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Title: Vulnerability and Adaptation in a Dryland Community of the Elqui Valley, Chile

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Abstract

Livelihoods in drylands are already challenged by the demands of climate variability, and climate change is expected to have further implications for water resource availability in these regions. This paper characterizes the vulnerability of an irrigation-dependent agricultural community located in the Elqui River Basin of Northern Chile to water and climate-related conditions in light of climate change. The paper documents the exposures and sensitivities faced by the community in light of current water shortages, and identifies their ability to manage these exposures under a changing climate. The IPCC identifies potentially increased aridity in this region with climate change; furthermore, the Elqui River is fed by snowmelt and glaciers, and its flows will be affected by a warming climate. This case study highlights the need for adaptation to maintain livelihoods in the region. Community vulnerability occurs within a broader physical, economic, political and social context, and vulnerability in the community varies amongst occupations, resource uses and accessibility to water resources, making some more susceptible to changing conditions in the future.

1 Introduction

It is widely accepted that climate change, largely attributed to anthropogenic emissions of greenhouse gases, is occurring and is a cause for international concern (IPCC, 2001; 2007). The global average temperature has increased by approximately 0.6°C in the last 150 years, with the 1990s being the warmest decade since about 1860 (Salinger, 2005; IPCC, 2007). Climate change induced temperature increases, changes in precipitation, and interactions with climate variability associated with phenomena such as El Niño Southern Oscillation (ENSO) are projected to alter the frequency, intensity and/or extent of climatic and weather extremes (Mata and Campos, 2001; IPCC, 2007). Due to these changing climatic conditions, it is expected that many regions will experience an increasing scarcity of natural resources (McCarthy et al. 2001; Tompkins and Adger, 2004). In particular, water resources are highly sensitive to climate variability and change (Miller, 1997; Arnell, 1999; McCarthy et al. 2001; Beniston, 2003; Arnell, 2004; Gerten et al. 2007). The implications for water-dependent communities and sectors relate to their exposures and sensitivities to changing moisture regimes and to their capacity to adapt to those changing conditions (Tol et al. 1998; Smit and Pilifosova, 2003; Smit and Wandel, 2006). The vulnerability of communities to climate change is influenced by the ways in which they are affected by climate conditions and by the manner in which they can moderate effects or risks through adaptive strategies (Adger, 2006; Fussel and Klein, 2006; McLeman and Smit, 2006).

For thousands of years societies have adapted their cultures and economies to their geography, including the prevailing climatic and hydrologic environments. Ecosystems greatly reflect moisture regimes and many areas of society and economy are dependent on water resources. Changes in climate and water could potentially have severe implications on environmental quality, economic development and social well-being (Arnell and Liu, 2001; Beniston, 2003). Although both natural and human systems have always had to deal with climatic conditions, including variability and extremes, changes in water resources due to climate change are expected to have dramatic impacts (Arnell, 1999; de Loe and Kreutzwiser, 2000; Beniston, 2003; Sivakumar et al. 2005).

In particular, drylands[1] are often challenged by the demands of existing climate variability, and it can be expected that climate change will have further implications for water resource availability in these areas (Frederick and Major, 1997; Miller et al. 1997; Ivey et al. 2004; Sivakumar et al. 2005). Warmer temperatures are expected to alter the hydrological cycle (Arnell, 1999; Arnell and Liu, 2001). Drylands are expected to experience decreases in water availability as precipitation, evaporation, infiltration and runoff are variable and particularly sensitive to climate variations (Arnell and Liu, 2001; Mata and Campos, 2001). This could have serious implications for the nearly 40% of the world's people who inhabit dryland areas (McCarthy et al. 2001; IISD, 2003). The IPCC estimates that by 2080 nearly 3 billion additional people will experience significant decreases in water resources due to climate change (McCarthy et al. 2001). An increase in water scarcity for these areas would have major implications for ecosystems, livelihoods, industries and human health.

To investigate how people's livelihoods are susceptible to climate change and how they might adapt to changing environmental conditions, studies have increasingly employed analytical approaches that focus on the vulnerability of a community or society (Polsky et al. 2003; Turner et al. 2003; Ford and Smit, 2004; Lim et al. 2005; Belliveau et al. 2006; Fussel and Klein, 2006). The broad purpose of this vulnerability approach is to document the ways in which communities are susceptible and the ways in which they deal with climate and related conditions, in order to identify needs and opportunities for adaptation (Sutherland et al. 2005; Lim et al. 2005; Ford et al. 2006; Smit and Wandel, 2006). This paper describes a vulnerability case study for the community of Diaguitas in the Elqui Valley, in Chile's dryland north-central region.

Dryland ecosystems, like the Elqui Valley, are susceptible to small changes in the water cycle. The Elqui Valley has been referred to as one of the most sensitive areas in South America to water variability (Downing et al. 1994; Kalthoft et al. 2006). The climate is strongly influenced by ENSO, receiving several years of dry conditions (La Niña) followed by a period of intense rainfall events (El Niño). The valley's economy is largely based on agriculture. Small-scale farms have decreased and the valley is experiencing a rapid increase of large-scale commercial operations. Agricultural products include table grapes for exportation, *pisco* grapes (for Chilean brandy) and smaller amounts of avocado and citrus. Production is dependent on irrigation with water derived predominantly from the Elqui River, fed by snow-melt in the Andes. Watersheds in dryland areas like the Elqui Valley are especially sensitive because rainfall is very low and variable, annual runoff is already highly variable, and drought is common (Sauchyn and Skinner, 2001;

Kalthoff et al. 2006). Understanding how dryland regions have been (and are currently) stressed by climate-related conditions, and how and to what degree they have coped or adapted to changing conditions is an important step in assessing their vulnerability to climate changes.

This paper characterizes the vulnerability of the community of Diaguitas, in the Chile's Elqui Valley, to water and climate-related stresses, in light of climate change and within a broader physical, economic, political and social context. The approach documents the multiple exposures and sensitivities faced by the community, and identifies their ability to adapt to these exposures, currently, and in light of expected changes in climate.

2 Vulnerability: Conceptual Evolution and Analytical Approach

The concept of vulnerability has developed in various fields and contexts, including natural hazards (Burton et al. 1978; Cutter, 1996; Cutter et al. 2003), ecology (Holling, 1973; Folke et al. 2002) political ecology (Blaikie et al. 1994; Wisner et al. 2004), food security (Sen, 1981; Watts and Bohle, 1993; Dilley and Boudreau, 2001) sustainable livelihoods (Chambers and Conway, 1992) and environmental change (Liverman, 1994). In the climate change field, vulnerability has emerged as a key concept relating to adaptation in both the policy and scholarly debates. The UNFCCC (Article 4.4, 1992) explicitly commits developed countries to assist developing countries "that are particularly vulnerable to the adverse effects of climate change." Action on adaptation has increasingly moved from estimating levels of vulnerability to attempts to reduce it by promoting adaptation. The concept of vulnerability has now been widely used to characterize and understand the implications of climate change at the community level (Adger, 1999; Leichenko and O'Brien, 2002; Vasquez-Leon et al. 2003; Ford and Smit, 2004, Sutherland et al. 2005; Ford et al. 2006).

Interpretations of vulnerability vary among bodies of literature. In much natural hazards scholarship and climate change impact studies vulnerability has been characterized mainly in terms of physical stimuli (magnitude, duration, frequency, etc) and their impacts (Burton et al. 1993; Liverman, 1994; Smith and Lazo, 2001; Brooks, 2003). Vulnerability is characterized by the distribution of a hazardous condition as it affects human occupancy and the degree of loss (life, property) associated with the occurrence of a particular event (landslide, earthquake, tsunami) (Cutter, 1996).

A somewhat different perspective on vulnerability focuses on the pre-existing state of a social system or community that renders it susceptible to harm. This interpretation highlights the conditions and processes that influence a society's exposure to stimuli and its ability to deal with hazards (Downing, 2003; Polsky et al. 2003). Attributes of social systems that can increase or decrease vulnerability include marginalization, inequity, presence and strength of institutions, food and resource entitlements, economics, and politics (Adger and Kelly, 1999; Adger, 2000; O'Brien and Leichenko, 2000; Pelling 2002).

This recognition of the human dimension of vulnerability has been well developed in the fields of food security (Sen, 1981; Bohle et al. 1994) and political ecology (Blaike and Brookfield, 1987; Bryant and Bailey, 1997; Pelling 1999; Mustafa, 2002; Paulson et al. 2003). These concepts are now employed in vulnerability and adaptation work in the field of climate change (Handmer et al. 1999; Kelly and Adger, 2000; Leichenko and O'Brien, 2002; Adger, 2003; Ford and Smit, 2004; Belliveau et al. 2006; Fussel and Klein, 2006). An examination of vulnerability inclusive of the human dimension includes an understanding of the human use of and access to resources, which in turn determines the ability of an individual or society to cope and adapt to change (Wisner et al. 2004). A commonly adopted notion of vulnerability in the climate change field refers to "the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes" (IPCC, 2001).

This literature examines relationships between nature and society at various scales. It focuses on the social structural constraints and political economic factors that cause differential access to resources and vulnerability to hazards, particularly on the part of marginalized groups (Bryant and Bailey, 1997; Mustafa, 2002; Paulson et al. 2003). Access to resources, livelihoods, the role of institutions and the political and economic systems are shown to be key components shaping people's ability to cope with environmental change (Blaikie & Brookfield, 1987; Watts & Bohle, 1993; Bohle et al. 1994; Adger & Kelly, 1999; Mustafa, 2002; Peet and Watts, 2004; Budds, 2004).

The vulnerability of a community is generally conceptualized as a function of the community's exposure (and/or sensitivity) to changing conditions and the community's adaptive capacity to deal with those conditions (Smit and Wandel, 2006). This broad conceptualization of vulnerability has been summarized formally as (after Smit and Pilifosova, 2003; Ford and Smit, 2004):

$$V_{ist} = f(E_{ist}, AC_{ist})$$

Where: V_{ist} = Vulnerability of system *i* to climatic stimulus *s* in time *t*

E_{ist} = Exposure of *i* to *s* in *t*

AC_{ist} = Adaptive Capacity of *i* to deal with *s* in *t*

Exposure is reflective of both the characteristics of the system (sometimes referred to as sensitivity or occupancy characteristics) and the climate conditions to which the system is sensitive (sometimes referred to as external stimuli or hazard) (Downing, 2003; Smit and Pilifosova, 2003; Smit and Wandel, 2006). Local conditions that influence exposure (e.g., settlement location and types, livelihoods, land-uses, etc.) reflect the broader social, economic, cultural, political and environmental conditions. A system’s exposure to a physical stimulus reflects the social sensitivity of the system. For example, a community whose livelihood is highly dependent on water resources is more exposed to drought than a community facing equivalent moisture conditions but having livelihoods that do not depend on the availability of water.

Adaptive Capacity describes a system's potential or ability to adapt or adjust to exposures in order to moderate damages, take advantage of opportunities or cope with effects (Wheaton and McIver, 1999; Bryant et al. 2000; Smit and Pilifosova, 2003; Yohe and Tol, 2002; Füssel and Klein, 2006; Smit and Wandel, 2006). Adaptive capacity is context specific and as it varies between countries, communities, among social groups, individuals, and over time. The adaptive capacity of a community is a dynamic function of local processes and conditions which in turn are influenced by broader socio-economic and political processes (Smit and Wandel, 2006). Adaptive capacity is influenced by assets and access to such resources as economic wealth, technology, information, infrastructure, knowledge and skills, social capital and institutions (Watts and Bohle, 1993; Adger, 2000, 2003; Smit and Pilifosova, 2001, 2003; Klein and Smith, 2003).

Adaptations, or particular adjustments in a system to better cope with external stress, are manifestations of adaptive capacity, and have the ability to modify the effects of external stimuli, including climate change. There are many forms of adaptation (Smit et al. 2000). Based on their timing, adaptations can be anticipatory or reactive. Depending on their degree of spontaneity they can be autonomous or planned. With respect to spatial scope they can be local to widespread and based on form they can be technological, behavioural, financial, institutional and/or informational (Smithers and Smit, 1997; Smit et al. 1999; 2000; Smit and Pilifosova, 2003). Early assessments of adaptation and climate change treated adaptation strategies as rather distinct measures, considered in light of scenarios of future climate (Brooks, 2003; Fussel and Klein, 2006; Smit and Wandel, 2006). Recent analysis of adaptation processes have shown that actions to adapt to climate risks most commonly represent modifications of existing resource management, risk management or sustainable development initiatives (Burton et al. 2002; Davidson et al. 2003; Huq et al. 2003; Huq and Reid, 2004; Smit and Wandel, 2006). Integrating adaptive strategies with sustainable development and livelihood initiatives is seen as a way to address immediate vulnerabilities and to improve the ability to deal with future exposures in light of climate change (Nelson et al. 2002; IISD, 2003; IUCN et al. 2004).

This conceptualization of vulnerability, recognizing that exposures and adaptive capacities of communities are dynamic and influenced by broader social and biophysical contexts operating at multiple scales, is broadly consistent with several other models of human-environment interactions and vulnerability (Polsky et al. 2003; Turner et al. 2003; Keskitalo, 2004; Lim et al. 2005) .

The approach used to guide this study, mirrors the above conceptualization of vulnerability, and has been used in a growing number of vulnerability and adaptation assessments around the world (Adger, 1999; Vasquez-Leon et al. 2003; Ford and Smit, 2004; Sutherland et al. 2005; Belliveau et al. 2006; Crabbe and Robin, 2006). This analysis begins with the community (or sector, industry, region) as the starting point, to identify how the community is exposed and sensitive, and in what ways its capacity to adapt is enhanced and constrained. The vulnerability approach involves an assessment of current vulnerability and an estimate of future vulnerability. The assessment of current vulnerability involves identifying and documenting the nature of past and current exposures faced by the community and the adaptive strategies they have employed, and how this reflects their capacity to adapt. It requires involvement of actors or stakeholders at various levels or sectors of society in order to identify the forces and factors to which the community is sensitive, and to characterize their adaptive strategies. Based on the current vulnerability, a second stage examines how climate change will alter the nature of the identified exposures, and in what ways the community has capacity to deal with these changes. Future exposures relate to conditions which are expected to represent risks or opportunities to the community, both those identified by the community and potential conditions (such as modeled scenarios of change) that may not yet be realized or problematic to the community. Future adaptive capacity is based on insights from past and current adaptations and from expected changes in the resources and assets that facilitate or constrain adaptation.

3 Case Study

3.1 Study Area

Chile is a country of significant geographic diversity. The Elqui Valley is in Chile's north-central Fourth Region, which is bounded by the Atacama Desert to the North, the Andes to the East, the fertile Central Valley to the South, and the Pacific Ocean to the West (Figure 1). This region is characterized by an arid climate. The Elqui valley is one of a series of transverse valleys running east-west from the Andes to the Pacific Ocean and covers 9 657 square kilometers.

INSERT FIGURE 1 – Location of the Elqui River Basin

The valley is narrow with steep slopes consisting of thin, dry, sandy soils and sparsely distributed steppe vegetation. The basin rises from sea level to 4 800 meters asl in less than 150 kilometers. Snow and ice accumulate in the high mountains and feed the basin's rivers. Annual rainfall in the Elqui Valley is very low, approximately 100 mm/year (Figure 2), although this varies from year to year and through the valley with an altitudinal gradient (approximately 83 mm at sea level to 200 mm at 3 750 masl). The majority of precipitation falls between May and August leaving the remaining months extremely dry. Simple linear regression over time indicated a statistically significant (95% confidence) decrease in annual precipitation at both Vicuña and La Serena (R^2 values of 0.103 and 0.076) over the period of available instrumental record. The Elqui River basin is subject to the ENSO phenomena, and experiences oscillatory periods of long and persistent dry periods (La Niña) and intense, but short, precipitation events (El Niño). ENSO events occur irregularly but typically every three to six years. Table 1 illustrates average annual precipitation values at Vicuña for years with six months or longer El Niño and La Niña influence from 1950 to 2000. Notwithstanding the coarseness of the analysis and high variation (particularly during El Niño years), El Niño years are associated with greater than average rainfall and La Niña years with below average precipitation (Table 1). Annual precipitation has approached or exceeded double the mean annual values during five of the 14 El Niño-influenced years from 1950 to 2000.

INSERT FIGURE 2 – Annual precipitation for La Serena (1869-1999) and Vicuña (1918-1999).

INSERT TABLE 1 – ENSO effect and annual precipitation at Vicuña, 1950-2000

The Elqui River has two main tributaries, both of which originate in the High Andes; the Turbio River originates in the high Andes in the northeastern part of the basin and the Claro River which drains the southeast. Diaguitas is downstream from their confluence. The Elqui River is characterized by high inter- and intra-annual variability (Figure 3). Flows at Algarrobal fluvial station, just upstream from Diaguitas, range from 2.4 m^2/s to 33 m^2/s throughout the year (Cepeda et al. 2004). Even though precipitation at Vicuña and La Serena has tended to decrease over recent decades, river discharge has not shown a corresponding trend (Figure 3). The main source of the Elqui River is snow and ice melt, and discharge closely reflects snowfall in the High Andes portions of the basin (Figure 3). Snowfall at higher elevations has not decreased in recent decades. River discharge is also expected to be related to increasing ablation of snow and/or ice associated with higher temperatures in the Andes (Strauch et al., 2006).

INSERT FIGURE 3 – Summer and winter discharge at Algarrobal Fluvial Station and Snowfall at La Laguna Snow Station

Chile is one of Latin America's most economically developed countries (World Bank, 2004). Since the time of the military government (1973-1990) Chile's economy has been market-oriented and characterized by a high level of foreign trade. Chile's agribusiness has emerged as one of the country's major export sectors. Chile's broad diversity in environmental conditions allows for the cultivation of a variety of fruits and vegetables, and in recent decades the fresh fruit industry has grown considerably. Between 1980 and 2004, fresh fruit exports grew from US$168 million to US$1.9 billion, an 11-fold expansion over 24 years. Chile now accounts for almost half of the Southern Hemisphere's exports of grapes, kiwifruit, apples and pears (ProChile, 2005). The expansion of agri-business is heavily dependent on irrigation, which now accounts for 85% of consumptive water use in the country (Hearne and Donoso, 2005).

In this dryland region, where the Elqui River is the prime moisture source, local farmers have seen substantial growth in agri-business crop operations. The Elqui Valley has a thriving commercial agriculture industry. Sprawling irrigated vineyards and plantations now cover nearly every accessible portion of the valley floor and are rapidly expanding up the mountainsides. Multi-national agricultural companies have had an increasing presence in the Valley over the past 15 years. Most agricultural activities in the basin are related to fruit-production, particularly table grapes, citrus fruits and avocados for export, but also grapes for *pisco* (brandy) production. These production systems are highly dependent on the discharge of the Elqui River for irrigation. Water from the Elqui River is diverted into irrigation canals which then weave through communities and make water available for use by owners of water rights.

Under the Chilean Constitution, water resources are defined as a ‘National Good of Public Use’ because they are essential for life, economic development, social objectives and environmental requirements (Productivity Commission, 2003). Therefore the state has the responsibility to regulate water use in a manner that meets these objectives (Productivity Commission, 2003). Chile uses a market-oriented approach to allocate water resources. Markets in water rights are employed with the intent to optimize the allocation and use of scarce water resources, under the assumptions that market pricing forces the highest value use of water, private property rights promote individual choice, and that the market is more politically neutral than the state in resource allocation (Haddad, 2000; Budds, 2004). The Water Code is the principal legislation governing water resources management. The *Direccion General de Aguas* (DGA), a government agency within the Ministry of Public Works, grants private water rights and plays the central role in the management and use of water resources. Water rights, which are not tied to particular parcels of land, are private rights of use to a public good (water) and, if available, are granted with no change; in the case of simultaneous competing requests, water rights are auctioned and granted to the highest bid. Once acquired, water rights have the same legal protection as any other private good, and can be freely traded, mortgaged or transferred (Budds, 2004). Legally all rights are specified in volumetric terms (e.g. liter/second). However, due to traditional practices and the variability and uncertainty of flows, rights are often expressed as a proportion of flow (Bauer, 1997; Productivity Commission, 2003).

The DGA exercises broad authority over water resource management, while much of the basin-level management and supervision over river flows is under the authority of the *Junta de Vigilancia* (JDV). The JDV administers and distributes water from natural water courses to owners of water rights of a basin or sections of the basin. The JDV provides supervision over user associations sharing common water resources such as a particular irrigation canal within a basin (*asociaciones de canalistas* and *comunidades de aguas*). The *Direccion de Obras Hidraulicas* (DOH), another government agency within the Ministry of Public Works, is responsible for the construction and maintenance of water infrastructure projects, inclusive of irrigation and rainwater drainage structures.

Potable water for household use in rural areas of the Elqui Valley is managed by *Comites de Agua Potable Rurales* (APR). Groundwater is pumped, treated and distributed to homes and industry. APRs are private, autonomous services providing basic potable water to small towns and communities that have a relatively high population density. Under the National Program of Rural Potable Water headed by the DOH, APRs are provided with the basic infrastructure and training to operate the machinery and obtain proper water samples for quality analysis.

Diaguitas (population 700) is located 80km from the coast at an elevation of 687 masl, (see Figure 1). Diaguitas is adjacent to the Elqui River at the base of the very steep hill, Cerro Mamalluca (2219 masl). Vineyards of three large export agricultural companies blanket the valley and hillsides of the community. These companies provide the main source of employment. Prior to the arrival of the companies, residents relied on the productivity of their *huertos* (gardens/small farms). However, small farmers can no longer compete with the low supermarket prices, and often can not refuse the salaries and high prices they are offered from the agricultural companies for their land and/or water rights. Effectively small farmers have few options but to work for the agricultural companies. There is also a small group of goat herders in the community who traditionally have grazed their livestock in a migratory fashion.

Most businesses and residents are either directly or indirectly dependent on water resources to sustain their livelihoods, either through employment from the agricultural companies (who require irrigation water for successful production and operation), through their own production of crops, to sustain vegetation and water sources for livestock, and for consumption of safe drinking water. Thus the community's livelihoods and well-being are sensitive to effects of variations in the climate and water regimes, particularly extreme conditions. However the vulnerability of community residents and their capacity to adapt to changes in climate within the broader social, economic, environmental and political context are not well understood. This is addressed through a vulnerability assessment of the community of Diaguitas, in which vulnerability is framed as a function of the community's exposures to conditions to which they are sensitive, and its adaptive capacity to deal with changing exposures (Smit and Pilifosova, 2003; Ford and Smit, 2004; Lim et al. 2005; Fussel and Klein, 2006). The objective of the case study is not to assume particular exposures and determinants of adaptive capacity, but to empirically identify the factors and processes that affect this community and that characterize the nature of the community's current and future vulnerability. This involves documenting the conditions that have had an effect on the livelihoods and lives of residents and businesses, tracing the multiple forces and processes that contribute to the community's sensitivities, characterizing the ways in which the community has coped with or adapted to stresses, and assessing the constraints and opportunities for adapting to future changes in conditions (Smit and Wandel; 2006).

3.2 Case study approach and methods

This type of research, sometimes called "community-based" or "bottom-up" (Clark et al. 2000; Sutherland and Smit, 2005; Belliveau et al. 2006) is necessarily participatory, as it depends, in part, on collecting data on exposures and adaptive strategies and constraints from community residents. These data are incorporated with instrumental records, direct observation and documentation, administrative and historical documents, and scientific projections to characterize current and future vulnerabilities.

Identifying community-relevant exposures and adaptive strategies required compiling data on the experiences of people living in the community. Establishing trust and credibility is essential for this kind of participatory research, especially in communities (like in the Elqui Valley) that have been subject to previous field research (Wallerstein, 1999). The field research team included two Chilean colleagues familiar with the region and Diaguitas. Living in the community was an essential element of the research in order to build rapport, familiarity, and a sense of commitment with the community. It also provided opportunities to experience events in the community, to listen and partake in casual conversation, and to ground-truth statements given by respondents. The research team members also attended community meetings and were taken on tours of *huertos*, vineyards, irrigation systems and community livelihoods. This experience helped recognize the various stakeholders, challenges, social interactions, rituals and customs, and also helped put specific exposures, sensitivities and adaptations in a more comprehensive context.

The more formal data gathering involved forty-eight semi-structured interviews, complimented by three focus groups. Twenty-six interviews were conducted with community residents, while the remaining twenty-two were carried out with representatives of the municipality, region and various institutions, particularly those involved in the water sector such as the APR, DOH, DGA, JDV and *asociaciones de canalistas.* These institutional interviews were key in this type of research in order to gain insights into the community's vulnerability from broader scales and contexts. It has been well documented that institutions can play a significant role in improving or hindering a system's vulnerability by facilitating or constraining adaptation to social and environmental change (Adger, 1998; Adger and Kelly, 1999; Smit and Pilifosova, 2001; Adger, 2003; Naess et al. 2005; IHDP, 2005) especially with respect to water resources (Ivey et al. 2004). These institutional interviews were tailored towards the interests, responsibilities and roles of the institutions as they related to the community-identified exposures and adaptive strategies.

Semi-structured interviews allow for respondents to discuss, unprompted, the problematic conditions faced by the community and/or personally through their experience, and how they coped with the situations. This is the prime source of data on current exposure, sensitivities and adaptive strategies. The semi-structured format also allowed for a number of predetermined issues to be considered in a systematic way, while allowing unbiased responses and encouraging digression for increased detail (Hay, 2000). A guide was used to structure the interviews and focus groups rather than a questionnaire. The key elements in the guide are given in Table 2. The guide was designed to allow respondents to identify items relevant to them, to minimize researcher influence through prompting, to encourage elaboration of experiences and insights, yet to check for information in key areas. The interviews and focus groups generated the documentation on community-relevant exposures and adaptive strategies.

INSERT TABLE 2 – Checklist of topics for semi-structured interviews and focus groups

Purposive sampling (Hay, 2000) of community members was used to identify groups of interviewees in order to gain insights from a representation of the community with respect to experiences and knowledge related to the study. The sample included men and women, small farmers, commercial agricultural companies, employees, goat herders, retired residents, small business owners, permanent, newly arrived and temporary residents, members of community clubs and water managers. The snowball sampling technique (Hay, 2000) was used to identify interviewees within each group. The two strategies complimented each other and proved to be an effective and efficient way to solicit participants for the research.

Each of the three focus groups consisted of between six and twelve participants who had not been formally interviewed. The purpose was to develop an understanding of relevant exposures, sensitivities and adaptive capacity in the community from varying perspective and the ways that the community has dealt with these. The focus groups provided a means of considering processes affecting vulnerabilities beyond individual households. The first focus group consisted of a group of community key informants; the second focus group was conducted with the *Club de Adultos Mayor* (Elders Club) and the third with students from the local school.

Information from observation, interviews and focus groups was supplemented by data from census records, publications, historical documents, newspapers, government reports, climate and hydrological records, and other research projects in the area in order to document the conditions and changes identified by the residents. In particular, climatologists, hydrologists and civil engineers provided information on climate and water conditions in light of changing climate as they related to the activities of the community.

4. Current Vulnerability

4.1 Current exposures and sensitivities

The community has had to deal with a range of environmental and socio-economic stresses; that is, multiple exposures were identified by the community. For the most part exposures are related, directly or indirectly, to water resources. However, the community also had strong concerns regarding problematic conditions experienced since the arrival of the agricultural companies. In general, the exposures to which Diaguitas is particularly sensitive stem from four main inter-related factors: global climatic phenomenon (especially ENSO), the physical landscape, international demand (fruit, wine), and national economic strategies (export-oriented). The analysis here focuses on vulnerabilities related to water and climate, although these are experienced through connections with other forces and processes (Figure 4).

INSERT FIGURE 4: Forces and processes related to the vulnerability of Diaguitas

4.1.1 Debris Flows and Flooding

The consequences of intense rainfall events were a dominant concern for the residents of Diaguitas. Episodes of heavy rains, or '*lluvias locas'* (crazy rains) tend to occur every few years, coinciding with El Niño conditions. During an El Niño year annual rainfall can be two to three times as high as the long-term mean. During the last decades of the 20th century, the frequency of precipitation events decreased but their intensity increased in conjunction with more frequent and intense ENSO events since the mid 1970s (Carrasco et al., 2005). Instrumental records of increasing extreme precipitation events are paralleled by community observations. Some community members feel that the rains have become much more intense in recent decades. Many indicated that rainfall used to be more moderate - it would rain for days but with less intensity.

Heavy rains lead to temporary high river flows and temporary lagoons and contribute to erosion (Cepeda et al. 2004). Diaguitas is located at the base of sparsely vegetated slopes consisting of dry, sandy sediment. These community-adjacent slopes are susceptible to debris flows when saturated. During the last decade, two major debris flows, in 1997 and 2004, affected the community when *lluvias locas* were experienced after prolonged dry periods. In 2004, more than 100mm of rain fell in six hours and triggered movement on the unstable slope. The resulting debris flows destroyed irrigation canals, caused river swells, blocked roads and made parts of the community inaccessible.

The physical landscape, steep and unstable slopes, sparse vegetation, and location of the community make Diaguitas susceptible to debris flows, but this is compounded by human modifications of the slopes which have reduced the sparse vegetation via grazing and clearing and leveling for crops. Land-use change, removal of natural vegetation and physical modification to the slopes contributes to slope failure (Gray and Sotir, 1996). Goat herders promote erosion and slope instability by grazing their animals on the available vegetation on the hillsides. Though there are currently fewer goat herders than in the past, reduced access to the valley floor and lower slopes has contributed to more intensive grazing of the upper slopes. Commercial agricultural operations influence slope instability by removing natural vegetation and physical modification of the hillsides. Large areas of steep land have been cleared of vegetation, smoothed or terraced, and irrigated for vineyards, citrus and avocado plantations. Commercially planted vegetation does not stabilize the slopes in the way that natural vegetation did, as the drip-irrigation fed roots of the vines are quite shallow and there is no canopy during the rainy season to protect the soil from the impact of the rain. In addition, agricultural soils tend to be more compacted and there is a decline in organic matter resulting from reliance on chemical fertilizers which also adds to their susceptibility to debris flows (Goudie, 2001).

The recent and rapid expansion of commercial vineyards and the changes in land cover and land uses have modified drainage patterns. Older residents of the community noted that previously there were multiple *quebradas* (ephemeral creeks) which drained the slopes during periods of intense rainfall. Water would not accumulate and the energy of the water would be dispersed. With the modified landscape there are only one or two *quebradas* where all the water is forced to descend, increasing the force of the flow and moving more debris. Many respondents indicated that when the land was covered by natural vegetation and the surface was unmodified by humans, the energy of the debris flows was dissipated and less of a threat. It was also noted that the debris flows have been more frequent since the arrival of the agricultural companies and the planting of monoculture commercial vineyards on the slopes.

The debris flows are very destructive and threaten the homes and lives of residents. They cause damage to homes, canals and vineyards and block roads and paths making it difficult to help other residents in more isolated parts of the community. Residents have been hospitalized with injuries and hypothermia and some have been left homeless and forced to relocate or replace their homes.

4.1.2 Dry periods and natural vegetation

There is evidence of declining average annual precipitation in the basin, most pronounced in the coastal area, in the order of 50% over the period 1900-2000 (Cepeda et al. 2004; Mall, 2005; Kalthoff et al. 2006). Between 1915 and 2003 the Elqui Valley experienced 16 years of drought conditions (30-60mm of precipitation) and 11 years of extreme drought conditions (less than 30 mm) (Fiebig-Wittmaack and Perez, 2005). Consistent with community insights, data for Diaguitas (see Figure 2) show that since approximately 1945 there has been a decrease in precipitation in the area (Cepeda et al. 2004; Carrasco, et. al., 2005; Kalthoff et al. 2006).

Prolonged dry periods, typically coinciding with La Niña episodes, directly affect the natural vegetation on which goat herders rely. During prolonged dry periods there is insufficient moisture for vegetation growth and the goats have insufficient feed over their usual grazing areas.

Dry periods were not perceived as a source of concern equally among the members of the community. The majority of Diaguitas' residents no longer rely directly on their own agricultural production since they have become dependent on wages from agricultural companies. The agricultural companies are not particularly sensitive to precipitation as they are more dependent on river discharge for irrigation than precipitation.

4.1.3 Irrigation water shortages

Agriculture in the Elqui River basin predominantly relies on irrigation. Water is delivered to agriculturalists via a complex system of canals and gates, and water rights in Diaguitas are administered as a portion of the water in the canal. In real terms, this translates as a defined period of time during which owners of water rights who are located on a particular canal (*canalistas*) are entitled to the water in the canal and are allowed to open their canal gates to capture this flow. The system depends on the availability of sufficient water in the canals and cooperation among the *canalistas*. Since the water in the canals relies on gravity feed from higher points on the Elqui River, periods of low flow could lead to insufficient water in irrigation canals and thus have implications for the security of agricultural production.

4.1.4 Access to potable water

Potable water in Diaguitas primarily comes from ground water. The community has a community well, two storage tanks and a local *Comite de Agua Potable Rural* (APR) to provide and distribute potable water to the community. The APR distributes potable water to residents who are billed monthly. Demand increases during the summer months due to temporary population increase and industrial and recreational potable water use. The packing departments of agricultural departments require potable water to prepare grapes for export. Migrant workers and tourists place additional pressure on the potable water supply, particularly so as increasing wealth and tourism have led to more swimming pools (which are filled with potable water). In addition, supply decreases during the dry summer months when aquifer recharge is slower or non-existent. During times of higher demand in the summer, the potable water supply is frequently shut off by the APR for the entire community, including agri-business. Water is shut off to individual households by the APR if a resident fails to pay their bills, which is an issue particularly for pensioners and seasonal workers. A water bill can amount to approximately 25% of a seasonal worker's salary at times.

4.1.5 Socio-Economic Exposures and Sensitivities

"then arrived the hand of the rich man and everything changed." –Resident of Diaguitas

An ideal climate for fruit production and international demand for grapes and other fruits, combined with Chile's export-oriented economic strategies have brought multi-national agricultural firms to the Diaguitas area. The companies have created many employment opportunities, but they have also brought other changes and challenges to the community.

Residents have become less dependent on their own agricultural production, and dependency on employment (wage labour) has increased. Many residents of Diaguitas are small farmers who do not have the ability to compete with companies and super markets. Residents sought employment with the companies for income, and some sold their land and/or water rights to the companies. As one respondent stated, "the small farmer really doesn't have a possibility". Even those residents who have some land often grow little because of lack of time, lack of markets and the stigma of growing basic food crops. A large portion of the community is now dependent, directly or indirectly, on the agricultural industry to maintain their livelihoods. There are very few employment opportunities in other industry or service activities, education levels are very low among the adults, and most young adults have only ever worked in commercial agriculture, forcing some men to leave the community for months at a time to work in other areas. Wages are low and employment is typically seasonal, leaving even employed residents with limited income.

Diaguitas has experienced a steady seasonal influx of migrant workers. Some workers choose to settle permanently while others work on contract for out-sourcing companies. Some of the agricultural companies use out-sourcing to bring in workers who will work for less money than community residents. This process has created social tension and community segregation between the original residents and the newcomers. The newcomers are blamed for bringing social problems to the community and there is a strong concern that the community's identity is being lost. The changing economic and social conditions, particularly the reduction in livelihood opportunities, contribute to the susceptibility of the community to climate-related exposures and influence the adaptive strategies available to deal with the hazards.

4.2 Current adaptive strategies and capacity

"*Here in Chile we adapt to everything*" – Resident of Diaguitas

Several adaptation strategies are commonly adopted to cope with the problematic conditions, with varying effectiveness. Adaptation strategies are evident at several levels of society, from the individual and household to community, municipal and regional institutions. The adaptive strategies are rather limited (Table 3) and many of them are reactionary, tending to address immediate consequences rather than the sources of the problems. These 'band-aid-like' solutions often leave the residents susceptible to future hazardous conditions.

INSERT TABLE 3 – Community and institutional adaptations to climate-related exposures, Diaguitas

4.2.1 Debris Flows and Flooding

There are several adaptations taking place to help prepare for and cope with the consequences of intense rainfall. After the 2004 debris flow, large bowl-like structures were constructed by the regional *Direccion de Obras Hydraulicas* on the slope above the community to collect descending debris and retain water. These engineering works have been effective in managing the consequences of less intense rain events but many are nearly at capacity. This renders them ineffective to cumulative or large flows, and places the community at risk. Currently there is no responsibility taken for these structures as the DOH that constructed the original capture areas does not have the responsibility to maintain them.

Two artificial channels were constructed by the DOH after the 2004 debris flows to divert water and debris away from the community and school. For the most part, these channels are narrow and simply dug into the loose sandy soil. The diversion channels have not yet been tested. However, the structures are deemed to be ineffective by residents and some regional engineers with the DOH on the grounds that the structures are not large enough to contain the large flows.

The regional emergency department, *Oficina Regional de Emergencia* (OREMI) is involved in planning for the prevention of and response to emergencies in the region. In recent years, OREMI has begun using the internet to obtain data on extreme weather forecasts and seismic activity. OREMI relays information on potential hazards such as debris flows and flooding to municipalities and emergency response organizations and thus allows for more timely actions. In response to the debris flow in 1997 the regional government built small 'shacks' for those who had lost their homes.

At the municipal level, prior to the beginning of the winter/rainy season, the Municipal Emergency Department distributes bulletins to households and conducts radio announcements to disseminate information on preparing for heavy rains. The bulletin and announcements remind residents to reinforce their roofs, windows and doors; remove debris from the yard; clean surrounding irrigation canals to avoid flooding; have a supply of food, water, batteries, a first aid kit and flashlight and supportive and to help neighbours.

In 1997 residents of Diaguitas created a Community Emergency Committee in response to a prolonged water shortage, an earthquake, and debris flows following heavy rains. Municipal and regional emergency departments and other institutions were slow to respond during these problematic conditions, and Diaguitas wanted to be better organized and prepared for future emergencies. However, due to a lack of resources (money, equipment) the committee could not function properly and no longer exists.

Although there may not be an organized community committee to help during emergencies, residents employ a range of adaptive strategies at the household level and canal association levels. When heavy rains are anticipated, residents commonly reinforce their homes (windows, roofs and doors) and purchase extra food and batteries and clean canals. The *asociacion de canalistas* cleans canals and closes irrigation gates in order to reduce the risks that canals overflow and the walls of canal walls are damaged. However, individuals commonly accept that debris flows are part of living in Diaguitas and do not currently have a comprehensive anticipatory strategy to lessen their vulnerability, and may again need to rely on government-provided temporary housing (as was the case after the 1997 events).

4.2.2 Dry periods and natural vegetation

During prolonged dry periods with low natural vegetation growth, goat herders have less access to fodder for their animals. In response, they migrate well down the valley, even to the coast, where there is generally more moisture to support vegetation due to the fog and increased atmospheric humidity from the ocean. However, this is costly for herders because often they have to rent vehicles to transport their herds. If the herders do not migrate they risk losing many goats, their milk production will be very low, and their incomes and livelihood threatened.

4.2.3 Irrigation water shortages

Diaguitas has often experienced and felt the impacts of insecure irrigation water supplies during periods of low discharge in the Elqui River. Agricultural companies have responded to past water stresses by increasing water use efficiency, implementing off-stream storage facilities, and securing access to additional water rights.

Increased water efficiency has been achieved in industrial agriculture in the Elqui Valley through use highly efficient drip-irrigation systems to reduce their water use and the implementation of concrete liners for secondary irrigation canals to minimize water loss through seepage. In addition, the agricultural companies have constructed large storage ponds which allow them to irrigate at times when needed for production, even when flows in the river and canal are low. These technologies reduce their susceptibility to periods of surface water scarcity. One agricultural company has also purchased water rights on two canals to ensure an extra supply of irrigation during extremely dry periods and spread the risk of one particular canal having insufficient flow for irrigation. In this case, one canal is used as the primary canal, while the water rights on the second canal are kept for emergency use. Agricultural companies have also sent employees to monitor usage along canals to ensure that individuals and other companies do not access more water than they are entitled to, thus increasing the chances that water will be in the canal when the company needs it.

At the community scale, during times of water shortages the *Junta de Vigilancia* or the *asociacion de canalistas*, have the discretion to lower the main canal gate and reduce the intake into the canal. During official drought emergencies, the *Direccion General de Aguas* has the authority to call for a reduction in all private water use (Hearne and Easter, 1997). Official drought zones are declared by the president of Chile forcing farmers to use less water. In times of water shortages, owners of water rights share the shortage by each receiving less of the available water.

Small producers use less efficient, traditional flood or furrow irrigation techniques, and irrigation is only an option if there is water passing through the canal on which they hold water rights. The lowering of the main canal gate during times of shortages requires the community to share the scarcity. Individual adaptation strategies are limited. Small farmers tend to accept the circumstances and associated potential losses; however, there are a few producers with small storage ponds for irrigation water. A program exists to assist individual farmers in improving the efficiency of their irrigation systems. Improvements could include cementing a portion of the canal, covering the canal, making a small reservoir and/or upgrading from furrow irrigation. After application, approval and inspection of the improvement project, the farmer may be refunded for 75% of incurred costs. However, it is beyond the capacity of most, if not all, small farmers to access these funds. Farmers do not have the resources to complete a computerized form, travel to the region's capital, pay a non-refundable application fee and fund the project itself. No farmer in Diaguitas has taken advantage of this program.

Occasional irrigation water shortages in Diaguitas have always existed. Larger producers are better able to adapt to the conditions due to greater economic and technological resources. However, they are still vulnerable to prolonged water shortages.

4.2.4 Access to potable water

Lack of access to potable water is related to insufficient or unreliable supply at the community scale, and an inability to connect to the potable water system due to the location of their dwelling and/or inability to pay for water at the individual level. The community has become accustomed to periods when there are insufficient potable water supplies, especially in the summer. Individuals adapt to supply insecurity by keeping barrels full of water. The fruit processing companies who use potable water for cleaning and packaging have had difficulty managing this problem, and often have to close down the packing department until the water is turned back on.

For those members of the community unable to connect to the potable water distribution system, the municipality delivers potable water. In the case of non-payment, the APR is generally sympathetic and lenient to those who can not always make their payments and often gives households several months to pay before shutting off the water. The government also provides subsidies to single mothers to help pay for potable water, a policy which has led to some couples not marrying in order to be eligible for these funds.

There appears to be no systematic, institutional set of procedures to deal with the recurring periods when potable water supplies are insufficient to meet demands in Diaguitas. The existing *ad hoc* arrangements by the APR, residents and companies would appear to ensure that the community remains sensitive to the limited and variable supplies of water in the valley.

5. Future Vulnerability

5.1 Future exposures

In the future, especially under climate change, several of the conditions to which Diaguitas is sensitive are likely to be exacerbated (Table 4). The capacity of the community to deal with these changing exposures relates to the opportunities and constraints evident in current adaptation processes, and how these might be moderated by changes in the society-economy and its institutions.

INSERT TABLE 4 – Expected changes in climate-related conditions for Diaguitas

Under climate change the Elqui River Basin can expect to experience increased frequency and intensity of ENSO processes, resulting in intense rainfall events (El Niño) and more frequent and prolonged periods of drought (La Niña) (Downing, 1992; IPCC, 2001; 2007; Cepeda et al. 2004). The cycle of prolonged dry periods followed by intense rainfall on the poorly consolidated sandy soils triggers debris flows. In north-central Chile, these occurrences typically correlate with El Niño events (Sepulveda et al. 2006). Since the mid-1970s, El Niño episodes have become both more frequent and more persistent and this trend is expected to continue (Francis and Hengeveld, 1998; Mata and Campos, 2001).

Although El Niño brings isolated periods of abundant and intense rainfall, average precipitation has decreased in the Elqui River Basin (Figure 2) and this trend could continue. Climate change scenarios (doubling of carbon dioxide concentration in the atmosphere relative to 1990 levels) have generally indicated a decrease in rainfall for this region (Downing, 1992; CONAMA, 1999; Cepeda et al. 2004; Christensen et al. 2007; CONAMA, 2007). A decrease in precipitation will directly affect farmers, commercial agriculture operations and goat herders who are very dependent on surface water. Further reductions in precipitation may force the remaining goat herders to abandon their livelihoods or migrate out of the region. A decrease in precipitation, together with changes in snow and ice supplies, will also affect groundwater recharge which is the source of potable water for Diaguitas.

The Elqui River is fed predominantly by snowmelt in the Andes. The current contribution of glaciers, notably El Tapado, is considered to be modest (Ginot et al. 2006). Under climate change it is expected that glaciers in this region will ablate (Mata and Campos, 2001) as glaciers in South America have receded dramatically in the past decades and many of them have disappeared (IPCC, 2001). As temperatures rise in the region, El Tapado may begin to recede and supply the Elqui River with additional discharge.

Rises in temperature and changes in the ENSO regime are likely to generate changes in the water cycle. There is evidence of elevation increase in the 0°C isotherm in this area (Carrasco et al. 2005). Currently, the 0°C isotherm is located around 2500 masl. Snow stations located at 2800m (El Indio) and 3100m (La Laguna) have recorded and average of 174.1mm and 152.2mm respectively of water column equivalent solid precipitation over the period 1981 to 1999. Currently, this winter precipitation maintains high summer flows[2]. A warming of 2°C to 4°C is expected by the second decade of the 21st century for this region (Downing, 1992; Cepeda et al. 2004; CONAMA, 2007), indicating that the

0°C isotherm may move into the altitudinal zone which currently serves to store winter precipitation for times when irrigation water is most needed. From the present to medium term, river discharge is expected to increase, and in the longer term river discharge is expected to decrease as snow and ice reserves diminish (IPCC, 2001; Cepeda et al. 2004). In addition, higher temperatures increase the water requirements for irrigation, in the order of 7% more irrigation water for each degree Celsius of temperature increase (Downing, 1992).

Currently, discharge levels are being sustained or increasing in the Elqui (Cepeda et al. 2004; Mall, 2005). As surface water resources increase, further agricultural expansion tends to be encouraged, and demand increases. In the longer term, depletion of snow and ice reserves, coupled with increased periodicity and severity of drought, could result in an overall reduction of the Elqui's flow to the point where current and future demands cannot be met. Figure 5 illustrates some of the potential effects of changes in climate in the shorter and longer terms.

INSERT FIGURE 5: Selected effects of climate change on Diaguitas

The potable water situation in Diaguitas is also susceptible to future changes. Currently there is little information with respect to the interaction between groundwater and surface water, precipitation and groundwater recharge in the Elqui Valley. However, given decreases in precipitation and lower river discharge, it is expected that there would be less aquifer recharge, thus less potable water supply. Demands on potable water are already heavy, and sometimes cannot be met. Increases in demand from agribusiness, seasonal labour and tourism it will be difficult to meet in a period of declining supply.

The effects of climate change on water, commercial activity and livelihoods in Diaguitas can be differentiated into shorter-term and longer-term. In the shorter-term, an increase in temperature will accelerate snowmelt resulting in an increase in river discharge, the source of irrigation water, likely contributing to the continued expansion of agri-business in the valley. This would bring employment opportunities, but also more migrant workers, social stresses, and increased demands for irrigation and potable water. In the longer-term, temperature increases would ultimately deplete the snow and ice reserves, resulting in decreased river discharge and groundwater recharge and reductions in the supply of irrigation and potable water along with increased water demands. The combination of higher water demands and reduced water supply would severely constrain agricultural operations at all scales and exacerbate existing stresses on the potable water supply. This would translate into a decrease in agricultural production and employment and lower security of potable water, thus affecting the industry, the regional economy and the livelihoods of the people of Diaguitas.

Countries, regions and communities with a large portion of the economy in agriculture face a significant exposure to climate change. All agricultural livelihoods in Diaguitas are exposed to climate change: goat herders may have insufficient natural vegetation for grazing their herds, small farmers will be affected by lower precipitation and less secure water supplies in canals, and agricultural companies will likely face inconsistent and insufficient surface water supplies for irrigation. Future water shortages would threaten the viability of the main sources of employment in the Elqui Valley, and put many livelihoods at risk.

5.2 Future Adaptive Capacity

The ability to undertake adaptations is understood to be dependent on, or influenced by, a variety of conditions including effectiveness of institutions, access to financial and technological resources, information and knowledge, kinship, and social capital (Watts and Bohle, 1993; Hamdy et al. 1998; Adger, 1999; Handmer et al. 1999; Toth, 1999; Kelly and Adger, 2000; Smit and Pilifosova, 2001; Wisner et al. 2004; Smit and Wandel, 2006). How and why people have adapted in the past provide indications about their potential to cope with changing conditions in the future. This study identified several adaptive strategies at various scales and constraints on the adaptive capacity of the community to changing climatic conditions.

Well-developed social institutions can help deal with climate-related risks (Adger and Kelly, 1999; Adger, 2000; Smit and Pilifosova, 2001; Tol et al. 2004; Ivey et al. 2004; Naess et al. 2005). In the Elqui Valley, institutions from the national to the community level provide a structure with the authority to manage both surface and potable water under changing climatic conditions. However, the limitations in communication and coordination across levels and among institutions impede effective planning and response. High turnover rates of employees in the municipality and regional organizations also limit effectiveness due to deficits in knowledge and experience.

Chile's institutional arrangements of water markets and water rights provide a means for allocating water resources that would face problems of inequity, if not ineffectiveness, under diminished water supplies. Small farmers will be constrained in their efforts to produce and adapt to changes in surface water in the longer-term, particularly through their inability to compete for more water rights in the future when supplies are decreasing and the agricultural companies will be facing difficulties meeting their demands. Budds (2006) notes that the Chilean Water Code was formulated to benefit industrial-scale private sector development and requires substantial reforms if it is to address social equity.

In many cases, greater economic resources can contribute to adaptive capacity (Kates, 2000; Smit and Pilifosova, 2001). Many of the municipal, regional and water management agencies identified a lack of human and financial resources as a major constraint on their capacity. Employees noted that tasks are often not completed due to lack of resources and there was insufficient money available for prevention projects. Similarly, the Diaguitas Community Emergency Committee that was created in 1997 by community members was dismantled due to insufficient economic resources. Economic and technological constraints can combine and limit adaptation options. In Diaguitas as small farmers are not able to take advantage of more efficient irrigation systems due to insufficient economic resources.

Kinship and social cohesion among community members can help to form adaptive strategies and enhance adaptive capacity (Pelling, 1998; Adger, 2003). Currently Diaguitas is experiencing segregation in the community and high social tension. Existing kinship ties and community identity are weakening with an influx of migrant workers. Any reduction in social tension would likely help adaptive capacity if for no other reason than freeing human resources for more productive investments. Pooling resources and ideas could allow for a coordinated approach to applying for funds to make improvements to the canals (increase efficiency of irrigation), and make improvements to the community to make it more attractive for tourism. Tourism would serve to diversify the economic base and provide more secure livelihoods in order to better respond to changes outside their control, so long as tourism growth is not dependent on increased water supplies. An additional constraint to adaptive capacity in the community relates to leadership and organization. Community organizations were dismantled during the coup in Chile, and there is still distrust among community members about participants' motives.

Greater access to information is expected to increase the likelihood of timely and effective adaptation (Fankhauser and Tol, 1997; Smit and Pilifosova, 2001). Adaptive strategies are formulated within the confines of available information and resources. In order to make effective plans and policy for the future, it is important for decision makers in the communities, municipalities, regions, water management institutions and so on, to know the current and past changes of hydrologic and climatologic regimes and how the livelihoods of the people are sensitive to them. In Diaguitas, there is limited knowledge about historical and expected hydrological and climate conditions, environmental changes, including climate change, and about how these combine with the land-use and economic changes to have implications for water resources and incomes. Without knowledge of the changing conditions and vulnerabilities, industry and institutions run the risk of not implementing anticipatory adaptations and/or reacting too late. Currently, institutions are planning predominantly for the short-term.

Overall there was a general collective lack of awareness and concern for possible future hazards and conditions. For example, most respondents did not believe that the average river flow could diminish, because the "mountains will always provide water". Respondents in the community and municipal, regional and water management institutions shared similar attitudes with respect to the future. Most of the respondents were not familiar with the term "climate change" and few were aware of the implications for their water resources and livelihoods. It was not surprising that little had been done to address risks associated with climate change. At the regional institutional and large-scale agricultural level, few respondents acknowledged climate change as a significant risk or concern to resources and/or industry and few take any precautions with respect to future climate conditions.

These insights are generally consistent with those of Sepulveda et al. (2006) who looked at the geological hazard, climatic relationship and human response of debris flows in Chile. Sepulveda noted that there was no real consciousness in Chile about the hazard of debris flows and that people tend to forget about disasters quickly. The study also found that the attitude of authorities' (such as OREMI) to natural disasters in Chile is mostly reactive rather than preventative.

5 Conclusion

This paper characterized the nature of vulnerability in the dryland community of Diaguitas, situated in the Elqui Valley of Chile. The vulnerability approach generated a description of the forces and processes contributing to current and future vulnerabilities in light of climate and climate change. The study focused on water resources and water use by documenting the exposures and adaptive strategies of the community, and assessing the role of climate change in affecting the community vulnerability.

Multiple exposures were identified related to water resources, climate and socio-economic conditions that stress the community. A dominant concern and risk to the community was rainfall abundance and intensity as this tends to trigger debris flows along the steep and unstable slopes. Both the community and regional water management agencies have found ways to cope with these conditions such as public education and infrastructure. Surface water shortages were also found to be problematic for some sectors of the community. Goat herders are particularly affected by prolonged dry periods, as are small landholders. The majority of Diaguitas residents no longer directly rely on their own agricultural production, but are affected through the commercial agricultural operations. The agricultural companies, who rely on surface water, use highly efficient irrigation, purchase additional water rights, and have water storage systems to reduce their sensitivity to variations in supply. Potable water access has been problematic for the community (individuals and companies) during the summer months, due to a combination of high demand and slower recharge of the aquifer. There have been some adaptations to help cope with lack of accessibility, notably keeping small reserves and subsidies.

The water and climate-related exposures were important to the community, but they were experienced in the context of other non-water related stresses. Community members are concerned about the changes that have occurred to their livelihoods since the arrival of the agricultural companies. While the companies provide employment, the community now is dependent on a single industry for low-wage seasonal employment. The social tensions that have been created since the arrival of the companies and the influx of migrant workers have begun to deteriorate the kinship system and erode elements of social networks. The social tensions and segregation in the community have become a hindrance in the community's ability to organize, for example, to adapt to certain exposures or promote additional industries in the community to reduce its sensitivity. This is currently problematic and in the future it is likely to be a challenge to adapt and take advantage of opportunities. These conditions influence the community's occupance characteristics and sensitivities, and thereby affect future vulnerability of the community.

For the most part, residents of Diaguitas were more concerned with meeting the needs of daily life rather than with what could happen in the future, even if they had experienced the effects of droughts and debris flows in the past. Most respondents were particularly concerned with changing social conditions, such as employment and crime in the community, and there was less concern about changes in the climate and water resources and their implications for the future.

In the future, the community is vulnerable to the hydrologic regime. An increase in frequency of El Niño years would likely instigate more debris flows due to the impact of the intense and abundant rainfall following the prolonged dry periods of La Niña, especially if the land-use changes continue to expose the slope surfaces. Temperature increases and changes in precipitation will affect the water cycle. In the short to medium term river discharge is likely to increase, but as snow pack and glacier resources diminish, river discharge could decrease. Such changes in water resources would have major implications for individuals, the commercial agricultural sector and water management institutions.

Several constraints to adaptation, at the community and institutional level could impede the capacity of Diaguitas and institutions to respond to future conditions associated with climate change. A lack of awareness of environmental changes and their implications for livelihoods and businesses, and a lack of concern for the future do not prompt precautionary planning. Adaptive responses tend to be reactive. The capacity of institutions and the community to adapt is limited by lack of information sharing, lack of financial or technological resources, and/or by limits in human capital. In particular, a weakened kinship and social organization in the community has likely decreased the capacity of the community to effectively deal with both current and future conditions.

This case study outlines the nature of a community's vulnerability to climate stresses in a dryland region of north-central Chile. Climatic conditions interact with the local physical environment and socio-political-economic systems to influence the vulnerability of the community. People in semi-arid regions currently exhibit vulnerability to existing climate conditions, many of which are expected to be intensified with climate change. It is noteworthy that this community was pre-occupied with stresses not directly related to climate change, yet which contribute to the vulnerability of the community. This study also shows that the coping ability of a community to deal with changes and risks will be greatly influenced by a number of factors (e.g. infrastructure, economic wealth, kinship, technology, information) including the role of institutions. Although institutions play a role of most adaptive strategies, their effectiveness in reducing the vulnerability of the community was limited.

Notes

1. Though not as arid as deserts, drylands are characterized by their limited water supply, low and highly variable rainfall, and recurrent drought. When surface water accumulates, often it is not easily retained as high temperatures and intense precipitation cause evaporation and rapid runoff (IISD, 2003).

2. Simple linear regression analysis of snow accumulation in the High Andes at La Laguna snow station with summer discharge at El Algarrobal fluvial station, three km upstream of Diaguitas, over the period 1955-2000 indicated a statistically significant relationship between winter snowfall and summer discharge (99% confidence) with an R-square of 0.889.

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References

Adger WN (1998) Observing institutional adaptation to global environmental change: theory and case study from Vietnam. Centre for Social and Economic Research on the Global Environment Working Paper GEC 98-21. University of East Anglia, Norwich, UK.

Adger WN (1999) Social vulnerability to climate change and extremes in coastal Vietnam. World Development 27: 249-269

Adger WN (2000) Institutional adaptation to environmental risk under the transition in Vietnam. Annals of the Association of American Geographers 90: 738-758

Adger WN (2003) Social capital, collective action, and adaptation to climate change. Economic Geography 79: 387-404

Adger WN (2006) Vulnerability. Global Environmental Change 16: 268-281

Adger WN, Kelly PK (1999) Social vulnerability to climate change and the architecture of entitlements. Mitigation and Adaptation Strategies for Global Change 4: 253-266

Arnell NJ 1999. Climate change and global water resources. Global Environmental Change 9: 31-49

Arnell N, Liu C (2001) Hydrology and water resources. In Climate Change 2001: Impacts, Adaptation, and Vulnerability - Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Chapter 18. Cambridge, UK: Cambridge University Press

Arnell NW (2004) Climate change and global water resources: SRES emissions and socio-economic scenarios. Global Environmental Change 14: 31-52

Bauer C (1997) Bringing water markets down to earth: The political economy of water rights in Chile, 1976-95. World Development 25: 639-56

Beniston M (2003) Climatic change in mountain regions: a review of possible impacts. Climatic Change 59: 5-31

Belliveau S, Smit B, Bradshaw B (2006). Multiple exposures and dynamic vulnerability: evidence from the grape industry in the Okanagan Valley, Canada. Global Environmental Change 16: 364-378

Blaikie P, Brookfield HC (1987) Land Degredation and Society. Methuen, London

Blaikie P, Cannon, T, Davis I, Wisner B (1994) At Risk: Natural Hazards, People's Vulnerability, and Disasters. Routledge, New York

Bohle HC, Downing TE, Watts MJ (1994) Climate change and social vulnerability. Global Environmental Change 4: 37-48

Brooks N (2003) Vulnerability, risk and adaptation: a conceptual framework. Working

Paper 38. Tyndall Centre for Climate Change Research

Bryant R, Bailey S (1997) Third World Political Ecology. Routledge, New York

Bryant CR, Smit B, Brklacich M, Johnston TR, Smithers J, Chiotti Q, Singh B (2000) Adaptation in Canadian agriculture to climatic variability and change. Climatic Change 45: 181-201

Budds J (2004) Power, nature and neoliberalism: the political ecology of water in Chile. Singapore Journal of Tropical Geography 25: 322-342

Burton I, Kates RW, White GF (1978) The Environment as Hazard. Oxford University Press, New York

Burton I, Kates RW, White GF (1993) The environment as hazard. Second edition. New York, Guilford Press

Burton I, Huq S, Lim B, Pilifosofa O, Shipper EL (2002) From impacts assessment to adaptation priorities: the shaping of adaptation policy. Climate Policy 2: 145–159

Carrasco J, Casassa G, Quintana J (2005) Changes of the 0ºC isotherm and the equilibrium line altitude in central Chile during the last quarter of the 20th century. Hydrological Sciences-Journal-des Sciences Hydrologiques 50: 933-948

Cepeda J, Fiebig M, Morales H, Salas S (2004) Description of the Elqui River Basin, IACC Project Working Paper No. 2. Universidad de La Serena

Chamber R, Conway GR (1992) Sustainable rural livelihoods: practical concepts for the 21st century. IDS Discussion Paper 296. University of Sussex, Brighton

Clark WC, Jäger J, Corell R, Kasperson R, McCarthy JJ, Cash D, Cohen SJ, Desanker P, Dickson NM, Epstein P, Guston DH, Hall JM, Jaeger C, Janetos A, Leary N, Levy MA, Luers A, MacCracken M, Melillo J, Moss R, Nigg JM, Parry ML, Parson EA, Ribot JC, Schellnhuber HJ, Schrag, DP, Seielstad GA, Shea E, Vogel C, Wilbanks TJ (2000) Assessing vulnerability to global environmental risks. Research and Assessment Systems for Sustainability Project, Environment and Natural Resources Program. Belfer Center for Science and International Affairs, John F. Kennedy School of Government, Harvard University

Christensen, J.H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R.K. Kolli, W.-T. Kwon, R. Laprise, V. Magaña Rueda, L. Mearns, C.G. Menéndez, J. Räisänen, A. Rinke, A. Sarr and P. Whetton, 2007: Regional Climate Projections.

In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

CONAMA (1999) Primera Comunicación Nacional Bajo la Convención Marco de las Naciones Unidas Sobre el Cambio Climático. Comisión Nacional del Medio Ambiente, Chile

CONAMA (2007) Estudio de la variabilidad climática en Chile para el siglo XXI. Comisión Nacional del Medio Ambiente, Chile

Crabbe P, Robin M, (2006) Institutional adaptation of water resource infrastructures to climate change in eastern Ontario. Climatic Change 78: 103-133

Cutter S (1996) Vulnerability to environmental hazards. Progress in Human Geography 20: 529-539

Cutter S, Boruff JB, Shirley WL (2003) Social vulnerability to environmental hazards. Social Science Quarterly 84: 242-261

Davidson O, Halsnaes K, Huq S, Metz B, Sokona Y, Verhagen J (2003) The development and climate nexus: the case of sub-Saharan Africa. Climate Policy 3S1: S97-S113

de Loë RC, Kreutzwiser R (2000) Climate variability, climate change and water resource management in the Great Lakes Climatic Change 45: 163-179

Dilley M, Boudreau TE (2001) Coming to terms with vulnerability: a critique of the food security definition. Food Policy 26: 229-247

Downing TE (1992) Climate change and vulnerable places: Global food security and country studies in Zimbabwe, Kenya, Senegal and Chile. Oxford: University of Oxford, Environmental Change Unit

Downing TE, Santibanez F, Romero H, Pena T, Gwynne RN, Ihl M, Rivera A (1994) Climate change and sustainable development in the Norte Chico, Chile: climate, water resources and agriculture. Oxford: University of Oxford, Environmental Change Unit

Downing TE (2003) Lessons from Famine Early Warning and Food Security for Understanding Adaptation to Climate Change: Toward a Vulnerability/Adaptation Science? In J.B. Smith, R.J.T. Klein and S. Huq, eds. Climate Change, Adaptive Capacity and Development. London: Imperial College Press

Fankhauser S, Tol RSJ (1997) The social costs of climate change: the IPCC second assessment report and beyond. Mitigation and Adaptation Strategies for Global Change 1: 385-403

Fiebig-Wittmaack M, Perez Valdivia C (2005) Eventos catastroficos naturales. In Cepeda J, Fiebig-Wittmaack M, Perez C, Trigos H, Zavala H. Caracterizacion bio-geo-fisica de la cuenca del rio Elqui. IACC Working Paper. Universidad de La Serena

Folke C, Carpenter S, Elmqvist T, Gunderson L, Holling CS, Walker B (2002) Resilience and sustainable development: building adaptive capacity in a world of transformations. Ambio 31: 437-440

Ford JD, Smit B. 2004. A framework for assessing vulnerability of communities in the Canadian Arctic to risks associated with climate change. Arctic 57: 389-400

Ford JD, Smit B, Wandel J (2006) Vulnerability to climate change in the Arctic: A case study from Arctic Bay, Canada. Global Environmental Change 16: 145-160

Francis D, Hengeveld H (1998) Extreme weather and climate change. Environment Canada

Frederick KD, Major DC (1997) Climate change and water resources. Climatic Change 37: 7-23

Füssel HM, Klein RJT (2006) Climate change vulnerability assessments: an evolution of conceptual thinking. Climatic Change 75: 301-329

Gerten D, Schaphoff S, Lucht W (2007) Potential future changes in water limitations of the terrestrial biosphere. Climate Change 80: 277-299

Ginot P, Kull C, Schotterer U, Schwikowski M, Gäggeler HW (2006) Glacier mass balance reconstruction by sublimation induced enrichment of chemical species on Cerro Tapado (Chilean Andes). Clim. Past 2: 21-30

Goudie A (2001) The nature of the environment. Malden, MA, Blackwell Publishers

Gray DH, Sortir RB (1996) Biotechnical and bioengineering slope stabilization: A practical guide for erosion control. New York, John Wiley and Sons

Haddad B (2000) Rivers of Gold: Designing Markets to Allocate Water in California.

Washington, D.C., Island Press

Hamdy A, Abu-Zeid M, Lacirignola C (1998) Institutional capacity building for water sector development. Water International 23: 126-133

Handmer JW, Dovers S, Downing TE (1999) Societal vulnerability to climate change and variability. Mitigation and Adaptation Strategies for Global Change 4: 267–281

Hay I (2000) Qualitative research methods in human geography. Oxford, Oxford University Press

Hearne RR, Easter KW (1997) The economic and financial gains from water markets in Chile. Agricultural Economics 15: 187-199

Hearne RR, Donoso G (2005) Water institutional reforms in Chile. Water Policy 7: 53-69

Holling CS (1973) Resilience and Stability of Ecological Systems, Ann. Rev. Ecol. Syst. 4: 1–23

Huq S, Rahman A, Konate M, Sokona Y, Reid H (2003) Mainstreaming adaptation to climate change in least developed countries. London: International Institute for Environment and Development Climate Change Programme

Huq S, Reid H (2004) Mainstreaming adaptation in development. IDSBulletin 35: 15–21

International Human Dimensions on Global Environmental Change (IHDP) (2005) Science Plan- Institutional Dimensions of Global Environmental Change. IHDP Report Series, No. 16

Intergovernmental Panel on Climate Change (IPCC) (2001) In Climate change 2001: Synthesis Report. A contribution of Working Groups I, II, III to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK, Cambridge University Press

Intergovernmental Panel on Climate Change (IPCC) (2007) In Climate change 2001: Synthesis Report. A contribution of Working Groups I, II, III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK, Cambridge University Press

International Institute for Sustainable Development (IISD) (2003) Livelihoods and climate change. Winnipeg, Manitoba, International institute for sustainable development

Ivey J, Smithers J, de Loe RC, Kreutzwiser RD (2004) Community capacity for adaptation to climate-induced water shortages: linking institutional complexity and local actors. Environmental Management 33: 36-47

IUCN, International Institute for Sustainable Development, Stockholm Environment Institute, Swiss Organization for Development and Cooperation (2004) Sustainable livelihoods and climate change adaptation. Available via http://www.iisd.org/publications/pub.aspx?pno=647

Kalthoft N, Fiebig-Wittmaack M, Meißner C, Kohler M, Uriarte M, Bischoff-Gauß I, Gonzales E (2006) The energy balance, evapo-transpiration and nocturnal dew deposition of arid valley in the Andes. Journal of Arid Environments 65: 420-443

Kates RW (2000) Cautionary tales: adaptation and the global poor. Climatic Change 45: 5–17

Kelly PM, Adger WN (2000) Theory and practice in assessing vulnerability to climate change and facilitating adaptation. Climate Change 47: 325-352

Keskitalo ECH (2004) A framework for multi-level stakeholder studies in response to global change. Local Environment 9: 425–435

Klein RJT, Smith JB (2003) Enhancing the capacity of developing countries to adapt to climate change: A policy relevant research agenda. In Smith JB, Klein RJT, Huq S. eds. Climate change, adaptive capacity and development. London, UK, Imperial College Press

Lim B, Spanger-Siegfried E, Burton I, Malone EL, Huq S (2005) Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies and Measures. Cambridge, UK, Cambridge University Press

Liverman DM (1994) Vulnerability to global environmental change. In Cutter SL. eds. Environmental Risks and Hazard. Toronto, Canada: Prentice Hall

Leichenko RM, O'Brien KL (2002) The dynamics of rural vulnerability to global change: the case of Southern Africa. Mitigation and Adaptation Strategies for Global Change 7: 1-18

Mall E (2005) Balance Hídrico en Cuencas Nivo-Pluviales de los Ríos Elqui, Limarí y Choapa, IV Región de Coquimbo. Universidad de La Serena

Mata LJ, Campos M (2001) Latin America. In Climate Change 2001: Impacts, Adaptation, and Vulnerability - Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Chapter 18. Cambridge, UK: Cambridge University Press

McCarthy JJ, Canziani OF, Leary NA, Dokken DJ, White KS (2001) In Climate Change 2001: Impacts, Adaptation and Vulnerability- Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press

McLeman R, Smit B (2006) Migration as an adaptation to climate change. Climatic Change 76: 31-53

Miller A, Rhodes SL, MacDonnell LJ (1997) Water allocation in a changing climate: institutions and adaptation. Climatic Change 35: 157-177

Mustafa D (2002) Linking access and vulnerability: perceptions of irrigation and flood management in Pakistan. The Professional Geographer 54: 94-105

Naess L, Bang G, Eriksen S, Vevatne J (2005) Institutional adaptation to climate change: Flood responses at the municipal level in Norway. Global Environmental Change 15: 125–138

Nelson V, Meadows K, Cannon T, Morton J, Martin A (2002) Uncertain predictions, invisible impacts, and the need to mainstream gender in climate change adaptations. Gender and Development 10: 51-59

O'Brien KL, Leichenko RM (2000) Double exposure: assessing the impacts of climate change within the context of economic globalization. Global Environmental Change 10: 221-232

Paulson S, Gezon LL, Watts M (2003) Locating the political in political ecology: An introduction. Human Organization 62: 205-217

Peet R, Watts M (2004) Liberation ecologies: environments, development and social movements. London, UK: Routledge

Pelling M (1997) What determines vulnerability to floods: a case study in Georgetown, Guyana. Environmental and Urbanization 9: 203-226

Pelling M (1999) The political ecology of flood hazard in urban Guyana. Geoforum 30: 249-261

Pelling M (2002) Assessing urban vulnerability and social adaptation to risk - evidence from Santo Domingo. International Development Planning Review 24: 59-76

Polsky C, Schroter D, Patt A, Gaffin S, Martello ML, Neff R, Pulsipher A, Selin H (2003) Assessing vulnerability to the effects of global change: An eight step approach. Belfer Center for Science and International Affairs, Harvard University, John F. Kennedy School of Government

ProChile (2005) Chilean Exports. Available via http://www.chileinfo.com/

Productivity Commission (2003) Water Rights Arrangements in Australia and Overseas: Annex J, Chile. Commission Research Paper, Productivity Commission, Melbourne

Salinger MJ (2005) Climate variability and change: past, present and future – an overview. Climatic Change 70: 9-29

Sauchyn DJ Skinner WR (2001) A proxy PDSI record for the southwestern Canadian plains. Canadian Water Resource Journal 26: 253-272

Sen A (1981) Poverty and Famines: an essay on entitlement and deprivation. Oxford: Clarendon Press

Sepulveda SA, Rebolledo S, Vargas G (2006) Recent catastrophic debris flows in Chile: Geological hazard, climatic relationships and human response. Quaternary International 158: 83-95

Sivakumar MVK, Das HP, Brunini O (2005) Impacts of present and future climate variability and change on agriculture and forestry in the arid and semi-arid tropics. Climatic Change 70: 31-72

Smit B, Burton I, Klein RJT, Street R (1999) The science of adaptation: a framework for assessment. Mitigation and Adaptation Strategies for Global Change 4: 199-213

Smit B., I. Burton, R. Klein and J. Wandel. 2000. An anatomy of adaptation to climate change and variability. Climatic Change 45, 223-251

Smit B, Pilifosova O (2001) Adaptation to climate change in the context of sustainable development and equity. In Climate Change 2001: Impacts, Adaptation, and Vulnerability - Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Chapter 18. Cambridge, UK: Cambridge University Press

Smit B, Pilifosova O (2003) From Adaptation to Adaptive Capacity and Vulnerability Reduction. In Smith JB, Klein RJT, Huq S, eds. Climate Change, Adaptive Capacity and Development. London: Imperial College Press

Smit B, Wandel J (2006) Adaptation, adaptive capacity and vulnerability. Global Environmental Change 16: 282-292

Smith JB, Lazo JK (2001) A summary of climate change impact assessments from the US Country Studies Program. Climate Change 50: 1–29

Smithers J, Smit, B (1997) Human adaptation to climatic variability and change. Global Environmental Change 7: 129-146

Steward DW, Shamdasani PN (1990) Focus groups: Theory and practice. London, UK: Sage Publications

Strauch, G, Oyzrzun J, Fiebig-Wittmaack, M, González E, Weise SM (2006) Contributions of the different water sources of the Elqui river runoff (northern Chile evaluated by H/O isotopes. Isotopes in environmental and health studies 42: 3-3-322

Sutherland K, Smit B, Wulf V, Nakalevu T (2005) Vulnerability in Samoa. Tiempo 54: 11–15

Tol RSJ, Fankhauser S, Smith JB (1998) The scope for adaptation to climate change: what can we learn from the impact literature? Global Environmental Change 8: 109-123

Tol RSJ, Downing TE, Kuik JK, Smith JB (2004) Distributional aspects of climate change impacts. Global Environmental Change 14: 259-272

Tompkins EL, Adger WN (2004) Does adaptive management of natural resources enhance resilience to climate change? Ecology and Society 9:10. Available via http://www.ecologyandsociety.org/vol9/iss2/art10

Toth FL (1999) Fair Weather? Equity Concerns in Climate Change. London: Earthscan.

Turner BL, Kasperson RE, Matson PA, McCarthy JJ, Corell RW, Christensen L, Eckley N, Kasperson JX, Luers A, Martello ML, Polsky C, Pulsipher A, Schiller A (2003) A framework for vulnerability analysis in sustainability science. Proceedings of the National Academy of Sciences 100: 8074–8079

United Nations Framework Convention on Climate Change (UNFCCC) (1992). United Nations Framework Convention on Climate Change. Convention Text. IUCC, Geneva

Vasquez-Leon M, West CT, Finan TJ (2003) A comparative assessment of climate vulnerability: agriculture and ranching on both sides of the US–Mexico border. Global Environmental Change 13: 159–173

Wallersetin N (1999) Power between evaluator and community: research relationships within New Mexico's healthier communities. Social Science and Medicine 49: 39-53

Watts MJ, Bohle HG (1993) The space of vulnerability: the causal structure of hunger and famine. Progress in Human Geography 17: 43-67

Wheaton EE, MacIver DC (1999) A framework and key questions for adapting to climate variability and change. Mitigation and Adaptation Strategies for Global Change 4: 215-225

Wisner B, Blaikie P, Cannon T, Davis I (2004) At Risk, 2nd Ed. London: Routledge

World Bank. 2004. Chile New Economy Study. Available at http://www.hacienda.gov.cl/publicaciones.php?opc=explore&id=10124&actual=10095

Yohe G, Tol R (2002) Indicators for social and economic coping capacity - moving toward a working definition of adaptive capacity. Global Environmental Change 12: 25–40

Table 1 ENSO effect and annual precipitation at Vicuña, 1950-2000

		Precipitation (mm)		
	No. of yrs	Mean *	Std. Dev.	Range
≤5 months El Niño or La Niña	21	91.5	75.2	1.3 – 258.5

≥ 6 months El Niño	16	133.9	80.7	33.9 – 269.5
≥ 6 months La Niña	14	68.3	26.5	20.5 – 110.7
All years	51	98.4	71.2	1.3 – 269.5

* Between group variation in annual precipitation is statistically significant at the 95% confidence level.

Table 2 Checklist of topics for semi-structured interviews and focus groups

Key Theme	Examples of Topics Covered
Background Information	• Identify livelihood • Length of time in Diaguitas • Water uses
Current Exposures	• Identify conditions that have been problematic regarding: - social, economic, biophysical - water and climate - past and/or present - to whom (individuals, community, producers, water managers, institutions) - how
Current Adaptive Strategies	• Identify how exposures are managed • Identify who (individuals, community, institutions, etc.) facilitates adaptation • Identify what facilitates and constrains adaptive strategies
Future Conditions	• Based on previously identified exposures, would projected changes in e.g. land-use, economy, climate and water resources be problematic? - would these changes affect individuals, community, producers, water managers, institutions - how would individuals, community, producers, water managers, institutions manage these changes

Table 3 Community and institutional adaptations to climate-related exposures, Diaguitas

Exposure-Sensitivity	Individual and Community	Institutions
Debris Flows and Flooding	• Residents reinforce their doors, roofs and windows. • Residents stockpile extra food and batteries. • Formed a 'Community Emergency Committee' after the 1997 mudslide. It no longer exists. • A spontaneous solidarity to help neighbours in times of emergency by helping to remove debris, clean canals.	• The Municipal Emergency Committee distributes a bulletin and broadcasts radio announcements reminding residents how to prepare for the winter/rain season. • The DOH constructed two artificial channels to deflect debris/water away from the community. • The DOH constructed pool-like structures to collect debris/water that descends down the hills. • 'Shacks' were provided by the government to those that lost their homes.
Dry Periods and Natural Vegetation	• Goat herders migrate to areas with more vegetation	
Irrigation Water Shortages	• An agricultural company has water rights on two canals, one for daily and the other for emergency. • Agricultural companies in the Elqui Valley use highly efficient irrigation systems. • An agricultural company sends an employee to check that canals are flowing on schedule. • Small farmers tend to accept circumstances/losses. • Few small farmers have storage ponds.	• The Junta de Vigilancia and/or the president of the canal are able to diminish the intake of the canals. • In drought emergencies the DGA is able to reduce all water use and seize water rights under orders of the President of Chile. • Public funds are available by application to improve irrigation efficiency.
Access to Potable Water	• Residents keep barrels full of water for times when water is shut off. • Some couples do not marry in order to receive a subsidy for single mothers to increase access to potable water.	• The APR does not shut off residents' water right away, as there are months when people are jobless and unable to pay their bill. • Subsidies are available from the government to single mothers to pay for potable water.

Table 4 Expected changes in climate-related conditions for Diaguitas

Condition	Expected Change
El Niño	The frequency and intensity of El Niño is likely to increase as a result of climate change (IPCC, 2001). Since the mid-1970s, the El Niño phenomenon has been more frequent and more persistent (Francis and Hengeveld, 1998, Carrasco et al, 2005).
Rainfall	A decrease in average precipitation is predicted (IPCC, 2007). In the past 100 years precipitation has decreased by 50% (Cepeda et al, 2004).
Drought Conditions	Climate change may result in more frequent and prolonged droughts (Downing, 1992; IPCC, 2001; Cepeda et al., 2004).
Debris Flows	An increase in El Niño events combined with changes in land use and the physical landscape has the potential to cause more debris flows.
Temperature	The north-central area of Chile can expect an increase in temperature (IPCC, 2001) of approximately 2-4 degrees Celcius during the second decade of the 21st century (Cepeda et al., 2004). Higher temperatures and hence higher crop evaporative demand, mean a tendency towards an increase in irrigation demands (IPCC, 2001). Increased temperatures will result in less snow accumulation in the High Andes as the 0 degree isotherm moves to higher altitudes.
River Discharge	Andean glaciers are predicted to recede (IPCC, 2001). Increase in discharge is expected in the short/medium term due to increased snowfall, the melting of snow and glacier reserves (Cepeda et al., 2004). In the long-term, as the reserves diminish and volume of melt decreases, flows will no longer be supported and will decline to below present levels (IPCC, 2001). Less snow accumulation in the High Andes will result in lower summer discharge.

List of Figures

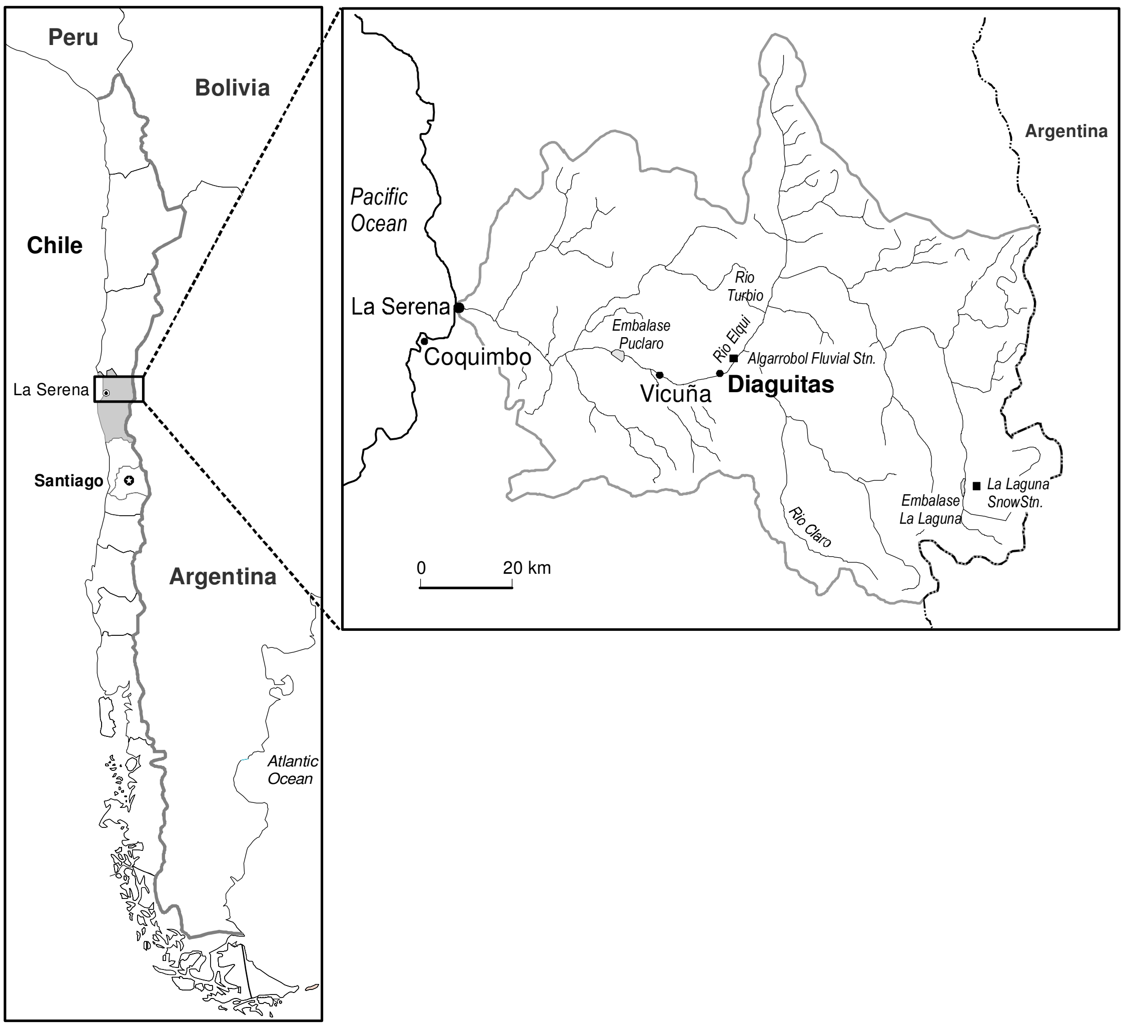

Figure 1 Location of the Elqui River Basin

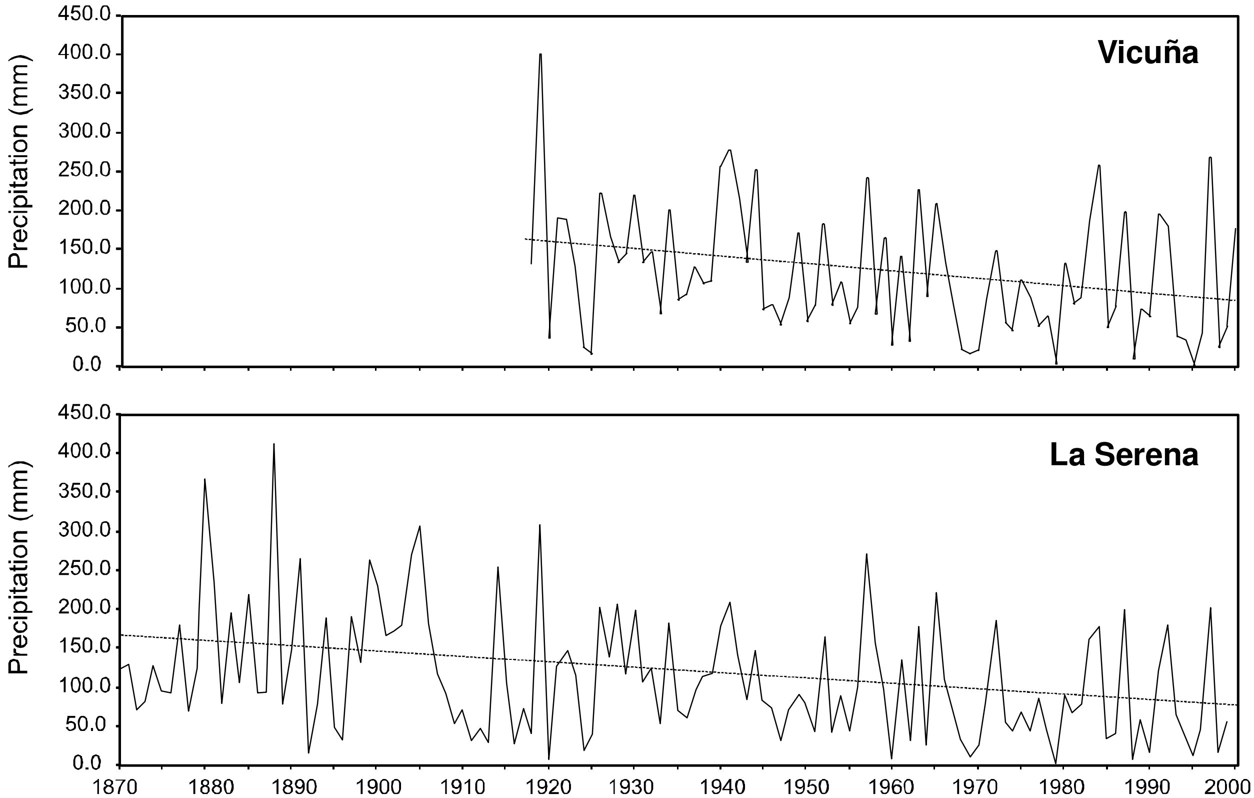

Figure 2 Annual precipitation for La Serena (1969-1999) and Vicuña (1918-1999)

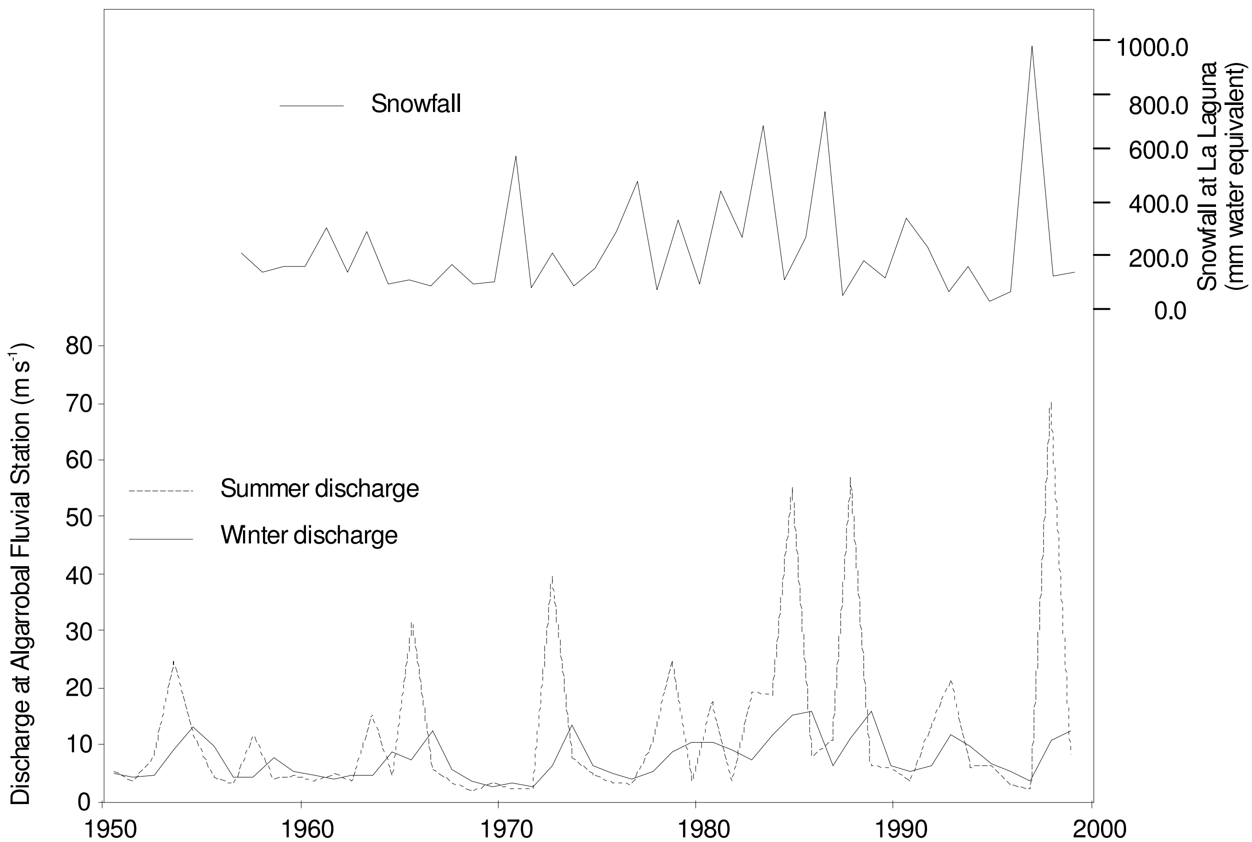

Figure 3 Summer and winter discharge at Algarrobal fluvial station and snowfall at La Laguna snow station.

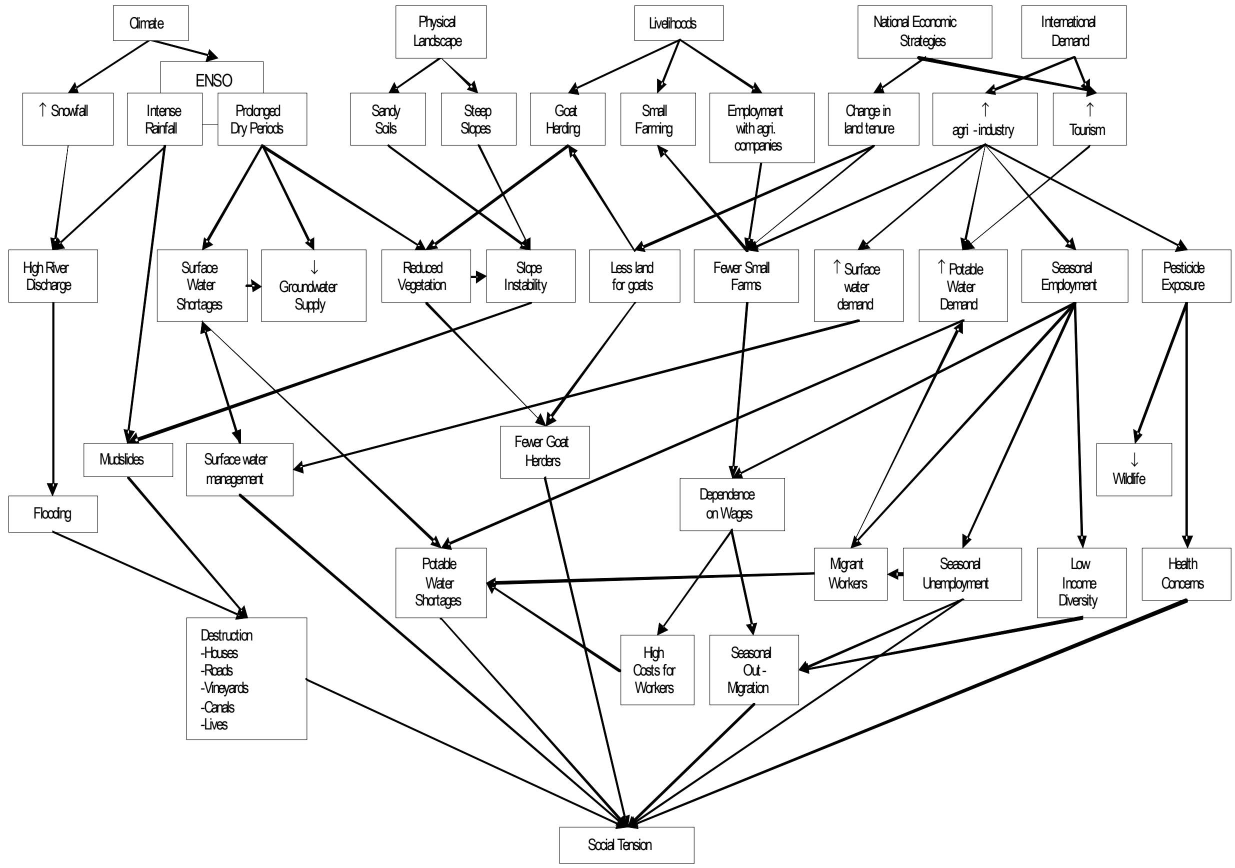

Figure 4 Forces and processes related to the vulnerability of Diaguitas

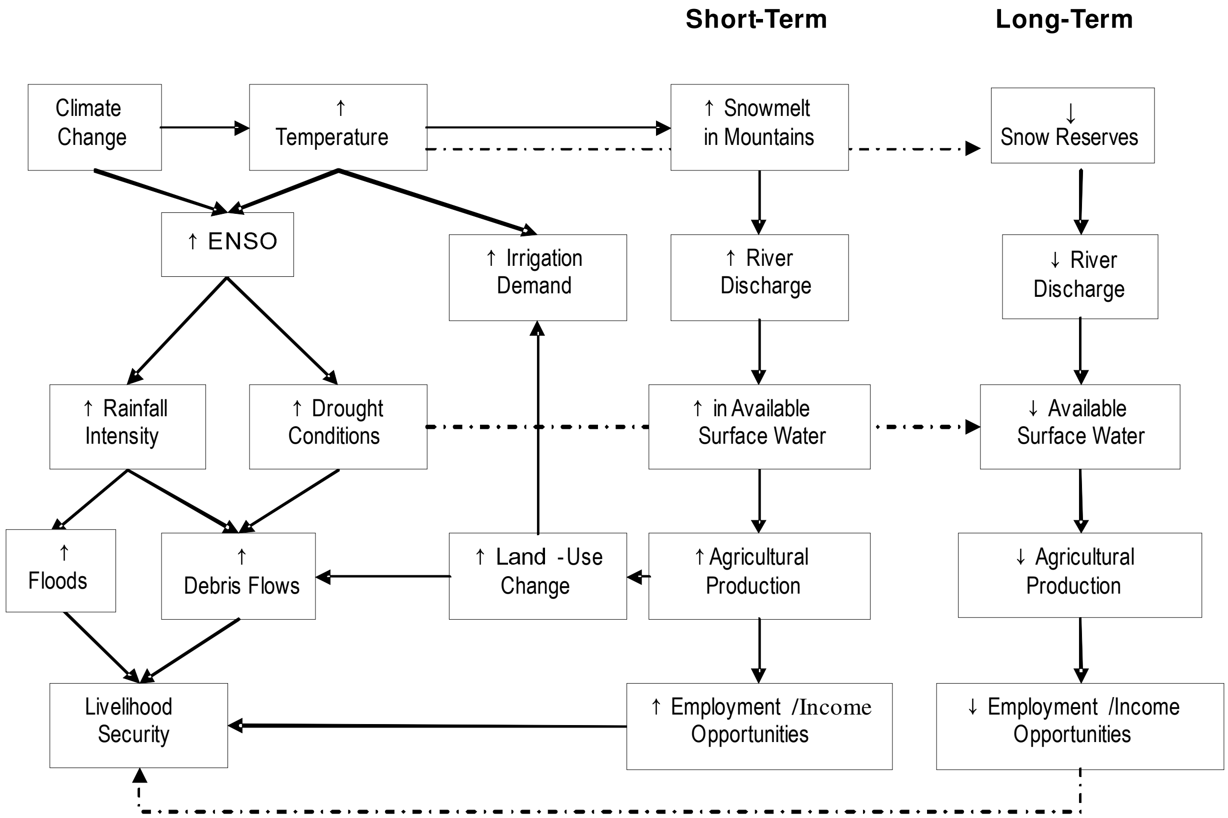

Figure 5 Selected effects of climate change on Diaguitas