Vulnerability of Communities to Environmental Change
as part of the project
Institutional Adaptation to Climate Change (IACC)
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1. Introduction

The concepts of Vulnerability, Exposure, Sensitivity, Adaptation and Adaptive Capacity have wide application. One way or another, they are all relative concepts – vulnerability *of* something *to* something, exposure *of* something *to* something, et cetera. The applications range in scale from the vulnerability of an individual or household to a particular climate stress such as drought, through the vulnerability of a community to various environmental stresses, to the vulnerability of humankind (or the global ecosystem) to all stresses and forces. These applications vary by spatial scale (individual to global), by phenomena (biological, economic, social, etc.), and by time scale (instantaneous, months, years, decades, centuries). In this paper, we do not develop applications relating to the vulnerability of physical or biological phenomena or systems, even though some of the concepts, e.g. adaptation, have long – if contested – use in those fields (Smit and Pilifosova, 2001; Smit and Pilifosova, 2003). This paper addresses applications to human systems and human-environment systems, meaning communities, households, groups, sectors, regions and countries.

To some degree, the most fundamental elements of the central concepts should be and are applicable at any spatial and temporal scale. However, depending on the scale of application, there are differences in how the concepts apply, how the nested hierarchies structure, and certainly how empirical or field applications can be undertaken. There have been some attempts to define universal characteristics of human vulnerability – factors that underlie vulnerability to any and all conditions and changes. In this paper, these broad conceptualizations of vulnerability are reflected in the models that characterize the more stress-specific vulnerabilities, particularly the higher-scale forces. At finer spatial scales and for particular types of communities these vary broad-scale forces are reflected in quite specific local conditions.

The aim of this paper is to develop and refine robust, generic model of vulnerability (and its associated concepts of exposure and adaptive capacity, etc.) with practical utility at a range of spatial and temporal scales. However, to simplify the presentation (e.g. to avoid giving applications at every stage to a wide range of scales), we focus on the vulnerability of communities to climate-related conditions and changes in the context of broader environmental and societal changes. Hence the "system" or "observation unit" of interest is the community (here used to mean some definable aggregation of households, interconnected in some way, and with a limited spatial extent). The conditions, stimuli or stresses (to which the communities may be vulnerable) are those related to climate and climate change (hence immediate or longer term), and these are considered in the context of other conditions and changes that are relevant to the community (*ie.* climatic stimuli are not considered in isolation).

The main reason for focusing this climate change issue at the community scale and for considering both current and future conditions is because it appears that practical initiatives that actually do something about improving adaptive capacity (and hence vulnerability) have been widely demonstrated at the community scale and are rarely evident at national scales. Notwithstanding the importance of broader national and international conditions, development initiatives, resource management and disaster preparedness seem to be most effective at subnational scales.

This paper provides an overview of the concepts of vulnerability, adaptation and adaptive capacity, especially as they have been used in the context of climate change. The paper reviews common interpretations and applications of the terms, and develops a conceptual model of vulnerability as it relates to human societies or communities. The paper also provides a critique of analytical approaches and methods to assess vulnerability and to identify and develop adaptation strategies and adaptive capacity.

The review is broad in that it relates to general concepts and applications, but given the focus of the IACC project, the paper pays particular attention to vulnerabilities related to **water** in environments such as Prairie Canada and Chile, and to the roles of **institutions** in enhancing capacity to deal with water-related hazards.

2. Climate Change, Water Resources and Institutions

It is widely accepted that climate change is occurring and it is recognized internationally as a cause for concern. In addition to an increase in average global temperature, changes in climate variations and in the magnitude and frequency of extreme events are expected (Houghton et al., 2001). However, the effects of changing climatic conditions will not be felt equally around the globe (Rosenzweig and Parry, 1994; O'Brien and Leichenko, 2000; Mirza, 2003; Tol et al., 2004).

Climate change and variability challenge countries, regions, sectors and communities that are most exposed and least able to respond or adapt to changing conditions, that is, those who are most vulnerable (Handmer et al., 1999; Smit and Pilifosova, 2003). Vulnerability, or susceptibility to harm, can be moderated by adaptive capacity – the ability to cope with change (Smit and Pilifosova, 2003; Füssel and Klein, 2002; Yohe and Tol, 2002).

Climate change is expected to stress both natural and human systems such as water resources, agriculture, forestry, and human health, and is expected that many regions will experience a greater scarcity of natural resources (McCarthy et al., 2001; Tompkins and Adger, 2004). Water resources are particularly sensitive to climatic variability and change.

The Intergovernmental Panel on Climate Change (IPCC) predicts that there will be a decrease in water availability for populations in arid and semi-arid areas which are particularly sensitive to climate variations. This could potentially be devastating for the approximately 30% of the world's population who currently live in regions that are water stressed (McCarthy et al., 2001). An increase in water scarcity for these areas could have serious implications for livelihoods, industry such as mining, power generation and agriculture, and cause or enhance soil degradation. In areas sensitive to water stress there is an interest in seeing how water resource management can be adapted to better deal with changing environmental conditions and to reduce vulnerability to climate change. Such improvement in adaptive capacity of water resource management would include considerations of the institutional arrangements and how these contribute to or reduce regional vulnerability to changing conditions.

The management of water resources necessarily involves both formal and informal institutions, such as household rights, community access, ownership structures, public management authorities, the market, and so on. The adaptive capacity of a community to deal with changes in water resources will be greatly influenced by the structure and effectiveness of institutions.

3. Bodies of Scholarship

Several bodies of scholarship provide insights into ways of conceptualizing this issue and ways of analyzing it, including the fields of climate change, natural hazards, water management and political ecology. These bodies of scholarship are not independent of each other, but they provide particular insights into concepts and methods.

The **climate change** literature gives insights on current and potential future climate, mainly through climate change scenarios and their modeled impacts. It primarily focuses on the biophysical impacts of climate change, and to a lesser degree estimates implications on socio-economic and resource systems (e.g. West et al., 2001). It provides an indicator of potential consequences of climate change (e.g. Yohe and Schlesinger, 2002; Ziervogel and Calder, 2003). Increasingly, studies of the implications of climate change have considered not only changes in average temperature, but also the increased risk of climate extremes (e.g Mirza, 2003; Bruce, 1999). In this field, vulnerability is most commonly seen as a residual impact (or "end point") of a specified climate change scenario, estimated for the purposes of gauging the seriousness (or "dangerousness") of climate change (O'Brien et al., 2003; Kelly and Adger, 2000). Where the purpose is to identify adaptation needs and implement or promote adaptation measures, there is increasing consideration of vulnerability in light of system exposure and adaptive capacity.

Natural hazards literature examines how people and societies respond to natural events with potentially adverse consequences for humans (or hazards), what factors influence response choices, and how risks are managed (Cutter, 1996; Hewitt, 1997). A natural event only becomes a hazard if it has the potential to adversely affect people; and thus hazards (and their worst-case scenarios, disasters) are socially constructed (Cannon, 2002). Risk of hazards such as flood or drought is of particular significance for water resource management, as management implies human dependence on the resource and its potential scarcity has the potential to negatively affect those who use it. Commonly, natural hazards scholars deal with one type of hazard, primarily from a physical science perspective. Vulnerability, in this scholarship, is considered a characteristic of people living in hazardous areas, *ie*. Disaster = Hazard + Vulnerability, with little attention to the interaction between hazard and vulnerability (Cannon, 2000).

Water resource management literature is concerned with the planned development, distribution and allocation of water resources for current and future human and natural uses (Stakhiv, 1996). A high relative water demand (water withdrawal/water use : discharge) in a given catchment or region determines vulnerability, and thus areas with high dependency on irrigation or industrial water and limited water supply (e.g. parts of South America, the American and Canadian Great Plains, sub-Saharan Africa) are considered vulnerable as their water supplies are not secure under potential climate change (Vörösmarty et al., 2000).

Political ecology provides a particular contribution by considering the broader social, economic and political conditions which influence the differential exposures of peoples and their adaptive capacities. It outlines the role of social structural constraints and political economic factors that cause differential access to resources and influence the vulnerability of marginalized groups (Bryant and Bailey, 1997; Mustafa, 2002). Vulnerability, therefore, is seen as a function of a person or community's dependence on and access to resources, and access relates to political power, institutional arrangements, poverty/wealth, livelihood strategies, and so forth. Blaikie et al. (1994) define vulnerability as the capacity to anticipate, cope with, respond to or recover from external stimulus.

The concept of vulnerability clearly has various meanings in the fields reviewed above. The definition and approach advocated for the IACC Project is based on synthesis and evolution in the fields above and other contexts.

4. Vulnerability Concepts and Definitions

The concept of vulnerability has been developed and employed with reference to various contexts, including food security (Sen, 1981; Watts and Bohle, 1993), environmental change (Liverman, 1994), and natural hazards (Cutter, 1996; Blaikie et al., 1994; Wisner et al., 2004). More recently, the concept has been employed in the climate change literature as a way to characterize and understand the implications of climate change for human communities (Handmer et al., 1999; Leichenko and O'Brien, 2002; Adger, 2003). The variations in the meaning and use of the term reflect various epistemological orientations including politically ecology, human ecology, physical science and spatial analysis (Cutter, 1996).

Broadly, the term vulnerability refers to susceptibility to harm (Smit and Pilifosova, 2003). Particular interpretations of vulnerability vary among bodies of literature and contexts used. In natural hazards scholarship, vulnerability has been referred to simply as the "degree or loss resulting from the occurrence of natural phenomena to a given element or set of elements" (UN Disaster Relief Organization, 1982). Similarly, vulnerability has been defined in the water management context as "how severe the consequences of failure may be" (Stakhiv, 1996). More recently, natural hazards work has moved beyond vulnerability as the potential magnitude resulting from a hazard to include determinants of vulnerability, or "the characteristics of a person or group and their situation that influence their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard, an extreme natural event, or process" (Wisner et al., 2004). This is congruent with a political economy conceptualization of vulnerability as a function of exposure, capacity and potentiality (Watts and Bohle, 1993) and Sen's (1981) argument that vulnerability is largely a societal construct which results from a lack of entitlements, democracy and power in the food security context. Vulnerability becomes "an aggregate of human welfare that integrates environmental, social, economic and political exposure to a range of harmful perturbations" (Bohle et al., 1994).

In recent years, the climate change community, as captured in the IPCC's Third Assessment Report, has commonly defined vulnerability as "the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes" (McCarthy et al., 2001). The "most vulnerable" thus are those who are most likely to be exposed to perturbation, possess limited capacity for adaptation, and are least resilient to recovery (Bohle et al., 1994).

Notwithstanding definitions in early natural hazards and water management scholarship that focused on magnitude of event and effect, recent work on the incorporates the notion that vulnerability of a system or community is a function or reflection of both the exposure (or sensitivity) of the system to hazardous conditions or risks and also the capacity of that system to absorb, cope, manage, deal with, adapt or recover from that exposure.

There is a general agreement that developing countries are deemed to be more vulnerable to climate change compared to developed countries, partly because of their exposure but mainly because of their limited adaptive capacity (Downing et al., 1997; McCarthy et al., 2001; Beg et al., 2002; Mizra, 2003; Handmer, 2003). Downing et al (1997) note that vulnerability of developing countries is higher in part due to their higher dependence on resources which are affected by climate (e.g. fishing, forestry, agriculture) relative to industrialized countries; *i.e.* they are more exposed. They also tend to have less economic, technological and other resources to deal with, adapt to and recover from hazardous exposures.

Within countries it is generally accepted that the poorer groups or communities are more vulnerable, both because they are often in more exposed livelihoods and locations, and because they have very limited capacity to adapt.

Vulnerability can be assessed at many scales: individual, household, community and nation. While some scholars apply the term at very aggregate scales (Barnett and Adger, 2003; Tol et al., 2003), vulnerability if often understood to pertain explicitly to individuals or social groups/communities (Adger and Kelly, 1999).

4.1 Dynamic Vulnerability

To most authors, vulnerability is a dynamic concept (Hewitt, 1997; Adger, 1999; Adger and Kelly, 1999; Handmer et al., 1999; Leichenko and O'Brien, 2002; Downing, 2003). Vulnerability is seen as a process in constant flux in an individual, group, location or activity through time. Handmer et al. (1999) characterize vulnerability as a process of continual evolution as its determinants (e.g. technological and institutional factors) change and evolve. Leichenko and O'Brien (2002) define dynamic vulnerability as "the extent to which environmental and economic changes influence the capacity of regions, sectors, ecosystems and social groups to respond to various types of natural and socio-economic shocks". Of course, this relates primarily to the adaptive capacity element of vulnerability. The exposure element is also dynamic as extreme conditions such as climate change, and as occupancy characteristics of groups evolve.

Adger (1999), Adger and Kelly (1999) and Handmer et al. (1999) emphasize the need to identify trends in vulnerability. Although this is often not specified explicitly, there is a distinction between, on the one hand, the vulnerability of a system (including dynamic vulnerability and including the dynamics of its exposures and its adaptive capacities) and, on the other hand, the broader conditions or forces (environmental, economic, social, cultural, institutional, etc.) that shape, constrain or influence the exposures and adaptive capacities. Smit and Pilifosova (2003) call these the "determinants" of vulnerability or adaptive capacity, and these forces and processes are also dynamic.

4.2 Physical and Social Vulnerability

Distinctions are sometimes made between physical and social vulnerability. Physical vulnerability is described as the sensitivity of the physical system, or the likelihood of exposure (Liverman, 1994; Cutter, 1996). Research in natural hazards and climate change often uses biophysical conditions to define vulnerability (Liverman, 1994; Smith and Lazo, 2001). Populations are considered vulnerable if they live in hazardous locations, and their ability to reduce the effect of hazard via adaptation is greatly downplayed. Thus, vulnerable populations are understood to be those who live in areas with a high probability of occurrence of potentially problematic physical phenomena (e.g. earthquakes, tsunamis, hurricanes…). Physical vulnerability is seen to be related to the degree of inundation with sea level rise, or the increased frequency of drought – and it is indicated that such vulnerability can be characterized independently of the resource use or livelihood features of the population, and independently of the population's abilities do deal with their physical hazards. This physical or biophysical vulnerability essentially is about the *exposure* of a system to physical stimuli with little reference to adaptation or livelihood strategies, and does not develop the social forces that may have influenced the location of certain groups in hazardous areas.

The term "social vulnerability" emerged from the recognition that exposure to environmental stress alone was not the only component influencing vulnerability (Liverman, 1994). Physical hazards, disasters, climate change and variability cause tremendous harm, but that harm (and hence vulnerability) is also influenced by existing social conditions. Social conditions enhance or reduce the susceptibility to harm from hazardous events (famine, drought, disease, flooding). Social vulnerability has been related to many factors including marginalization, equity, the role of institutions, food and resource entitlements, economics and politics (Adger and Kelly, 1999; Adger, 2000; O'Brien and Leichenko, 2000; Pelling 2002). These are considered attributes of a social system that increase exposure and/or limit adaptive capacity. An examination of social vulnerability includes an understanding of the human use of and access to resource which in turn determines the ability of an individual or society to cope with and adapt to change (Wisner et al., 2004).

Sen (1981) recognizes the role of social vulnerability in exacerbating or reducing impacts of a hazardous physical event. The occurrence of famine is not simply because of natural events but also the social, economic and political conditions that make people susceptible to the event and limit the capacity to cope or deal with it. Thus, the capacity to adapt to hazard stress is rooted in the ability of an individual or community to compete for access to rights, resources and assets (Sen, 1981; Blaikie et al., 1994). Mustafa (2002) showed the importance of the unequal distribution of power and wealth as fundamental elements of vulnerability to floods. Other fields, such as natural hazards, resource management and sustainable development, have increasingly employed concepts of vulnerability that recognize both physical stimuli and human conditions contribute to exposure and are essential to adaptive capacity.

In the climate change scholarship, social vulnerability has been described as an issue of entitlements, where access, availability, and distribution of resources determine or influence or define the level of vulnerability of a social group (Liverman 1994; Adger and Kelly, 1999). The extent to which individuals, groups or communities are entitled to use resources determines the ability of that population to cope and adapt to stress (Adger an Kelly, 1999). Inequality affects vulnerability by constraining the options of systems when faced with changing conditions, i.e. by constraining their adaptive capacity. Inequity within a population can increase social vulnerability to climate change as climate change can alter communal allocation of resources.

5. Conceptual Vulnerability Model

Consistent throughout the literature is the notion that the vulnerability of any system (at any scale) is reflective of a function of both the exposure of that system to hazardous conditions and the ability or capacity of the system to cope, adapt or recover. These concepts are labeled in different ways and given different emphases in various fields.

A conceptual model of vulnerability has emerged from the climate change community scholarship (Kelly and Adger, 2000; Downing, 2001; Smit and Pilifosova, 2003; Yohe et al., 2003). Vulnerability here is characterized as a function of the exposure of a system to climate change and its adaptive capacity. A system may be a household, community, sector, ecosystem, activity, nation and so on. Generally, a system that is more exposed to a climate stimulus will be more vulnerable, and a system that has more adaptive capacity will tend to be less vulnerable due to its ability to cope with the exposure. Vulnerability, and the elements of exposure and adaptive capacity, are dynamic (they vary over time), they may vary from stimulus to stimulus, and they are place and system-specific (*i.e.* their features and determinants tend to differe drom to community to community and from place to place). This idea can be expressed formally as:

$$V_{ist} = f(E_{ist}, A_{ist}) \qquad (1)$$

Where

V_{ist} = vulnerability of system i to climatic stimulus s in time t

E = exposure of i to s in t

A = Adaptive Capacity of i to deal with s in t

The functional relationship between the two components is not defined as vulnerability is context specific and dynamic. However, it is understood that vulnerability is a positive function of exposure and a negative function of adaptive capacity (Smit and Pilifosova, 2003). The subscript i denotes that the nature of the elements making up vulnerability, and the broad forces influencing them, are specific to particular systems (households, communities, regions, sectors, locations), even though they might relate to common processes and conditions (resources, access, wealth, equity, etc.). The subscript s recognizes that, even for a particular system, vulnerability is unlikely to be the same for all stimuli (e.g. increasing temperature, floods, sea level rise, low-frequency droughts, high-frequency droughts, high-frequency extended droughts, etc.). Not only is the physical stimulus distinct, but it is also unlikely that the exposure of people differs with the type of stimulus, and the adaptive capacity may vary with the type of stimulus. The subscript t is a crude acknowledgement that vulnerability (and its elements and determinants) are dynamic, that is, they vary over time. Here this is suggested with a simple subscript, though this should be interpreted as more of a continuous property than discrete time points. Algebraically, the dynamic nature of vulnerability as expressed in (1) can be re-stated as a differential equation:

$$\frac{dV}{dt} = f\left(\frac{dE}{dt}, \frac{dA}{dt}\right) \qquad (2)$$

5.1 Exposure

Exposure is a property of the system relative to climatic conditions. Exposure is dependent on both the characteristics of the system and on the attributes of the climate (Downing, 2003; Smit and Pilifosova, 2003). Smit and Pilifosova (2003) illustrate this concept at a coarse level: Switzerland and Bangladesh have different exposures to sea level rise (vastly different elevation of land, proximity to sea), whereas Florida and Bangladesh have more similar exposures to sea level rise (both low-lying locations adjacent to open water). However, the exposures of Florida and Bangladesh also differ considerably. Even if the sea level rise itself is similar in the two places, the nature of human settlement, the density of population in exposed areas, the structure of buildings and infrastructure, the dependence of people's livelihoods on conditions related to sea level, and so on all influence exposure, and these differ between Florida and Bangladesh.

Exposure is not simply the presence of some external stress, nor can it be seen as some summation of external forces and local conditions. Rather, exposure represents the juxtaposition and interaction of local conditions (reflecting broader forces) and external physical stimuli (also reflecting broader physical systems). Exposure is a property of a system that reflects jointly the physical stimulus and the occupance characteristics of the system relative to that stimulus. The occupance characteristics are similar to the term sensitivity used in some treatments. Here sensitivity is a part of exposure, in that exposure to a physical stimulus only has meaning relative to the occupance characteristics (sensitivity) of a system.

The term exposure is sometimes used to describe climatic conditions or events occurring or expected in a particular place. We use the term climate stimulus or condition to refer to these. The term exposure is not a property of climate, but a property of the affected system (e.g. community). It refers to the manner and degree to which a system is unprotected from or at risk to some stimulus. Clearly exposure reflects the characteristics of the system relative to the stimulus. A community located on a low-lying coast with unprotected houses is more exposed to a given sea level rise stimulus than a community located further from the sea confronted with the same stimulus, or a similarly located community with protection confronted with the same stimulus. Similarly, a community whose livelihood is highly dependent on water is more exposed to droughts than a community facing equivalent drought yet having livelihoods that do not depend on the availability of water.

Figure 1 shows diagrammatically how the exposure of a system (e.g. a community) to a climate change risk (e.g. drought) reflects a combination of the probability of the particular climatic conditions (which reflects the broader climate regime and the non-climate conditions which influence the stimulus) and of the occupance characteristics (or sensitivity) of the system to the stimulus. The occupance characteristics (e.g. settlement location and types, livelihoods, land uses, etc.) reflect broader social, economic, cultural, political and environmental conditions. Many of these "determinants" of occupance or sensitivity are similar to those that influence or constrain a system's adaptive capacity.

The stimulus part of exposure may be broken down into particular characteristics (e.g. drought frequency, magnitude, duration, speed of onset), just as the occupance or sensitivity part can be characterized according to various elements. For those who prefer such associations expressed algebraically:

$$E = f(P,O) \qquad (3)$$

Where

E = Exposure

P = Physical Stimulus

O = Occupancy Characteristics (Sensitivity)

Physical Stimulus in turn is:

$$P = f(C, N) \qquad (4)$$

Where

C = Climate System

N = Non-climate Conditions

Occupance is expressed as:

$$O = f(S, E, P, R, L\ldots) \qquad (5)$$

Where

S = Social Conditions

E = Economic System

P = Political System

R = Resources

L = Location

Replacing P and O in (3) with (4) and (5):

$$E= f((C,N),(S,E,P,R,L\ldots) \qquad (6)$$

So the exposure of a system in a particular location over time reflects the occupancy characteristics of the system relative to the climatic stimuli that influence those characteristics. The climatic particular stimuli, in turn, reflect the broad climatic regime and various nonclimatic conditions that influence or constrain the attributes of the stimuli (e.g. onset, frequency, magnitude and effect). The occupancy characteristics of the system that contribute to its exposure reflect the broad social, economic, political, resources and location conditions within which the system functions.

While this conceptualization of Exposure indicates the general characteristics that make it up, it does not imply that there are universally applicable indicators of physical stimulus, occupancy characteristics, or the broader physical and socio-economic-political conditions within which they evolve. The relevant "variables" for the elements may be quite system specific.

For example, an agricultural community which is dependant on fresh-water supplies may be exposed to longer dry spells, which are a reflection of changes in the climate regime and perhaps regional deforestation, because the community's agricultural livelihoods are susceptible to moisture deficits. If the community livelihoods were not water dependent, they would not be exposed to longer dry spells even if the physical stimulus were present.

The research challenge to characterize or assess the Exposure element of vulnerability is to identify those combinations of climate conditions and system occupancy characterisctics that are considered to be problematic, risky or hazardous in some way. These are rarely known *a priori*. The empirical research task is to identify, document and describe the combinations of occupancy characteristics and physical stimuli that matter in the system of interest.

Two systems with identical exposures need not have the same vulnerabilities because one may have considerable capacity to deal with, manage, or adapt to the exposures (hence reducing vulnerability), with the other may have limited ability to cope, manage, adapt or recover (and hence have greater vulnerability).

5.2 Adaptive Capacity

Adaptive Capacity is widely used to describe a system's ability do deal with exposure or risk (Wheaton and McIver, 1999; Bryant et al., 2000; Smit and Pilifosova, 2003; Yohe and Tol, 2002;

Füssel and Klein, 2002). The IPCC defines adaptive capacity as "the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences". Adaptive capacity is context-specific and varies from country to country, from community to community, among social groups and individuals over time. However, the scales of adaptive capacity are not independent: the capacity of a household to cope with climate risks depends on some degree on the enabling environment of the community, and the adaptive capacity of the community is reflective of the adaptive capacity of the region (Smit and Pilifosova, 2003).

Adaptive capacity is analgous to a host of other commonly-used terms, including adaptability, coping ability, management capacity, stability, robustness, flexibility, and resilience (Stakhiv, 1996; Smithers and Smit, 1997; Adger and Kelly, 1999; Smit et al., 1999; Jones, 2001; Fraser et al., 2003; Tompkins and Adger, 2004). Fraser et al. (2003) identify adaptive capacity as social resilience and describe it as the ability of a society to respond to environmental changes. Inherent in this is a recognition that an assessment of the effects of climate change requires an understanding of how communities adapt or cope with change. Similarly, a system's "coping range" is defined by the range of conditions that a system can deal with, accommodate, adapt to, and recover from (de Loe and Kreuzwiser, 2000; Jones, 2001; Smit et al., 2000; Smit and Pilifosova, 2001 and 2003). Most communities and sectors can cope with normal climatic conditions and deviation from the mean to some degree. However, exposures involving extreme events that may lie outside the coping range may exceed the adaptive capacity of the community, which increases vulnerability (Figure 2).

A system's coping range is not static as it appears in Figure 2. Coping ranges are flexible and respond to changes in economic, social, political and institutional conditions over time. For instance, population pressure or resource depletion may gradually reduce a system's coping ability and narrow its coping range, while economic growth or improvements in technology could lead to an increase in adaptive capacity (deVries, 1985; Smit and Pilifosova, 2003).

Figure 2 illustrates a system's coping range with respect to both exposure and adaptive capacity, and hence vulnerability. Moisture deficit and the occurrence and severity of drought conditions vary from year to year, yet the system is able to cope with a degree of variation around the mean or average conditions. The amount of variation the system can deal with is indicated in the shaded area, here called the coping range (which could also be called the adaptive capacity of the system). However, as mean moisture deficit increases (as is expected with climate change), the entire distribution shifts and the system will experience (and be more vulnerable to) an increase in the frequency and magnitude of events beyond the coping range. To the extent that the system may be able to expand the coping range or enhance its adaptive capacity to deal with these exposures, it will reduce its vulnerability to drought risk. The forces that influence the ability of the system to increase adaptive capacity are the driving forces, external factors, influencing processes and determinants of adaptive capacity.

The graphical representation of coping range presented in Figure 2 shows increases in coping range over time. It should, however, be noted that the coping range can also decrease for a variety of reasons. External socio-economic and political factors (e.g. war, the collapse of an institution such as a crop insurance program, loss of a key decision-maker) may lead to a narrower coping range with respect to a stress such as drought. Furthermore, increased frequency of events near the limit of the coping range may decrease the threshold beyond which the system cannot cope/adapt/recover (e.g. two consecutive years of high moisture deficit which are not beyond the limits of the normal coping range present little problem in the present but require drawing on stored resources – and the consumption of these resources subsequently narrows the coping range until they can be built up again, so a third and fourth year of the same magnitude may well exceed the now smaller coping range). Similarly, conditions which are within the coping range may introduce unforeseen side effects which will narrow the coping range. For example, a warm, wet year may be an ideal year for crop production and lead to high yields. Subsequent years of warm, wet conditions can, however, encourage the development of pest and fungal outbreaks and actually decrease yields and thus the coping range is reduced. Finally, a catastrophic event beyond the limit of the coping range may permanently alter the system's normal coping range if it is not able to recover from it (e.g. a system that relies on irrigation water, captured in a dam. A very wet year, far beyond the normal conditions expected, may lead to the dam's failure, and thus the previous coping range cannot be returned to in a subsequent "average" year.

Just as exposure can be seen as a system property reflective of broader conditions and processes within which the system evolves, so too can adaptive capacity be seen as reflective of broader conditions. For example, a frequently cited manifestation of adaptive capacity is the initiation or adoption of adaptive measures. Adaptations, or change in the system to better deal with exposures, reflect adaptive capacity. Clearly there are many forms and "levels" of adaptations, and these can be classified by timing relative to stimulus (anticipatory, concurrent, reactive), intent (autonomous, planned), spatial scope (local, widespread) and form (technological, behavioural, financial, institutional, informational) (Smit et al., 2000).

It is also possible to distinguish adaptations according to the degree of adjustment or change required from (or to) the original system. For an agricultural system facing water shortage exposures, a simple adaptation might be to use more drought resistant cultivars. A more substantial adaptation might be to shift away from crop farming to pastoralism. An even more substantial adaptation might be to abandon farming altogether.

In the hierarchy of adaptations and adaptive capacity (Figure 3), these are shown as different levels or regimes of adaptation. The ability to undertake adaptations (the adaptive capacity) is widely understood to be dependent on or influenced by any of a variety of conditions, including managerial ability, access to financial, technological and information resources, infrastructure, the institutional environment within which adaptations occur, political influence, kinship networks, etc. (Watts and Bohle, 1993; Hamdy et al., 1998; Adger, 1999; Handmer et al., 1999; Kelly and Adger, 2000; Toth, 1999; Smit and Pilifosova, 2001; Wisner et al., 2004). These conditions can be distinguished according to local determinants (e.g. the presence of a strong kinship network which will absorb stress) and broader socio-economic and political systems (e.g. the availability of state-subsidized crop insurance).

The determinants of adaptive capacity are not independent of each other. For example, the presence of a strong kinship network may increase adaptive capacity by allowing greater access to economic resources, increasing managerial ability, supplying supplementary labour and buffering psychological stress. Similarly, economic resources will facilitate the implementation of a new technology and ensure access to training opportunities and may even lead to greater political influence. Individual determinants, thus, cannot be isolated: adaptive capacity is generated by a combination of determinants which interact and vary in space and time. Consequently, the determinants of adaptive capacity will behave differently in different contexts (e.g. a strong kinship network can be expected to play a much larger role in a subsistence-based agricultural society than in a developed world agribusiness context).

The role of institutions in facilitating or constraining adaptive capacity with respect to water in agriculture is of particular importance for the IACC project. Appendix 1 presents definitions of institutions and discusses their relationship to adaptive capacity and vulnerability. Appendix 2 outlines water resource management in light of climatic variability and change, with particular attention to institutions.

To date, there is very little consensus (or documented support) for a robust, generic model of the local elements of adaptive capacity or the broader factors, determinants or "drivers" that influence or constrain the abilities of communities to deal with hazards or stressful conditions. Here we give only an illustration of the types of conditions and factors that might apply at two scales.

At the community (local) scale, Adaptive Capacity can be expressed algebraically as:

$$A_{local} = f(D, F, I, S, T...) \qquad (7)$$

where

A_{local} = *Adaptive Capacity*

D = Distribution of Resources and Access

F = Financial Resources

I = Institutional Effectiveness

S = Social Cohesion

T = Available Technology

The determinants of Adaptive Capacity vary from community to community, due in part to local conditions and exposures and in part to broader conditions and determinants. At the regional/national scale, Adaptive Capacity can be expressed as:

$$A_{local} = f(D, F, I, S, T...) = f(G, E, P, R) \qquad (8)$$

where

G = Globalization

E = Economic System

P = Political System

R = Resources

Hence the Adaptive Capacity of a community is a function of local processes and conditions which in turn are influenced by broader socio-economic and political processes and widespread resource availability. Consequently, even if our scale of analysis is the household or community, an estimation of the determinants of adaptive capacity requires an awareness of the larger context within which the community operates.

Note that the factors that broadly constrain Adaptive Capacity (equation 8) are very similar to those that constrain occupance (equation 5) and consequently exposure (equation 6). The relationship among Exposure (physical stimulus, occupance) and Adaptive Capacity is illustrated in Figure 4. For example, a kinship system (social cohesion) may influence livelihood strategies (deriving all household income from agriculture) as well as adaptive capacity (being able to call on the resources of family members to mitigate/recover from an extended drought). Thus, while many factors which determine vulnerability are relevant for the assessment of both Exposure and Adaptive Capacity, their manifestations and influence on vulnerability are different.

6. Assessing Vulnerability of a Community

The IACC/MCRI project is about assessing vulnerabilities of communities to climate change, with a particular interest in exposures and adaptations related to water use, and the roles of institutions in current and future adaptive capacity.

The general vulnerability model provides a framework to structure empirical work in communities, with the primary purposes being to identify their vulnerabilities and to assist in their enhancing of adaptive capacity. The preceding sections outlined the conceptual model and rationale of the vulnerability approach (i.e. the *why* of vulnerability assessment). This section outlines some general principles for applying the approach (i.e. the *how* of vulnerability assessment). A general model of the stages of vulnerability assessment is presented in Figure 5.

6.1 Project Design

Applying the vulnerability approach requires the active involvement of stakeholders. If the aim is to document a community's current exposures and adaptive capacity, it is necessary to see potential stresses from the perspective of individual community members. In order to do this, it is necessary to establish some degree of validity, rapport and trust with the community. In many cases, a natural mistrust of researchers exists, and this is increased if there is any potential that the researcher is seen as a government informant or representative of an organization that has a controversial history in the community. Thus, it is necessary to carefully research communities to identify potential stakeholders as well as the community's history at the time of community selection. This stage of project design relies on **secondary sources** and **key informants** from representative organizations (e.g. crop producer associations, farmers' unions) and relevant government departments. In some situations, it may be helpful to employ survey techniques to enable a preliminary scoping exercise.

Involving community stakeholders in the assessment from the outset increases the chances for successful data collection. This is particularly important if the researchers come form cultural or socio-economic circumstances which are very different from those of community members, and even more so if there is a language barrier. In many instances, it is helpful to be introduced to the community via a preliminary community consultation which outlines why the researchers will be in the community. Community consultations can be organized by the researchers in collaboration with regional associations or local government representatives. The objectives of the consulations are:

- To introduce the researchers to the community
- To allow the community to express concerns about research objectives (or decline to be part of the presearch)
- To refine the research objectives/questions based on preliminary feedback
- To identify local facilitators/collaborators

The fourth objective is particularly important, since the intimate involvement of a local increases the validity of the researchers in the community's eyes, enables further identification of sensitive wording/issues which might be inadvertently used/addressed by researchers and helps to overcome language/cultural barriers.

6.2 Assessing Current Vulnerabilities

Regardless of the particular information gathering instrument or instruments used, and assuming the necessary protocols, stakeholder engagement, familiarization, etc. activities have been undertaken, an assessment of current vulnerabilities requires information on Current Exposures and Current Adaptive Capacity

6.2.1 Current Exposures

This involves identifying and documenting the **conditions or risks that people** (individuals, households, groups, organizations) **have had to deal with (and are dealing with) in their lives**, livelihoods, businesses, sectors, etc. Assessing current exposures requires an answer to the question, *what sort of problematic conditions is the household/community/group/institution dealing with/ has dealt with in the past?* This entails documenting both the physical and other stresses that are identified by the people, and the occupance characteristics (livelihoods, settlement, etc.) that make the condition problematic or risky or a stress. Ideally, the enquiry will first be open-ended (not prompted) to permit identification of the types of conditions (and their relative importance) from the perspective of the stakeholders. Subsequently, community stakeholders could be asked to respond to given physical and other conditions that are expected to be stresses, and lists of household or community characteristics that are expected to contribute to exposure.

While the exercise should identify and document all stressors, IACC work should give particular attention to those stresses which are directly or indirectly related to water supply, resources, management and use.

6.2.2. Current Adaptive Capacity

This involves identifying **the ways in which the community deals with exposures.** The goal here is to answer the questions, *how have individuals/households/groups/institutions dealt with/coped with/managed/ adapted to the problematic conditions in the past? What adaptations or adaptive strategies were employed, how, why, by whom, under what circumstances? How effective or otherwise were they?* Furthermore, assessing current adaptive management requires an identification of the broader conditions that constrain or facilitate adaptive initiatives. *If there have been measures or policies that helped deal with exposures, what were the conditions that made them feasible and effective? Are there needs and opportunities not realized because of some constraining factors ?* (e.g. insufficient economic resources, technological limits, equity concerns, conflicts, unclear authority, inadequate institutional structures or management…)

Together, these questions represent the characterization of current adaptive capacity and provide a basis for assessing the community's ability to address changing conditions and risks in the future.

This stage of the vulnerability approach requires the active participation of community members, and can be greatly facilitated by interested and respected local partners. However, it should also be recognized that some of the information which will be gathered (e.g. a household's access to financial resources) is by nature sensitive and confidential, and thus participants need to be confident in confidentiality. In other cases, the depth of information collected is enhanced by having multiple participants in the same space, since this can generate useful discussions. For this reason, community-level field work requires the employment of various ethnographic techniques, including **focus groups, in-depth personal interviews** (both with resource users and local representatives or **key informants**), and **participatory observation**.

6.3 Assessing Future Vulnerability

The assessment of future vulnerability (and thus future exposure and adaptive capacity) combines local knowledge/community data sources with secondary sources and scientific modeling.

6.3.1 Future Exposures

Future Exposures relate to **conditions which are expected to represent risks or opportunities to the community at a later date**. The identification of current exposures provides a description of those conditions that are particularly pertinent to the community. These relevant conditions can be considered by **climate modeling, hydrologic modeling, policy analysis, demographic analysis, key informant interviews and others** to assess the likelihood of changes in these (community relevant or community-identified) conditions in the future. For example, an assessment of current exposure may reveal that the community has, in the past, been challenged to meet community demand for freshwater supplies for agriculture. Currently, the majority of community members engage in agriculture, and this is encouraged by state-level food security policies. Climate and hydrologic modeling may reveal that there is a likelihood of diminishing water supplies while demographic analysis reveals a classic "pyramid" age-sex distribution indicating rapid future population growth. Policy analysis shows little indication of a change in institutional encouragement of agriculture. Thus, researchers can conclude that future exposure will be greater due to the combination of these factors.

This type of analysis represents a somewhat different (but not independent of) approach from the conventional scenario modeling of climate change. In this approach, the choice of variables to be modeled is influenced by an identification of *relevant* exposures. In addition, the climate, water and ecosystem analysts may identify some expected changes in conditions beyond the experience of the community residents, and, once these are related to occupancy characteristics of the community, these too would be included in "future exposures".

6.3.2 Future Adaptive Capacity

This component has two related parts. The first assesses **the manner and degree to which the current management practices could deal with or accommodate the estimated future exposures**. More broadly, the assessment could consider the degree to which the community's adaptive capacity has the scope, resilience, resources and potential to deal with expected future exposures.

Data sources at this stage are a combination of information collected through ethnographic work at the local level and insights from key informants at local, regional and national scales as well as the results from scientific analyses such as modeling and policy and demographic analysis. Combining future exposures and future adaptive capacity to identify future vulnerability necessarily becomes an integrative exercise which, ideally, involves both local partners and researchers with producer association and government representatives as appropriate.

6.4 Adaptation Strategies

An assessment of future vulnerability naturally leads to considerations of application (or even prescription) in that it aims to **identify the strategies or opportunities which would facilitate the community to better deal with, manage or adapt to future exposures**, particularly building on the existing adaptive management structures and processes (commonly referred to as "mainstreaming"). This phase would also seek to identify constraints on the improvement of adaptive capacity.

At this stage, the process moves from assessing to doing. Consequently, the role of the researcher changes. In the earlier project design and assessment and modeling phases, action was primarily researcher-driven with local / institutional involvement. In the Adaptation Strategies stage, action is primarily in the hands of individuals and households and institutions such as sectoral associations, local, regional and national governments with the goal of increasing adaptive capacity. The researcher becomes an observer rather than an active participant.

6.4 Continuing the Adaptation Process

The vulnerability approach does not end with the application of recommended strategies. Vulnerability assessment explicitly acknowledges the dynamic nature of exposure and adaptive capacity. To this end, it is desirable to continue assessment and re-assessment of adaptation strategies (and adaptive capacity, and exposure). While the lead in implementing the adaptation process is necessarily taken by local actors and institutions at various scales, the researcher maintains active involvement via a monitoring function. This can be achieved through on-going contact with local collaborators, and field visits and follow-up ethnographic work as necessary.

7. Conclusion

This paper outlines a conceptual approach to and a framework for conduction vulnerability assessment. It outlines the necessity of considering determinants of exposure and adaptive capacity at various scales over time, and highlights the importance of time and place-specific vulnerability assessment.

Although many commonalities exist, there is no universal prescription for increasing adaptive capacity and hence decreasing vulnerability. Similarly, there is no one methodology which is appropriate for all community assessments. The choice of technique used for establishing validity and trust in a community, involving stakeholders, and data collection instruments is context specific. It is essential that researchers are highly adaptable and have the judgment to employ the ethnographic techniques which are most appropriate in a given instance.

The approach and framework presented here are of necessity nature general: it can be applied, using various techniques, in vastly different contexts with specific methodological considerations for each. To date, it has been employed to study community vulnerability to climate variability and change (particularly sea level rise) in developing nations (Samoa, Bangladesh), agricultural community vulnerability to climate change in British Columbia and Ontario, indigenous community vulnerability to environmental change and Inuit food security vulnerability in light of wider socio-economic changes in the Canadian Arctic.