be tape recorded for documentation purposes, unless otherwise requested by you. Please let me know if you do not want the interview to be taped; you also change your mind after the interview starts, just let me know. Recorded tapes will be stored in digital format in my personal computer for the duration of the study. Once the study in completed, the data will be stored for a year and then erased.

The results of the study may be used in reports, presentations, or publications. Your responses will remain anonymous, unless you wish to be quoted. I will be the only person who can access the raw data collected from this study.

I will use the data collected from the interview to understand collaboration and communication among policy-makers in US-Mexico border cities. My study will contribute to our understanding of climate-change planning and provide insight into how vulnerability is affected in cities with very different structures, cultures, and resources.

Please contact me at bjmarque@asu.edu or 787-619-7383 if you have any questions or concerns regarding the research study. If you have any questions about your rights as a subject/participant in this research, or if you feel you have been placed at risk, you can contact the Chair of the Human Subjects Institutional Review Board, through the ASU Office of Research Integrity and Assurance, at (480) 965-6788.

Your participation will be greatly appreciated. Your answers may contribute to flood prevention and mitigation in border communities. Thanks. Please sign here if you wish for your responses to be quoted (otherwise they will remain anonymous):

____

APPENDIX E

HISTORICAL FLOODS IN AMBOS NOGALES

Historical Floods in Ambos Nogales[a]

Year[b]	Observations	Declaration in Mexico	Declaration in USA
1887	Unusually heavy rains which flooded streets, destroyed bridges, and washed away railroad tracks.	-	-
1926	Thatcher, Douglas, Nogales and Safford were flooded and many adobe houses crumbled. In Nogales damage was $12,000.	-	-
1930	Due to rushing waters and accumulated water and mud, four deaths occurred in Nogales, Sonora. In Nogales, Arizona many adobe buildings collapsed. Total damage was estimated at $20,000	-	-
1932	Floodwater inundated the two border cities of Nogales to a depth of four feet, crumbling adobe buildings, flooding homes and businesses, overturning and demolishing automobiles, and tearing down the international boundary fence. Damage was estimated at $75,000	-	-
1935	Flood waters inundated sections of the Rillito Valley, and considerable damage occurred at Helvetia and other locations between Tucson and Nogales.	-	-
1957	In Sonora, three deaths were recorded and 60 families were left homeless by the flood.	-	-
1977	Four-day rainfall amounts ranged from 4 to 14 inches, exceeding average annual precipitation amounts in some places. Nogales experienced the highest rainfall with 8.30 inches. Over $1 million dollars in damages, and 40 houses inundated.	-	Disaster
1980	Very heavy rains in the upstream on the Santa Cruz River caused considerable flood damage to mobile homes, houses, commercial buildings and streets in Santa Cruz County	-	Disaster
1983	This was Arizona's most destructive flood and the 7th major flood in less than six years. Nogales experienced the highest rainfall with 9.72 inches.	-	Disaster
1994	Thunderstorms around Nogales caused extensive flooding and heavy runoff. A woman and her two children were drowned when their pickup truck was caught in flood waters on *Cinco de Febrero* Street in Nogales, Sonora. Many homes and businesses were flooded, but no estimates of damage were made.	-	-
2000		Disaster	-
2001		Disaster	Disaster

2007	Flooding severely damaged the Nogales Was on the American side.	Emergency	-
2008	Flood in Nogales, Sonora was made worse by an obstruction in the drainage channel built by the US Border Patrol	Disaster	Disaster
2010	Flooding cause severe damage to the Nogales Wash.	Emergency	Emergency

[a]This data was compiled from multiple sources: NOAA, CENAPRED, FEMA, and periodicals
[b]For space reasons, some years for which a flood was recorded but no description of damage was provided were left out of the table. These years include: 1905, 1909, 1914, 1915, 1965, 1978, 1993, 2000, 2001, 2003, and 2004.

NOAA: http://www.wrh.noaa.gov/twc/hydro/floodhis.php
CENAPRED: http://atl.cenapred.unam.mx/metadataexplorer/EES/BDDEDD.html
FEMA: http://www.fema.gov/femaNews/disasterSearch.do