4

Assessing Current Climate Risks

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4.1. Introduction

As part of Component 2 of the Adaptation Policy Framework (APF), *Assessing Current Vulnerability*, this Technical Paper (TP) focuses on how to assess the historical interactions between society and climate hazards. Key concepts related to current climate risks are outlined, and conceptual models that can be used to assess climate risks over short- and long-term planning horizons are introduced and described. Two major approaches to assessing those risks – a natural hazards-based approach and a vulnerability-based approach – are outlined. These two methods are complementary and can be used separately or together, as outlined in this TP and in TP3.

Understanding the historical interactions between society and climate hazards, including adaptations that have evolved to cope with these hazards, is a critical first step in developing adaptations to manage future climate risks. The characterisation of current climate hazards is also a key step towards building scenarios of future climate. In TP5, the methods described here are combined with climate scenario-building techniques to assess future risks.

This paper asserts that understanding current climate risks is a more appropriate basis for developing adaptation strategies to manage future climate risks than simply collecting baseline climate data and perturbing that data using scenarios of climate change. The relationships between current climate risks, vulnerability to those risks and the adaptations developed to manage those risks are often neglected in assessment methodologies – but not always in assessments themselves. Adaptation will be more successful if it accounts for both current and future climate risks. Even if future adaptation strategies are very different from those currently in use, today's adaptation will inform those strategies.

The main outputs that adaptation project teams can produce using this TP are:

1. Assessment of adaptive responses to past and present climate risks;
2. Knowledge of the climate drivers influencing current climate risks that will provide a basis for constructing scenarios of future climate (TP5); and
3. Understanding the relationship between current climate risks and adaptive responses that provides a basis for developing adaptive responses to possible future climate risks.

4.2. Relationship with the Adaptation Policy Framework as a whole

This paper is linked directly to the APF Component 2, *Assessing Current Vulnerability*. Dealing specifically with current climate impacts and risks, TP4 takes into account natural resource drivers, socio-economic drivers, adaptation experience and the policy environment, and is thus connected to other TPs in the following way:

- TP2: *Engaging Stakeholders in the Adaptation Process* – Stakeholders are vital in identifying various aspects of the coping range, including the key climatic variables and criteria for risk assessment, including thresholds.
- TP3: *Assessing Vulnerability for Climate Adaptation* – This TP explores methods of assessing current and future vulnerability to climate change including variability. Methods of assessing vulnerability in TP3 can be combined with methods of hazard identification – outlined in this TP – to assess risk.
- TP5: *Assessing Future Climate Risks* – This TP describes how climate–society relationships may change under climate change and discusses how climatic information can be applied within a variety of risk assessments.
- TP6: *Assessing Current and Changing Socio-Economic Conditions* – This TP can be used to analyse the changing social responses to past and present climate. These techniques can be used to construct a dynamic view of changes in the ability to cope with climate over time.
- TP7: *Assessing and Enhancing Adaptive Capacity* – This TP describes the potential to respond to an anticipated or experienced climate stress. Analysis of the historical ability to cope with climate risks can indicate the adaptive capacity of a particular system.
- TP8: *Formulating an Adaptation Strategy* – This TP looks at specific choices to adapt to risks recognised in this TP and TP5.

4.3. Key concepts

4.3.1. Risk

Risk is a term in everyday use, but is difficult to define in practice due to the complex relationships between its Components. Risk is the combination of the likelihood (probability of occurrence) and the consequences of an adverse event (e.g., climate hazard)[1]. In this TP, we describe the major elements of risk such as hazard, probability and vulnerability, though other terminology (e.g., exposure) can be used (TP3). These elements of risk can be applied in various ways depending on factors such as the level of uncertainty, whether the focus of an assessment is broad or specific and on the direction and emphasis of the approach used. Here, we describe two major approaches to assessing climate risk, a natural hazards-based approach and a vulnerability-based approach. These approaches rely most on whether the starting emphasis is on the biophysical or the socio-economic aspect of climate-related risk. In other words, is the emphasis on the climate hazard or on socio-economic outcomes? These two approaches are complementary and can be developed separately or together.

A *hazard* is an event with the potential to cause harm.

[1] Beer and Ziolkwoski, 1995; USPCC RARM, 1997.

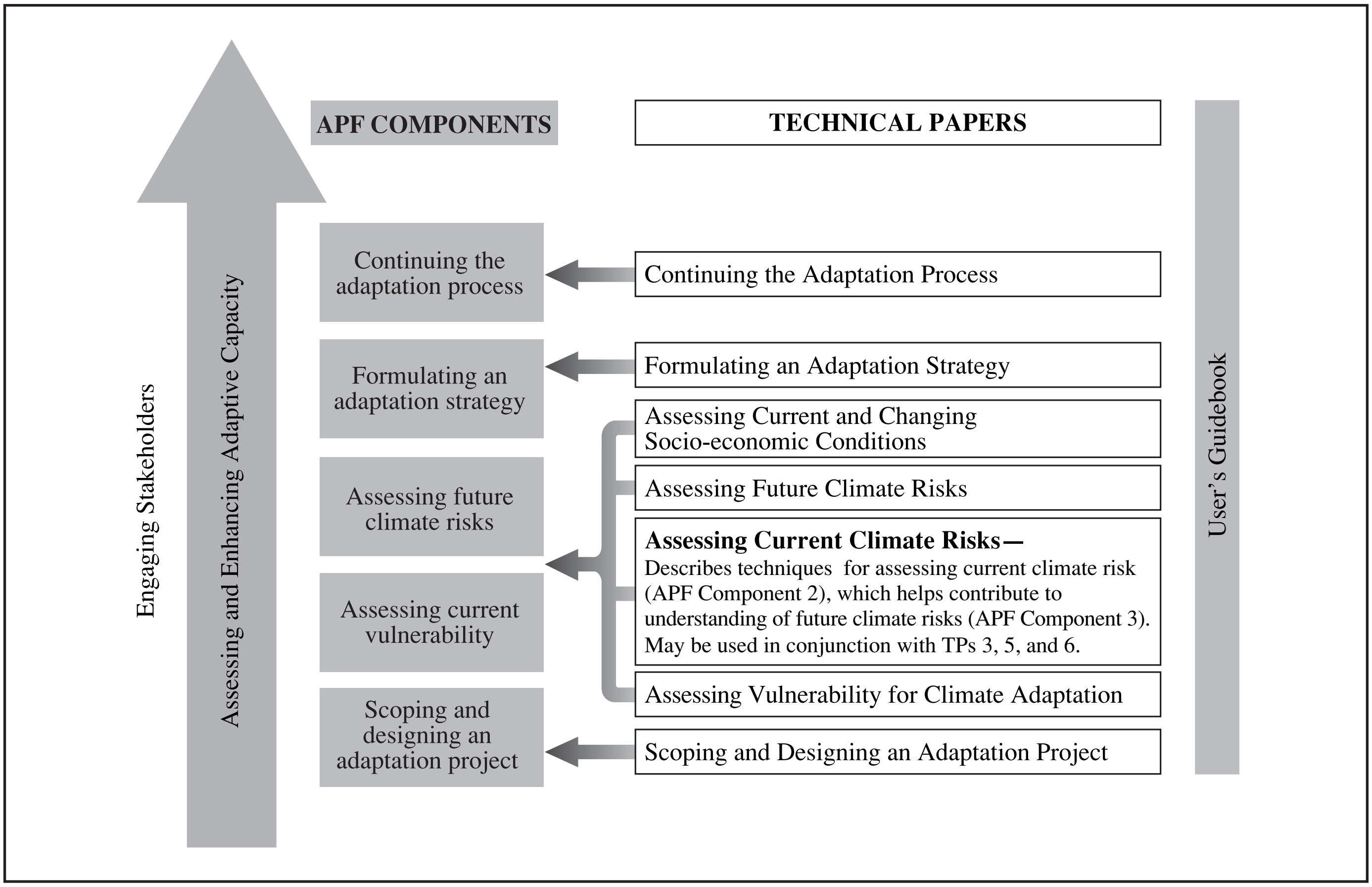

Figure 4-1: Technical Paper 4 supports Components 2 and 3 of the Adaptation Policy Framework

Examples of climate hazards are tropical cyclones, droughts, floods, or conditions leading to an outbreak of disease-causing organisms (plant, animal or human). Probabilities can be associated with the frequency and magnitude of a given hazard, or with the frequency of exceedance of a given socio-economic criterion (e.g., a threshold). Probability can range from being qualitative (using descriptions such as "likely" or "highly confident") to quantified ranges of possible outcomes, to single number probabilities. Vulnerability is broadly defined in TP3. Here, we limit our use of the term vulnerability to refer to climate vulnerability – specifically, the outcomes of climate hazards in terms of cost or any other value-based measure. Specific vulnerabilities (e.g., to drought, flood or storm surge) can also be assessed within the investigation of more broadly based social vulnerability, as described in TP3.

4.3.2. *Natural hazards-based approach*

The natural hazards-based approach to assessing climate risk begins by characterising the climate hazard(s) and can be written as:

Risk = Probability of climate hazard x Vulnerability

Hazard is generally fixed at a given level and used to estimate changing vulnerability over space and/or time. For example, a flood of a given height or a storm with a given wind speed may increase in frequency of occurrence over time, increasing the risk faced (assuming that vulnerability remains constant).

4.3.3. *Vulnerability-based approach*

The vulnerability-based approach begins by characterising vulnerability to produce criteria by which risk is assessed, e.g., by assessing the likelihood of exceeding a critical threshold.

Risk = Probability of exceeding one or more criteria of vulnerability[2]

Fixing the level of vulnerability allows the magnitude and frequency of climate-related hazards contributing to that vulnerability to be diagnosed. This is the "inverse method" as described in Carter et al. (1994). While commonly used in other disciplines, this technique has not been widely used for assessing climate change risks. If adaptation occurs, then successively larger and/or more frequent climate hazards can be coped with (e.g., a farming system adapting to drought should be able to manage

[2] Other formulations of risk are possible, but most will fall into the above two groups. Here, we have tried to provide a broad framework for assessing risk that will encompass more specific approaches.

more severe droughts before that system becomes vulnerable).

Two other methods mentioned in TP1 are the policy-based approach and the adaptive-bcapacity approach:

- Risk assessment techniques can be used in the policy-based approach where:
  - a new policy being framed is tested to see whether it is robust under climate change;
  - an existing policy is tested to see whether it manages anticipated risk under climate change.

- The adaptive-capacity approach investigates a system to determine whether it can increase the ability to cope with climate change, including variability. This approach will also be informed by a better knowledge of climate risks.

4.3.4. Adaptation, vulnerability and the coping range

Over time, societies have developed an understanding of climate variability in order to manage climate risk. People have learned to modify their behaviour and their environment to reduce the harmful impacts of climate hazards and to take advantage of their local climatic conditions. They have observed biophysical and socio-economic systems responding automatically to climate, and have tried to understand and manage these responses. This social learning is the basis of planned adaptation. *Planned adaptation* is undertaken by all societies, but the degree of application and the methods used vary from place to place. In modern societies, public sector adaptation may rely largely on science and government policy, and private sector adaptation on market forces, business models and regulation. Traditional societies may rely on narrative traditions, bartering of trade goods and local decision-making. All of these methods can be expressed using a common template.

This template has three climate ranges, depending on whether the outcomes are beneficial, negative but tolerable, or harmful. Beneficial and tolerable outcomes form the *coping range* (Hewitt and Burton, 1971). Beyond the coping range, the damages or losses are no longer tolerable and an identifiable group is said to be vulnerable. This structure is shown in Figure 4-2. A coping range is usually specific to an activity, group and/or sector, though society-wide coping ranges have been proposed (Yohe and Tol, 2002). The coping range provides a template that is particularly suitable for understanding the relationship between climate hazards and society. It can be utilised in risk assessments to provide a means for communication and, in some cases, may provide the basis for analysis.

The climatic stimuli and their responses for a particular locale, activity or social grouping can be used to construct a coping range if sufficient information is available. For example, in an agricultural system, this may include aspects of rainfall variability, temperature and other important prerequisites for understanding crop growth, information about crop yield and prices and knowledge of what constitutes a sustainable level of yield. Analyses can then be used to show which levels of yield are good, marginal, poor and which pose a serious threat. For a water sys-

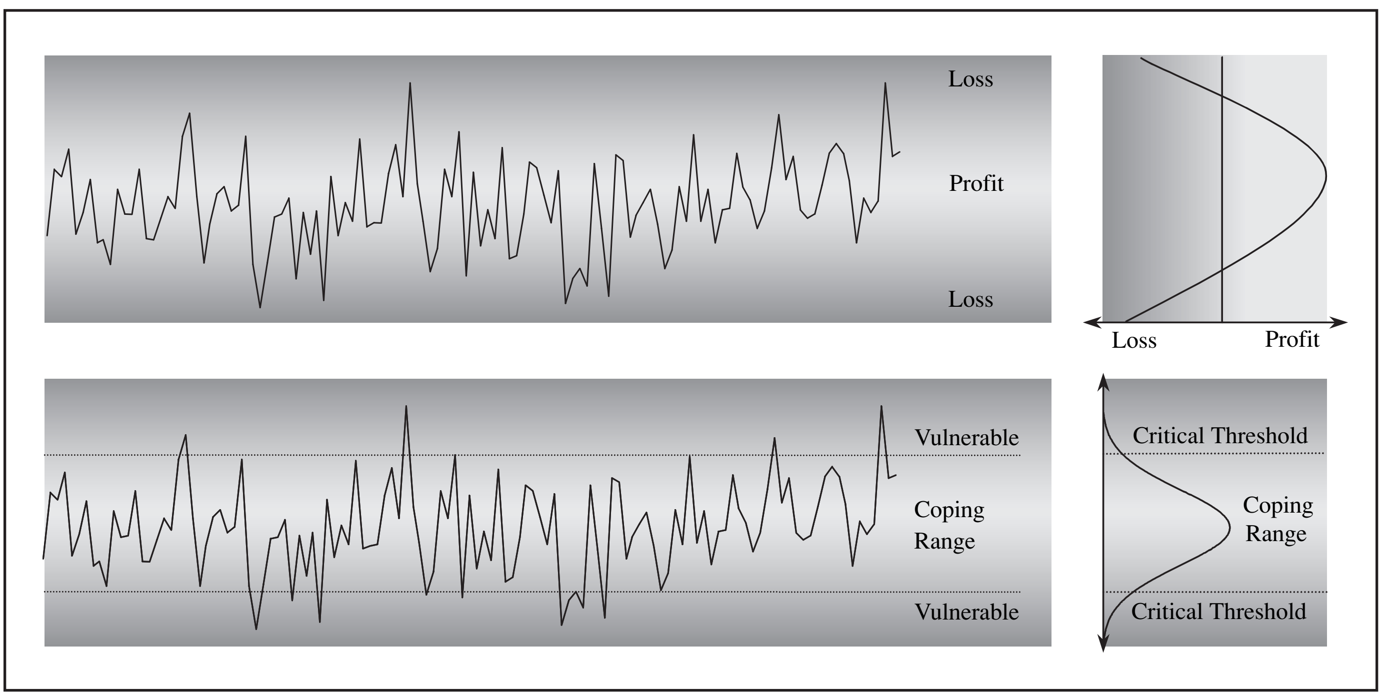

Figure 4-2: Simple schematic of a coping range under a stationary climate representing rainfall or temperature and crop yield. Vulnerability is assumed not to change over time. The upper time series and chart shows a relationship between climate and profit and loss. The lower time series and chart shows the same time series divided into a coping range using critical thresholds to separate the coping range from a state of vulnerability.

tem, climate drivers may include accumulated rainfall and evaporation, if supply is being addressed, or rainfall intensity and duration, if flooding is being addressed. On a coastline, climate variables contributing to storm surge, tidal regimes and sea level anomalies may be linked to thresholds related to the degree of coastal flooding or property damage. Coping range Components can range from simple "rule of thumb" estimates to accurate representations of a system based on detailed modelling.

Figure 4-2, upper left, shows a time series of a single variable, e.g., temperature or rainfall, under a stationary climate. If conditions get too hot (wet) or cold (dry), then the outcomes become negative. The response curve on the upper right represents the relationship between climate and levels of profit and loss for some measure, e.g., crop yield. Under normal circumstances, outcomes are positive but become negative in response to extremes of climate variability.

Using a response relationship between climate and other drivers and specific outcomes, we can select criteria or indicators representing different levels of performance for the purposes of assessing risk (Figure 4-2, lower left). For example, a yield relationship can be divided into good, poor or disastrous segments or coping capacity can be delimited by a critical threshold. More complex criteria, perhaps based on vulnerability analysis (TP3, Activities 2 and 3), may represent factors such as the ability to grow next season's seed supply, grow next year's food supply, break even economically, or produce sufficient surplus to pay for supplementary food and children's school fees. Note that in Figure 4-2, the critical threshold representing the ability to cope is held constant, but in the real world is dynamic, responding to internal process in addition to external climatic and non-climatic drivers (Annex A.4.3).

By adapting the knowledge of climate–society relationships held within a community, as well as within public and private institutions, the project team may be able to develop a relationship linking climate to criteria that represent a given level of vulnerability. For example, a narrative history of past droughts and the responses to those droughts can be matched with rainfall records to construct a fuller picture of climate–society relationships that can then be assessed under conditions where both climate and society may change (TP2, Activity 2; Tarhule and Woo, 1997).

Therefore, risk can be assessed by calculating how often the coping range is exceeded under given conditions (Figure 4-2, lower right). The method of assessing risk can range from qualitative to quantitative. Qualitative methods can be carried out by building or using an existing conceptual model of a specific coping range and assessing risk in terms of qualifiers such as low, medium and high. Quantitative methods will begin to assess the likelihood of exceeding given criteria, such as critical thresholds. Quantitative modelling will allow these relationships to be assessed under changing conditions. When undertaking mathematical modelling using the coping range, it is advisable to modify the mathematical models to suit the conceptual models rather than let the structure of the models dominate the assessment.

The coping range is a very useful concept because it fits the mental models that most people have concerning risk. People have an intuitive understanding of the situations they face regarding commonly encountered climatic risks – which risks can be coped with, which cannot and what the consequences may be. This understanding can be extended to other less commonly encountered risks and to never before experienced situations that may occur under climate change. Stakeholders will also have different coping ranges. An assessment may wish to explore those differences in order to gather a common activity-wide coping range for the purposes of assessment, or to explore the differences between coping ranges, e.g., why do certain groups cope better with a situation, and how do we share that capacity with others?

4.4. Guidance on assessing current climate risks

The goal of this section is to guide the user through the process of assessing current climate risks, as outlined in Figure 4-3, rather than provide a tight prescription for how to proceed. There are two major paths one can use, depending on whether the starting point focuses on climate or on vulnerability to climate. For example, a project focusing on the identification of regional climate hazards and how they may alter vulnerability will probably be more suited to a natural hazards-based approach. Approaches focused on the nature of vulnerability or critical thresholds may well start at that point then work backwards to determine the magnitude and frequency of hazards contributing to that vulnerability. Natural hazards-based approaches are favoured where the probabilities of the climate hazards can be constrained, where the main drivers of impacts are known and where the chain of consequences between hazard and outcome is well understood. The vulnerability-based approach will be favoured where: the probability of the hazard is unconstrained, there are many drivers and there are multiple pathways and feedbacks leading to vulnerability. Steps can be carried out in any order to suit the needs of an assessment and can be skipped if they are not considered necessary. Previous information on risks and hazards can also be introduced. The most basic elements needed are a conceptual model of the system and a basic knowledge of the hazards and vulnerabilities in order to prioritise risk. Both qualitative and quantitative methods can be used to assess risk depending on the quality of information needed by stakeholders and the data and knowledge available to provide that information.

4.4.1. Building conceptual models

Component 2 of the APF requires an understanding of the important climate–society relationships within the system being investigated. Those relationships are dominated by the climate impacts within the system and the sensitivity of the system response. *Climate sensitivity* is defined as the degree to which a system is affected, either beneficially or adversely, by climate-related stimuli (IPCC, 2001). Sensitivity affects the magnitude and/or rate of a climate-related perturbation or

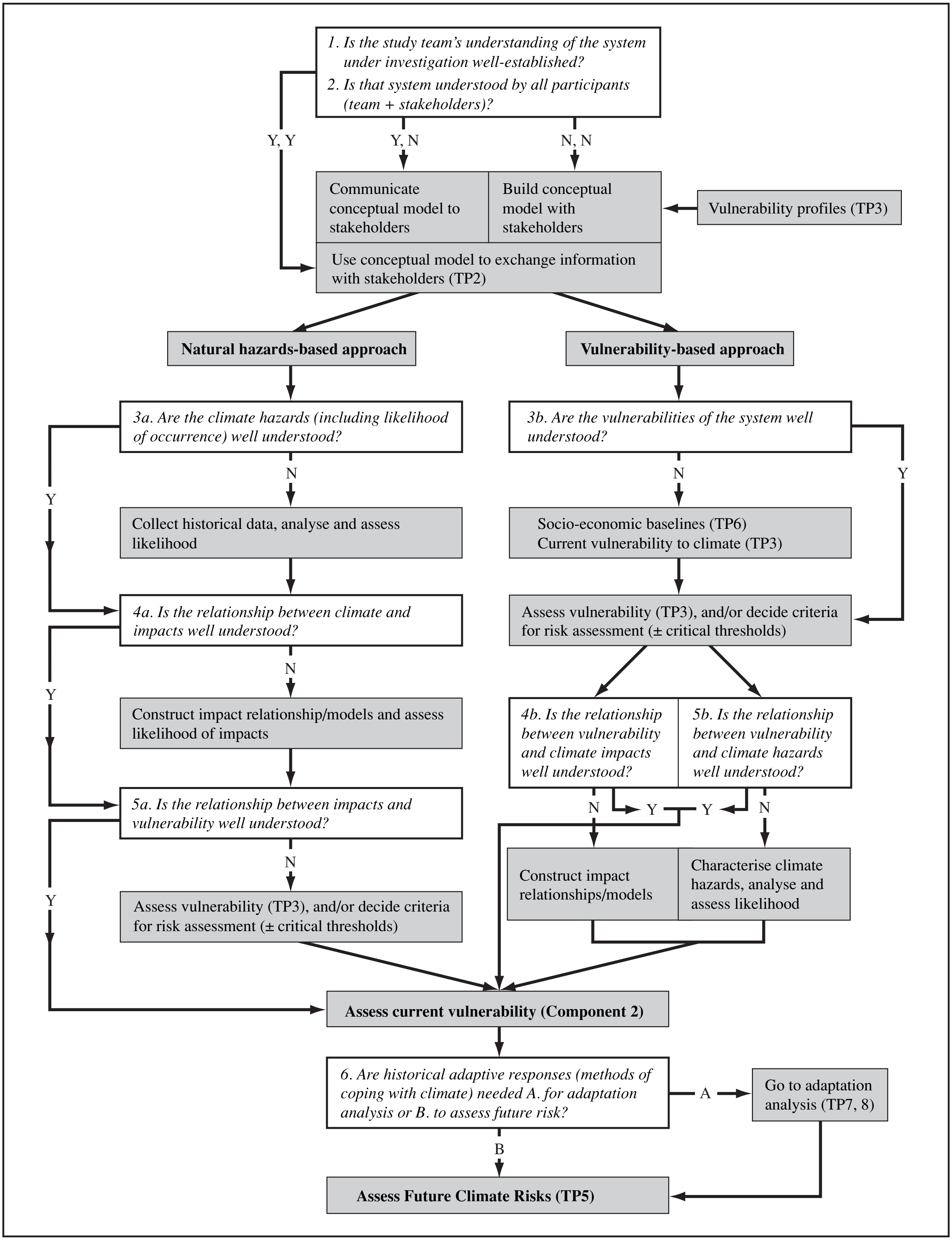

Figure 4-3: Flow chart for assessing current climate risk

stress, while vulnerability is the degree to which a system is susceptible to harm from that perturbation or stress (TP3 presents the development of conceptual models for assessing vulnerability).

Climate–society relationships can be identified through stakeholder workshops, or may be well known from previous work. The creation of lists, diagrams, tables, flow charts, pictograms and word pictures will create a body of information that can be further analysed. TP2 describes a number of ways this can be carried out with stakeholders. Establishing conceptual models in the early stages of an assessment can help the different participants develop a common understanding of the main relationships and can also serve as the basis for scientific modelling. In this chapter, we utilise the coping range extensively because of its utility as a template for understanding and analysing climate risks, but it is not the only such model that can be used. Other models include decision support systems, causal chains of hazard development, and mapping analysis (e.g., using geographic information systems). A comprehensive list of methods is provided in TP3.

4.4.2. *Characterising climate variability, extremes and hazards*

The characterisation of climate variability begins with understanding the aspects of climate that cause harm, i.e., the climate hazards. With reference to the coping range, climate hazards are the aspects of climate variability and extremes that have the potential to exceed the ability to cope.

A starting question could be: "Are the climate hazards (affecting the system) known and understood?" There are two steps to this: the identification of the relevant climate hazards and their analysis. If the hazards for a system need to be identified, or their impact on the system investigated, the following questions can be addressed:

- Which climate variables and criteria do stakeholders use in managing climate-affected activities?
- Which climate variables most influence the ability to cope (i.e., those linked to climate hazards)?
- Which variables should be used in modelling and scenario construction?

These questions can be investigated by ways such as:

- Moving through a comprehensive checklist of climate variables in stakeholder workshops.
- Literature search, expert assessment and information from past projects.
- Exploring climate sensitivity with stakeholders, through interview, survey or focus groups.
- Building conceptual models of a system in a group environment.

Different aspects of climate variability will need to be examined. For example, rainfall can be separated into single events, daily variability and extremes, seasonal and annual totals and variability, and changes on longer (multi-annual and decadal) timescales. Daily extremes are important in urban systems for flash-flooding, inter-annual variability for disease vectors, and seasonal rains for dry-land agriculture. Temperature can be divided into mean, maximum and minimum daily averages, variability and extremes. In each system, people will have a different set of variables that they use to manage that system. Even though this management may not be scientific, it may be very sophisticated. Each of these variables involves a different level of skill in terms of climate modelling and has different degrees of predictability under climate change – information that is critical for building climate scenarios.

Hazards are not the same as extreme events, though they are related. Hazards are events and combinations of events with a propensity to cause harm, whereas extreme events are defined through rarity, impact, or a combination of both. Some extreme

Table 4-1: *Typology of climate extremes (based on Schneider and Sarukhan, 2001)*

Type	Description	Examples of events	Typical method of characterisation
Simple	Individual local weather variables exceeding critical levels on a continuous scale	Heavy rainfall, high/low temperature, wind speed	Frequency/return period, sequence and/or duration of variable exceeding a critical level
Complex	Severe weather associated with particular climatic phenomena, often requiring a critical combination of variables	Tropical cyclones, droughts, ice storms, ENSO-related events	Frequency/return period, magnitude, duration of variable(s) exceeding a critical level, severity of impacts
Unique or singular	A plausible future climatic state with potentially extreme large-scale or global outcomes	Collapse of major ice sheets, cessation of thermohaline circulation, major circulation changes	Probability of occurrence and magnitude of impact

events are defined as such because they occur rarely, such as a one in 100-year flood. Some more common events have extreme impacts, as in hurricanes or tropical cyclones, referred to as extreme events because of the damage they cause, rather than through rarity. Table 4-1 shows a typology of extreme climate events from the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report (TAR). A number of changes in extremes expected under climate change, and their impacts, are also associated with current extremes (Annex A.4.2).

Stress may occur in response to a shock associated with an extreme weather event, or accumulate through a series of events or a prolonged event such as drought. Risk assessment requires us to move from characterising extremes to defining hazards.

A climatic hazard is an event, or combination of climatic events, which has potentially harmful outcomes. Depending on the approach taken, hazards can be characterised in two ways: the *natural hazards-based approach*, where the focus is on the climate itself, and the *vulnerability-based approach* that stresses on the level of harm caused by an impact.

- The natural hazards-based approach is to fix a level of hazard, such as a peak wind speed of $10ms^{-1}$, hurricane severity, or extreme temperature threshold of 35°C, then to see how that particular hazard affects vulnerability across space or time. Different social groupings will show varying degrees of vulnerability depending on their physical setting and socio-economic capacity.
- The vulnerability-based approach sets criteria based on the level of harm in the system being assessed then links that to a specific frequency, magnitude and/or combination of climate events. For example, if drought is known to harm a social group, we may choose to look at a given level of stress due to crop failure, and then determine the climatic characteristics that cause those shortages. Or if loss of property due to flooding is the level of vulnerability, then the rainfall and flood peak contributing to that level of flooding may constitute the hazard (and may be due to both climate and catchment conditions caused by land-use change). The level of vulnerability that provides this trigger can be decided jointly by researchers and stakeholders, chosen based on past experience or defined according to policy.

Figure 4-3 provides pathways for both of these approaches.

4.4.3. Impact assessment

Impact assessment under current climate can be used to establish a framework for how a climate hazard acts on society, or can look at vulnerability, then determine which climate hazards are involved. Qualitative methods can stand alone, or can establish the relationships prior to a modelling study.

Qualitative methods

Relationships between climate variables and impacts can be analysed by a number of methods such as ranking in order of importance, identifying critical control points within relationships, and quantifying interactions through sensitivity analysis (e.g., through workshops, focus groups and questionnaires). Often, this knowledge exists in institutions (e.g., agricultural extension networks) where important relationships are well known. In such cases, stakeholder workshops may allow the information to be gathered relatively easily. In other situations, several stakeholder workshops may be needed, the first to familiarise stakeholders with the issue of climate change (TP5, Figure 5-2) and to establish areas of shared knowledge and gaps, before investigating the specifics of a particular activity (TP2). Cross-impacts analysis, detailed in Annex A.4.1, can be used to manage the information gathered at such workshops.

The exploration of climate sensitivity with stakeholders is part of "learning by doing". By listing and discussing the climate variables that are important to them, stakeholders can consider the adaptations they currently use, the important thresholds or criteria they use in management and how those variables might change under climate change (TP2, Activity 3). Scenario builders and impact researchers have the opportunity to ask stakeholders which types of climatic events are important to them, and how they have responded to extreme events in the past (e.g., the relationship between climate events and changes in adaptive capacity, see TP7). This process is very useful if introduced with an overview of climate change and expected impacts. It is also an opportunity to discuss the policy and institutional environment, how non-climatic factors interact with climate in specific activities and issues of sustainable development (Activity 4, TP3). For example, in Bangladesh, damage from cyclones of the same intensity was US$1,780 million in 1991 and US$125 million in 1994. Reduction in damage was mainly due to setting up institutions after the 1991 cyclone and effective cyclone preparedness in 1994.

Quantitative methods

Quantitative impact assessment involves the formal assessment of climate, impacts and outcomes within a modelling framework. There is extensive literature on how to carry out impact assessment that includes IPCC assessment reports, impacts and adaptation assessment guidelines, and works within the individual disciplines (e.g., Carter and Parry, 1998; Carter et al., 1994; IPCC-TGCIA, 1999; UNEP, 1998).

In assessing current risk, impact modelling will largely concentrate on assessing the impacts of extreme events and variability, perhaps undertaking modelling to extend the results based on relatively short records of historical data (e.g., through statistical analysis). Sensitivity modelling in testing changes to variability and investigating extreme event probabilities can be of benefit later when climate scenarios are being constructed. Furthermore, given the difficulty in combining various types of climate uncertainty (discussed in TP5), sensitivity modelling of impacts under climate variability will help identify which uncertainties need to be represented in scenarios.

4.4.4. *Risk assessment criteria*

As mentioned earlier, risk is a function of the likelihood of a harmful event and its consequences. Likelihood can be attached to the frequency of a hazard and/or to the frequency of given criteria being exceeded. All risk assessments need to be mindful of which criteria are important: what is to be measured and how are values to be attached to various outcomes?

Each assessment needs to develop its own criteria for the measurement of risk. Assessment criteria can be measured as a continuous function or in terms of limits or thresholds. For example, in farming, crop yields can be divided into good, moderate, poor and devastating yields depending on yield per hectare, per family or in terms of gross economic yield. There may be a minimum level of yield below which hardship becomes intolerable. This level can become a criterion by which risk is measured. It marks a reference point with known consequences to which probabilities can be attached. More sophisticated assessment may utilise different frequencies and combinations of good and bad years.

Levels of criteria that associate climate and impacts are known as *impact thresholds*, where the threshold marks a change in state. Impact thresholds can be grouped into two main categories: *biophysical* and *socio-economic*.

- Biophysical thresholds mark a physical discontinuity on a spatial or temporal scale. They represent a distinct change in conditions, such as the drying of a wetland, floods, breeding events. Climatic thresholds include frost, snow and monsoon onset. Ecological thresholds include breeding events, local to global extinction or the removal of specific conditions for survival.
- Socio-economic thresholds are set by benchmarking a level of performance. Exceeding a socio-economic threshold results in a change of the legal, managerial or regulatory state, and the economic or cultural behaviour. Examples of agricultural thresholds include the yield per unit area of a crop in weight, volume or gross income (Jones and Pittock, 1997).

Critical thresholds are defined as any degree of change that can link the onset of a critical biophysical or socio-economic impact to a particular climatic state (Pittock and Jones, 2000). Critical thresholds can be assessed using vulnerability assessment and mark the limit of tolerable harm (Pittock and Jones, 2000; Smit et al., 1999). For any system, a critical threshold is the combination of biophysical and socio-economic factors that marks a transition into vulnerability. The construction of a critical threshold can be used to limit the coping range. If this threshold can be linked with a level of climate hazard, then the likelihood of that threshold being exceeded can be estimated subjectively if the relationship is known qualitatively, or calculated if the relationship is quantifiable.

Table 4-2 lists a number of criteria, including thresholds, which have been used in climate risk assessments. They range from the biophysical to the socio-economic, from being universal to context-specific, and from the subjective to the objective. For example, economic write-off for infrastructure is socio-eco-

Table 4-2: *Examples of criteria used in impact and climate risk assessments (based on Jones, 2001)*

SECTORS	CRITERIA	EXAMPLES
Agriculture		
Animal health	• Temperature stress (also production)	Ahmed and El Amin (1997)
Animal production	• Parasites and disease	Estrada-Peña (2001); Sutherst (2001)
Crop production	• Carrying capacity	Hall et al. (1998)
	• Accumulated degree days to fruit and/or harvest	Kenny et al. (2000)
	• Yield	Chang (2002); Onyewotu et al. (1998); Mati (2000); Ferreyra et al. (2001)
Agro-meteorology	• Monsoon arrival	Smit and Cai (1996)
	• Multiple indices	Salinger et al. (2000); Sivakumar, (2000); Hammer et al. (2001)
Economic	• Net/Gross income per ha/farm/region/nation	Kumar and Parikh (2001)

SECTORS	CRITERIA	EXAMPLES
Biodiversity		
Species or community abundance	• Vulnerable • Endangered • Sustainable population levels	Country/species specific
Species distribution	• Climate envelope shifts beyond current distribution	
	• Quantified change in core climatic distribution	Villers-Ruiz and Trejo-Vásquez, 1998)
Ecological processes	• Climatic thresholds affecting distribution	
	• Critical levels of mean browsing intensity	Kienast et al. (1999)
	• Climatic threshold between eco-geomorphic systems	Lavee et al. (1998)
Phenology	• Mass bleaching events on coral reefs	Hoegh-Guldberg (1999)
	• Winter chill – e.g., frequency of occurrence below daily min. temp. threshold	Hennessy and Clayton-Greene (1995), Kenny et al. (2000)
	• Cumulative degree days for various biological thresholds	Spano et al. (1999)
	• Day length/temperature threshold for breeding	Reading (1998)
	• Temperature threshold for coral bleaching	Huppert and Stone (1998)
Coastal zone		
General	• Salinity	Nicholls et al. (1999)
	• Flooding and wetlands	Ewel et al. (1998)
	• Mangroves	Arthurton (1998)
	• Planning for disasters/hazards	Pethick (2001)
	• Coastal dynamics	Dickinson (1999)
	• Critical thresholds for atolls	Perez et al. (1996); Yim (1996)
	• Regional assessment/multiple factors	El Raey (1997)
	• Infrastructure/economics	
Forestry		
	• Distribution	Somaratne and Dhanapala (1996); Eeley et al. (1999)
Hydrology		
Water quality	• Regulated water quality standards for factors such as salinity, dO, nutrients, turbidity.	Widespread and locally specific.
Water supply	• Regulated and/or legislated annual supply at system, district at farm level	Jones (2000); Bronstert et al. (2000)
	• Water storage stress	Lane et al. (1999)
	• Renewable supply/water stress	Jaber et al. (1997)
	• Institutional frameworks	Arnell (1999); Savenije (2000)
Streamflow	• Maintenance or low-flow event frequency and duration	El-Fadel et al. (2001) Panagoulia and Dimou (1997)
	• Change in runoff and streamflow	Mkankam Kamga (2001)
Flooding	• Flood events	Panagoulia and Dimou (1997); Mirza (2002)
Drought	• Palmer drought severity index	Palmer (1965)
	• Drought exceptional circumstances	White and Karssies (1999)
Hydroelectric power	• Current mean and minimum energy supply	Mimikou and Baltas (1997)

SECTORS	CRITERIA	EXAMPLES
Human Health		
Vector-borne diseases	• Aggregate epidemic potential • Climatic envelope/indices of disease vector • Critical density of vector to maintain virus transmission	Patz et al. (1998) McMichael (1996); Hales et al. (2002) Jetten and Focks (1997); Martens et al. (1999); Lindblade et al. (2000a & b)
Thermal stress	• Heat and cold temperature levels and duration	McMichael (1996)
Multiple Indices	• Disease and disaster	Patz and Lindsay (1999); Epstein (2001); Watson and McMichael (2001)
Infrastructure		
	• Economic "write off", e.g., replacement less costly than repair • Infrastructure condition falling below given standard	See TP8 for cost-benefit analysis
Land degradation		
Erosion	• Threshold for overland flow erosion	Tucker and Slingerland (1997)
Montane systems		
Glacial lakes	• Catastrophic collapse and flooding	Richardson and Reynolds (2000)
Montane cloud forests	• Loss of ecosystem	Foster (2001)

nomic, context-specific and subjective, based on assumptions used in cost-benefit analysis. Degree-days to harvest for a crop is biophysical, universal and objective, but a threshold based on economic output from that crop will be socio-economic, context-specific and probably subjective.

Criteria for risk assessment can be developed using vulnerability analysis (TP3). Where criteria are context-specific, stakeholders and investigators can jointly formulate criteria that become a common and agreed metric for an assessment (Jones, 2001). These may link a series of criteria ranked according to outcomes (e.g., low to high), or be in the form of thresholds. Critical thresholds can be defined simply, as in the amount of rainfall required to distinguish a severe drought, e.g., <100 mm rainfall over a dry season, or can be complex, such as the accumulated deficit in irrigation allocations over a number of seasons (Jones and Page, 2001; TP5 Annex A.5.1). Widely applicable thresholds can be obtained from the literature. Other thresholds may be legal or regulatory (e.g., building safety standards, water quality standards).

There are no hard and fast rules for constructing thresholds – they are flexible tools that mark a change in state that is considered important. For example, stakeholders may link a given deficit of rainfall with drought hardship that leads to regional out migration, or loss of fresh water supply. Although annual and seasonal total rainfall is on a continuous scale, a change in behaviour associated with given amounts may constitute a threshold. Thresholds can vary widely over time and space, so each assessment has to identify the adequate criteria. This will depend on a trade-off between the level of information available and what criteria are considered important.

4.4.5. Assessing current climate risks

This section demonstrates different methods of assessing risk under current climate. Within the broad framework of assessing risk, it is possible to conduct assessments that range from being qualitative to those that apply numerical techniques. As uncertainty decreases, the use of analytic and numerical methods increase, and the capacity to understand the system over changing circumstances increases. The following list outlines this development:

1. Understanding the relationships contributing to risk
2. Relating given states with a level of harm (e.g., low, medium and high risk)
3. Using statistical analysis, regression relationships
4. Using dynamic simulation
5. Using integrated assessment (multiple models or methods)

These methods can be used to undertake the following investigations:

- Understanding the relationship between climate and society at a given point in time
- Establishing current climate and society relationships

prior to investigating how climate change may affect these relationships (e.g., setting an adaptation baseline)
- Developing an understanding of how past adaptations have affected climate risks
- Assessing how technology, social change and climate are influencing a system, in order to be able to separate changes due to climate variability from changes due to ongoing adaptation (e.g., Viglizzo et al., 1997)
- Assessing how known adaptation strategies can further reduce current climate risks

Choice of method

The following examples show that there are a number of ways to assess climate risk. The method applied in Box 4-1 is hazard-driven, starting with the frequency and magnitude of extremes and their relationship to property damage and insurance claims. The assessment in Box 4-2 deals with famine, and in Box 4-3 with malarial outbreaks. In both cases, they have begun with the impacts causing vulnerability, and then identified the climate hazard driving those impacts. Adaptation in the form of early warning systems has been applied in the first case and recommended in the second. In both cases, socio-economic factors also affect the level of vulnerability. In Box 4-2, high prices and conflict make populations more vulnerable to drought. In Box 4-3, land-use change is exacerbating the climate hazard, specifically high minimum temperatures, increasing the survival of malaria vectors. Box 4-4 begins with an impact factor, crop yield, then identifies how deviations in yields are increasing over time; although average yields are increasing, so is vulnerability to bad years.

These differences help to explain why this TP does not offer tight prescriptions for constructing risk relationships in Section 4.4. Likewise, Figure 4-3 is not meant to provide similarly tight prescriptions. Either the right- or left-hand path, or both, can be taken. Questions can be missed. Perhaps this information already exists or is not needed for a particular assessment. It is also possible to start with impacts in the middle of the diagram and work forward to vulnerability and backwards towards hazards. In that case, techniques from TP3, this paper and TP6 could be utilised.

The natural hazards-based approach has been the traditional approach for assessing climate risks but, where the link between hazards and vulnerability are unclear, or where there are complex relationships between climate and non-climatic drivers, a vulnerability-based approach could be considered. This may involve setting desirable or undesirable criteria in the form of thresholds, then determining how hazards contributed to meeting or avoiding those criteria. For example, how achievable are given levels of water yield and quality, and food security, if the criteria for those are set first, then levels of exposure to climate hazards are determined? If the type and magnitude of hazard that may breach a given level of vulnerability is known, adaptation can then ensure that even larger hazards are managed.

Examples

Box 4-1 describes the vulnerability of property to wind damage in the south-eastern United States. This assessment takes a natural hazards-based approach (the left-hand path in Figure 4-3), where relationships between effective mean wind speed and property damage have been created and expressed in annual insurance claim and damage ratios. Having created these relationships, it would be possible to set thresholds for exceedance, e.g., the level where an insurance company may decide to charge higher premiums or to withdraw protection altogether. Alternatively, such criteria could be used to increase building-strength regulations in high-risk zones.

Box 4-2 describes a natural hazards-based approach to disaster prevention, where an early warning system is used to reduce the risk of famine accompanying drought and to increase the ability of people to cope with drought. The development of a Famine Early Warning System (FEWS) has increased the coping range of local populations, but incomplete uptake of the system, and the short-term nature of adaptation strategies means that significant risks still exist. This suggests that although the FEWS has increased the coping range to current climate variability, the delivery of its outputs needs to be fine-tuned and more widely disseminated. Continuing shocks are continuing to reduce the coping capacity of populations, requiring short-term risk management before considering longer-term adaptation options under climate change. This example is one where the current risks are so high, detailed risk assessment of possible future conditions are not required to prioritise adaptation options. In addition to short-term food aid, productive assets and viable livelihoods can only be restored by promoting longer-term development strategies and investments aimed at addressing the root causes of vulnerability to drought and food insecurity (FEWS NET, March 19, 2003).

Box 4-3 is an example of a risk assessment that follows the right-hand path of Figure 4-3. The investigation begins with an impact – malarial outbreak in highland East Africa – aiming to identify the hazards leading to those impacts. The major reason for the increase in malarial outbreaks was an increase in warmer micro-climates in villages near cleared swamps. This indicated that land use change is a factor in increasing malaria risk through increasing minimum temperatures. However, the basic climatic hazard was associated with the warmer temperatures of the El Niño event of 1997/98, which caused a malaria epidemic in the region. Lindblade et al. (2000a and b) also identified critical thresholds for *Anopheles* mosquito density that is associated with minimum temperatures. These densities could be used to develop sampling strategies to contribute to early warning systems. The identified hazards were of climatic (El Niño) and socio-economic (land-use change) origin. Further risk assessment under climate change would need to include both climatic and socio-economic drivers of change.

Box 4-4 shows an assessment of current climate risks within a system that is also changing due to non-climatic influences. Changing technology and cropping area have influenced rice production in Indonesia, creating a trend that masks the impacts

Box 4-1: Assessing property damage from extreme winds

The following example from Huang et al. (2001) assesses property damage from a model of extremes winds. Figures 4-4 and 4-5 show two damage relationships between effective mean wind speed and weighted claim and damage ratios from the southeastern United States. These ratios are the proportion of claims and damages made observed from Hurricanes Andrew and Hugo. One hundred percent of weighted claims or damages indicates that the maximum damage has been reached. Using Monte Carlo modelling of wind fields based on historical hurricane data and the data in Figures 4-4 and 4-5, Huang et al. (2001) estimated the spatial vulnerability to damage in Florida as expected annual claim and damage ratios for Florida (Figures 4-6 and 4-7).

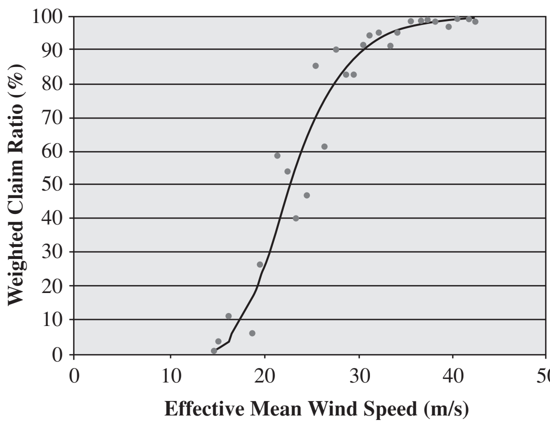

Figure 4-4: Claim ratio vs. effective mean surface wind speed

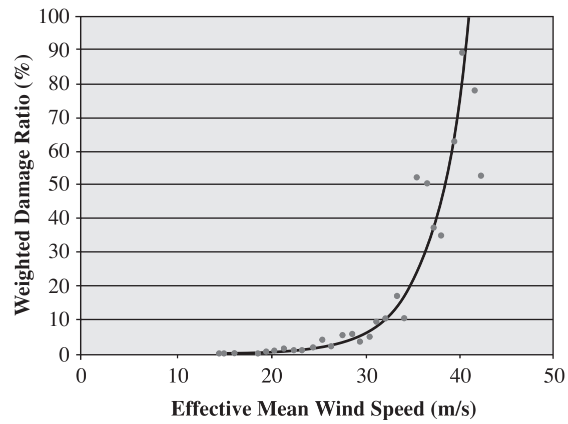

Figure 4-5: Damage ratio vs. effective mean surface wind speed

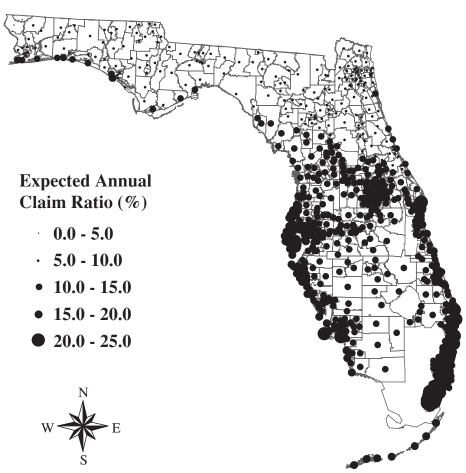

Figure 4-6: Expected annual claim ratio for each zip code in Florida

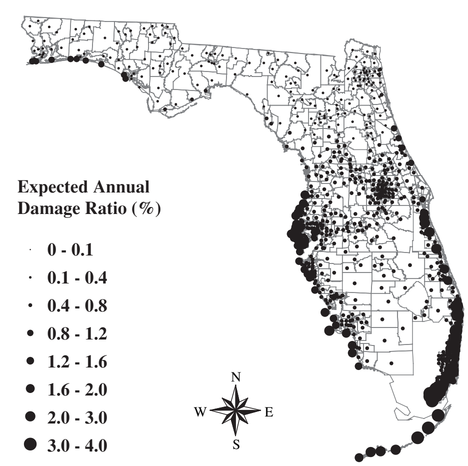

Figure 4-7: Expected annual damage ratio for each zip code in Florida

What critical thresholds or any other criteria measuring vulnerability could be used for the above information? Based on mean wind speed, weighted claims data increase markedly at >20 ms^{-1}; damage ratios increase markedly at >30 ms^{-1} and are a maximum at 41.4 ms^{-1}. Huang et al. (2001) also include information about 50-year return interval wind gusts. Based on levels of property damage, a 2% expected annual damage ratio would see damage occurring to the total value of a building at least once in its 50-year design life. Thresholds could also be set by the insurance industry at levels where damage rates exceed returns. Under climate change, such thresholds may change spatially, or may change in likelihood of exceedance in a single location.

Box 4-2: The use of climate forecasts in adapting to climate extremes in Ethiopia

Introduction

In Ethiopia, famine has long been associated with fluctuations in rainfall. For example, a serious humanitarian disaster occurred during the 1984–5 Ethiopian drought when close to one million people perished. During 2000–1, a more serious drought affected most of Ethiopia. The failure of the 2000 *Belg* (secondary) rains was more critical compared to the case of 1984. This followed consecutive years of drought in 1998 and 1999, which had killed livestock and over-stretched the coping capacities of local populations. During the year 2000 however, a humanitarian crisis was averted due to a functioning Famine Early Warning System (FEWS) which had been put in place. However, another drought in 2002 has continued to decrease the ability of populations to cope.

Hazard assessment

The mean rainfall in Ethiopia ranges from about 2000 mm in the southeast to <150 mm in the northeast. There are three seasons: *Bega*, a dry season (October – January); *Belg*, a short rain season (February – May) and *Kiremt*, a long rain season (June – September). Trend analysis showed declining rainfall over the northern half and south-western areas of Ethiopia. A vulnerability assessment showed that a decrease in rainfall over the northern parts of Ethiopia was expected. An investigation with three global climate models also indicated a risk of more frequent droughts under climate change.

Impacts

The major negative impact is on food supply, since Ethiopia is dependent on rain-fed agriculture. Droughts affect the Greater Horn of Africa regularly and the resulting food crisis can easily affect up to twenty million people in Ethiopia alone. Apart from widespread famine, livestock perish and there is potential for armed conflict among communities. Increases in both climate variability and the intensity of drought in Ethiopia are anticipated under climate change.

Adaptation measures

Following the human disaster in 1984, Ethiopia developed a comprehensive Famine Early Warning System, which integrated climate forecasts for Ethiopia with other information such as harvest assessments, vegetation indices and field reports. By 1999, early warning signals showed that a major famine was likely by 2000, due to drought and the border conflict between Ethiopia and Eritrea. As a result, the United States Agency for International Development (USAID) and European Union significantly increased their food aid commitments. Although there was a significant loss of livestock and livelihoods, a humanitarian disaster was averted. The FEWS played a significant role in sensitising the government and the famine early warning community. This also encouraged small anticipatory actions by affected populations, which improved their coping capacity.

Constraints

In spite of a reasonable FEWS by the year 2000, government and donor decisions were not entirely driven by the FEWS. This meant that the potential maximum coping range could not be achieved in Ethiopia. Often the early warning bulletins did not target the appropriate audience. Secondly, the application of seasonal climate forecasts emphasised short-term responses, increasing the risk of reinforcing short-term strategies at the expense of longer-term adaptations and limiting resilience to increased climate change including variability. By early 2003, yet another drought and high prices had reduced the coping capacity of populations even further, and the FEWS had issued a pre-famine alert for 11.3 million people.

Conclusion

Despite the probabilistic nature of climate forecasts and early warning systems, a well-designed FEWS can improve the resilience and coping capacity of communities to the impacts of climate variability and change. Early warning systems combined with good seasonal climate forecasts are cost-effective. Early warning information must be disseminated in a timely way to all stakeholders in formats they can understand or appreciate. However, as the events of 2002–3 show, repeated shocks can reduce coping capacities, requiring even greater intervention by outside agencies.

This text is based on Kenneth Broad and Shardul Agrawala's report in Science Vol. 289, 8 September 2000; the Initial National Communication of Ethiopia to the UNFCCC and on-line at: http://www.fews.net.

of climate. Despite this upward trend, drought still poses a risk to the majority of farmers in Indonesia. By developing a regression relationship to remove the production-based trend, it is possible to independently analyse the impacts of poor years on production and therefore, to assess the role of climate on drought risk. It shows that although adaptation is improving crop yields, individual poor years still constitute a risk.

This example has investigated question 4a in Figure 4-3: "Is the relationship between current climate and impacts well understood?" A vulnerability analysis of which populations were affected by low yields in bad years and how they were affected would help link climate hazards in terms of the El Niño–Southern Oscillation (ENSO) to vulnerabilities related to crop failure.

4.4.6. Defining the climate risk baseline

An assessment of current climate risks (baseline) is needed for assessing future risks. Planned adaptation to future climate will be based on current individual, community and institutional behaviours that, in part, have been developed as a response to current climate. Existing adaptation is a response to the net effects of current climate (change, including variability) as expressed by the coping range. Adaptation analogues show that adapting to a future climate is influenced by past behaviour (Glantz, 1996; Parry, 1986; Warrick et al., 1986). This includes both autonomous and planned responses. Adaptation measures need to be consistent with current behaviour and future expectations if they are to be accepted by stakeholders. The analysis of behavioural responses to current climate variability also aids in the construction of climate scenarios.

Because the interactions between climate and society are dynamic (see Annex A.4.3 for a detailed explanation, also TP6), a climate-risk baseline needs to be created. This is an initial risk assessment at time = t_0, or even t-10, which provides the refer-

Box 4-3: Investigating Malaria risks in highland East Africa

Impacts and vulnerability

As highland regions of Africa historically have been considered free of malaria, recent epidemics in these areas have raised concerns that high elevation malaria transmission may be increasing. Hypotheses about the reasons for this include changes in climate, land use and demographic patterns. The effect of land use change on malaria transmission in the southwestern highlands of Uganda was investigated. Two related studies investigated the role of climate and malaria in highland Uganda and devised critical thresholds of vector density to provide early warnings of new outbreaks (Lindblade et al., 2000a and b).

Hazard assessment

From December 1997 to July 1998, during an epidemic associated with the 1997-8 El Niño, mosquito density, biting rates, sporozoite rates and entomological inoculation rates were compared between eight villages located along natural papyrus swamps and eight villages located along swamps that have been drained and cultivated. Since vegetation changes affect evapotranspiration patterns and thus, local climate, differences in temperature, humidity and saturation deficit between natural and cultivated swamps were also investigated. On average, all malaria indices were higher near cultivated swamps, although differences between cultivated and natural swamps were not statistically significant. However, maximum and minimum temperatures were significantly higher in communities bordering cultivated swamps. In multivariate analysis using a generalized estimating equation approach to Poisson regression, the average minimum temperature of a village was significantly associated with the number of *Anopheles gambiae s.l.* per house after adjustment for potential confounding variables. It appears that replacement of natural swamp vegetation with agricultural crops has led to increased temperatures, which may be responsible for elevated malaria transmission risk in cultivated areas.

Critical thresholds linking vector density with malarial outbreaks

Because malaria transmission is unstable and the population has little or no immunity, these highlands are prone to explosive outbreaks when densities of *Anopheles* exceed critical levels and conditions favour transmission. If an incipient epidemic can be detected early enough, control efforts may reduce morbidity, mortality and transmission. Three methods (direct, minimum sample size and sequential sampling approaches) were used to determine whether the household indoor resting density of *Anopheles gambiae* s.l, exceeded critical levels associated with epidemic transmission. A density of 0.25 Anopheles mosquitoes per house was associated with epidemic transmission, whereas 0.05 mosquitoes per house was chosen as a normal level expected during non-epidemic months. It is feasible, and probably expedient, to include monitoring of *Anopheles* density in highland malaria epidemic early warning systems. Although the local severity of the malaria epidemic was associated with changing microclimates associated with land use, the positive correlation between average minimum temperature and household densities of *Anopheles* mosquitoes shows that warmer seasons associated with El Niño and global warming pose a continuing threat.

Box 4-4: Calculating climate-driven anomalies in the rice production system of Indonesia

This assessment analysed 20 years of national rice production in Indonesia (BPS, 2000) to determine the impact of annual climate anomalies in a cropping system with an upward trend in yields. In the period 1980–1989, national rice production in Indonesia increased consistently from year to year, the increase slowing after 1989 (Figure 4-8). This increasing trend was due to improvements in crop management technology, variety and expansion of the rice planting area. In order to obtain anomaly data, this trend was removed by applying a regression equation. The steps of analysis are as follows:

1. Develop a regression equation to fit the rice production data
2. Calculate the deviation of observed data from the regression line as anomaly data
3. Separate the production anomalies between normal years and extreme years (Figure 4-8)
4. Evaluate trend of the anomalies between good years and bad years. Good years represent normal climate, while bad years represent extreme dry years due to the ENSO phenomenon.

Figure 4-9 shows that the anomalies for the bad years (squares) became more negative with time while those for good years (diamonds) became more positive over time. This indicates that the production loss due to extreme climate events tends to increase, or that the rice production system is becoming more vulnerable.

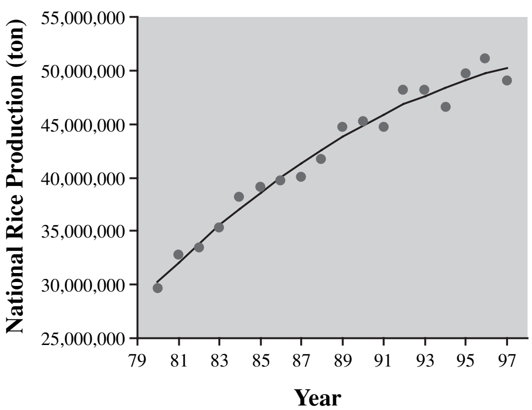

Figure 4-8: Rice production data and regression line

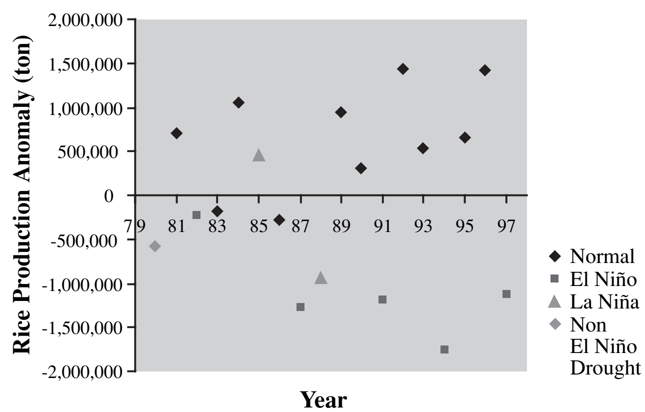

Figure 4-9: Rice production anomalies

ence on which future risks are measured. It is not the same as a climate baseline, which may be 1961–90, or longer. The climate-risk baseline can be tied to a period when both socio-economic and climate data are available, or to a period when particular infrastructure or policy was put in place. For example, when undertaking a risk assessment of water resources, Jones and Page (2001) used a climate baseline of 1890–1996, but the catchment and water resource management model they used was adjusted at flow rules set in 1996, so the risk became a measure of how the 1996 catchment would have behaved under historical climate. This allows a climate-risk baseline to be established using the full range of historical climate with modern catchment management rules.

4.5. Conclusions

By applying the methods outlined in this TP, the team can assess adaptive responses to past and present climate risks, and gain an understanding of the relationship between current climate risks and adaptive responses. This understanding will provide a basis for developing adaptive responses to possible future climate risks. The assessment of climate hazards causing present climate vulnerability will also help decide which climate hazards need to be incorporated into scenario development.

Although an understanding of current climate–society interactions is an important starting point for adaptation to future climate, it would be dangerous to assume that new hazards will not arise and that new adaptations may not be needed. In most cases both current and future risk will need to be investigated. If knowledge of current climate risks is already established, then the team may move straight to TPs 5 and 6 to develop an understanding of how climate and socio-economic change may affect future climate risks. However, where current climate vulnerability is high, then adaptation to those risks will be required to develop sufficient capacity to cope with future risks (e.g., Box 4-3). In this case, basic information about how climate may affect those risks in the future could be sufficient.

The assessment of future climate risks is described in TP5.

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ANNEXES

Annex A.4.1. Cross-impacts analysis

The results from a sectoral or regional investigation can be collated and analysed through the use of sensitivity and cross-impacts matrices[3]. The feedback from stakeholders is usually positive when such matrices are used. The activity/variable matrix shown in Table A-4-1-1 is an example from a project carried out in the Hunter Valley, Australia. From a stakeholder workshop, key climate and climate-related variables were listed and linked to selected activities or exposure units. The questions asked were what aspects of climate currently cause impacts in your region, and what activities are affected? The climate variables were then linked to how they affected each activity using a weighting of 3, 2, or 1 to denote strong, moderate or weak influences. Activities were divided into four main groupings: agriculture, coastal and marine, catchment and the built environment. The row and column values were summed and the results shown in Table A-4-1-2.

Table A-4-1-2 shows two outcomes of the analysis. The climate variables having the greatest impact are aspects of rainfall variability, with a lesser emphasis on temperature. Moisture levels

Table A-4-1-1: *Weighted sensitivity matrix of key climate variables and climate-related variables compared with selected activities or exposure units based on Table 1 of the workshop report (Hennessy and Jones, 1999).*

Sensitivity matrix linking climate drivers (below) with activities (across)	Poultry	Dairy	Grazing	Cropping	Wine	Horses	Marine (esp. fisheries)	Beach	Coastal water supply	Harbour	Inland water supply	River management	Dryland/irrigation salinity	Forest & biodiversity	Urban infrastructure	Air quality	Waste	Health	Industry, coal & power	Driving force
Rainfall - average		2	1	2	2				1		3	2	2	2	2	1			1	21
Rainfall - extreme		1	2	2	1	1	1	2	2		2	3	3	2	3		2	2	1	30
Rainfall - variability		2	3	3	2		2		1		3	3	1	1	2					23
Drought		2	3	3	2	1	1		2		3	2	2	3				2	2	28
Temperature - average	1	2	1	2	2		2			1		2	1	2		2	1		1	20
Temperature - max	3	2	2	2		2	1					3		1	3		2	1	2	24
Temperature - min		2	2	2	2	2								1	2		1	1	1	16
CO_2		2	2	2	2	1								2						11
Cloud				1											1	1				3
Pressure																1				1
Humidity	2	1			2									1	2			1	1	10
Wind		1	1	1	1		1	2		2				1	2	2		2		16
Evaporation	2						1				2	1	2	1			1			10
Soil moisture		3	3	3	3	2					1			2	1		2			20
Stream flow							2		1		3	3	2	1	1			3	1	17
Flood		2	1	1	1	1	1			3	2	3	2	1	3		3	3	2	29
Water table							2		3		1	1	1	1	1		2			12
Water salinity				1	1		1		3		2	2	3	1				2	1	17
Irrigation		2	1	2	3						2	2	1							13
Sea level							1	3	3	3					2					12
Storm surge								3		3					1					7
Waves							2	3	1	2										8
Lightning														1	1				1	3
Hail				2	3										2					7
Fire			1		1	1								3	1	2		1	2	12
Total sensitivity	8	24	23	29	28	11	18	13	17	14	24	27	20	27	30	9	14	18	16	

[3] These matrices were illustrated in Carter et al. (1994) but have not been widely used.

on land or in the atmosphere are also important. The activities showing the largest climatic sensitivity influence are largely rural land-based activities. Coastal aspects have a moderate exposure to climate variables due to a few ocean-related variables being very important while most others have little influence. Those activities with a broad exposure to climate are difficult to assess due to the number of forcing variables and feedbacks. The criteria of low, medium and high have been chosen subjectively, and are intended to indicate the relative importance of the various results.

Cross-impacts analysis can be used to map the relationships between drivers and dependent variables in a system. Table A-4-1-3 contains all climate variables, catchment-related variables and major activities shown in Table A-4-1-1 on both axes (some variables more important to the urban, agricultural and coastal systems were removed or combined). Each variable on the vertical axis was examined to determine whether it is likely to force a change in all other variables on the horizontal axis. Where this condition was true, an entry was made in the appropriate cell. Where variables act upon each other, both cells are marked. Note that economic and social activities affecting the catchment have been omitted. Table A-4-1-3 is a cross-impacts matrix based on the variables in Tables A-4-1-1 and A-4-1-2. A caveat with this type of analysis is that the identification of cause-and-effect is subjective, where:

i. two variables may be interdependent, but this interdependence is not well understood, or

ii. a sequence of consequences may indirectly link a variable and an activity.

Figure A-4-1-1 shows the results from Table A-4-1-3 on a forcing/dependency graph. The variables on the upper left are those that show strong external forcing but are not affected much by what is going on inside the system. Those labelled autonomous on the lower left may be important in specific cases but have a minor role overall. The upper right variables are relay variables that are highly dependent on factors within the system, but are also strong influences on other variables. These variables are likely to exhibit feedbacks. On the lower right are the dependent variables that are sensitive to many other variables above and to the left of them. These latter variables are the important

Table A-4-1-2: *Results of sensitivity matrix showing the climate and related variables with the greatest forcing and activities with the broadest sensitivity to climate*

Forcing and sensitivity category and range of weighted values	Climate and related variables (forcing)	Activities (sensitivity)
High (21-30)	Rainfall – extreme Flood Drought Temperature – max Rainfall – variability Rainfall – average	Urban infrastructure Cropping Wine River management Forest & biodiversity Inland water supply Dairy Grazing
Moderate (11-20)	Temperature – average Soil moisture stream flow Water salinity Temperature – min Wind Irrigation Water table Sea level Fire	Dryland/irrigation salinity Industry, coal & power Marine (esp. fisheries) Coastal water supply Health Harbour Waste Beach Horses
Low (1-10)	Humidity Evaporation Waves Storm surge Hail Cloud Lightning Pressure	Air quality Poultry

Table A-4-1-3: *Interaction matrix for climate change – catchment interactions for the Hunter River in New South Wales under climate change. (Forcing marks where a change in the variable on the vertical axis forces a change in a variable on the horizontal axis; read across the matrix. Dependency is read down the matrix.)*

Interaction Matrix for Catchment-Climate Change Impacts	Temperature (average)	Temperature (maximum)	Temperature (minimum)	Precipitation (average)	Precipitation (intensity)	Precipitation (variability)	Drought	Radiation/sunshine	Cloudiness	Humidity	Evapotranspiration	Evaporation (open water)	Wind	CO_2	Soil Moisture	Recharge	Runoff	Streamflow (peak)	Streamflow (average)	Streamflow (variability)	Water storage	Water supply (domestic)	Water supply (irrigation)	Water supply (power)	Riverine aquifer	Mine dewatering	Water quality (nutrients)	Water quality (turbidity)	Water quality (dO)	Water quality (salinity)	Stream/wetland ecology	Algal blooms	Land degradation (erosion)	Land degradation (salinity)	Fire	Vegetation cover	Biodiversity	Forest	Agriculture	Urban areas	Coastal zone	Forcing
Temperature (average)		1	1		1						1	1			1						1						1		1		1	1			1	1	1	1	1	1	1	18
Temperature (maximum)	1										1	1																	1		1	1			1		1	1	1	1	1	12
Temperature (minimum)	1																												1						1	1	1	1	1	1	1	9
Precipitation (average)							1	1	1	1					1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1		1	1	1	1	1	1	1	1	29
Precipitation (intensity)															1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	25
Precipitation (variability)				1			1			1					1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	30
Drought				1		1		1	1	1	1	1			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	33
Radiation/sunshine	1	1					1		1	1	1	1			1																1	1					1	1	1	1	1	15
Cloudiness			1	1	1	1	1	1		1	1	1			1																	1							1			12
Humidity				1	1		1		1		1	1																							1	1	1	1	1			11
Evapotranspiration	1						1		1	1					1	1	1		1	1	1	1	1	1		1	1		1	1	1			1	1	1	1	1	1		1	25
Evaporation (open water)							1														1	1	1	1						1	1										1	8
Wind											1	1																					1		1	1		1	1	1	1	9
CO_2	1														1																1					1	1	1	1		1	8
Soil Moisture										1	1					1	1	1	1	1	1		1		1		1	1			1		1	1	1	1	1	1	1			20
Recharge																			1	1			1											1								4
Runoff																1		1	1	1	1	1	1				1	1		1	1	1	1	1		1	1	1	1	1		19
Streamflow (peak)																1				1	1				1	1	1	1	1	1	1	1	1			1	1	1	1	1	1	18
Streamflow (average)																		1			1	1	1	1	1	1	1	1	1	1	1	1							1	1		15
Streamflow (variability)																1			1		1	1	1	1	1	1	1	1		1	1	1										13
Water storage																		1	1	1		1	1	1	1	1	1	1	1	1	1	1							1	1		16
Water supply (domestic)																			1	1	1		1								1									1	1	7
Water supply (irrigation)															1				1	1	1	1			1		1				1			1					1			10
Water supply (power)																			1	1	1	1	1			1					1								1	1		9
Riverine aquifer																		1	1	1	1		1				1	1	1	1	1								1			11
Mine dewatering																			1	1									1	1	1											5
Water quality (nutrients)																													1		1	1									1	4
Water quality (turbidity)																													1		1	1								1	1	5
Water quality (dO)																															1											1
Water quality (salinity)																										1		1			1								1	1		5
Stream/wetland ecology																											1	1	1			1					1				1	6
Algal blooms																						1						1	1		1						1			1		6
Land degradation (erosion)											1				1	1	1	1			1	1					1	1	1		1	1		1		1	1	1	1	1	1	19
Land degradation (salinity)											1											1	1			1		1		1	1		1			1	1	1	1	1		13
Fire											1			1	1	1	1	1		1							1	1	1				1			1	1	1	1	1	1	17
Vegetation cover	1									1	1			1	1	1	1	1		1							1	1	1	1	1	1	1	1	1		1	1	1		1	22
Biodiversity											1																1		1		1		1	1	1	1		1	1		1	11
Forest	1									1	1			1	1	1	1	1	1	1	1		1	1			1	1	1	1	1		1	1	1	1	1		1			24
Agriculture											1			1	1	1	1	1		1			1		1		1	1	1	1	1	1	1	1	1	1	1	1		1		22
Urban areas			1							1			1	1	1	1	1	1			1	1		1			1	1	1	1	1	1	1		1	1	1	1	1		1	24
Coastal zone																															1	1			1	1	1					5
Dependency	7	2	3	4	3	2	7	3	5	10	15	7	1	5	16	15	12	15	15	19	19	16	18	11	11	12	22	21	23	18	34	21	14	13	17	20	24	22	29	22	22	

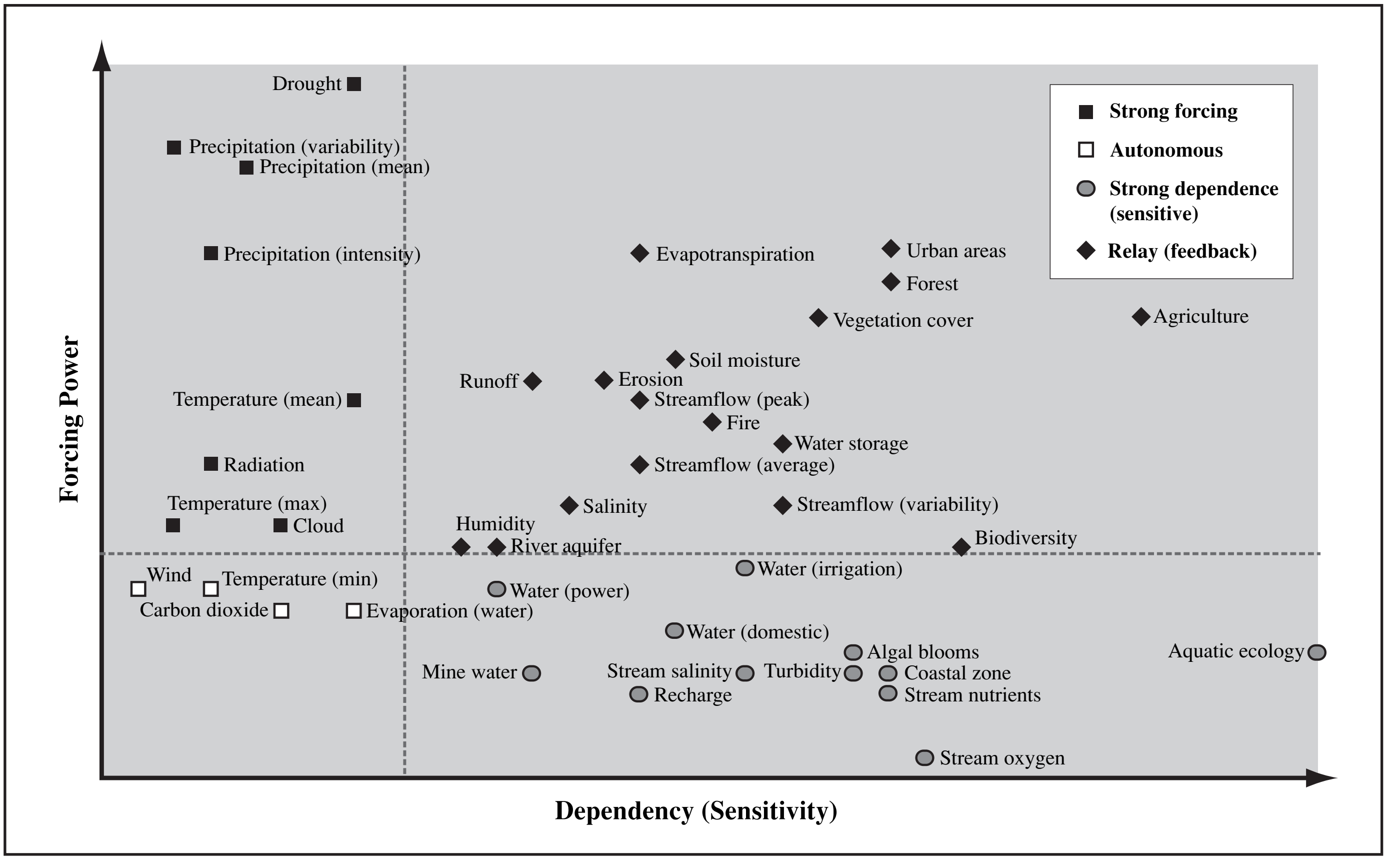

Figure A-4-1-1: Forcing/dependency chart for climate, catchment processes and catchment-based activities in the Hunter River Valley (based on the cross-impacts analysis presented in Table A-4-1-3.)

outputs for the system. They are used to construct measures of environmental quality and to monitor how well the system is working. They are also the most vulnerable. This type of analysis can show:

- which drivers are external to the system (in the top left quadrant),
- which variables are important drivers but are themselves modified by feedbacks within the system (top right), and
- the most important indicators of health and water quality (shown in the lower right of the system and affected by everything else).

The results may be no surprise to the research team but this type of analysis is useful for managers and other stakeholders who are dealing with complex environmental systems.

Annex A.4.2. Examples of impacts resulting from projected changes in extreme climate events (from Carter and La Rovere, 2001)

Projected Changes during the 21st Century in Extreme Climate Phenomena and their Likelihood[a]	Representative Examples of Projected Impacts[b] (all high confidence of occurrence in some areas[c])
Simple Extremes	
Higher maximum temperatures; more hot days and heat waves[d] over nearly all land areas (Very Likely[a])	• Increased incidence of death and serious illness in older age groups and urban poor • Increased heat stress in livestock and wildlife • Shift in tourist destinations • Increased risk of damage to a number of crops • Increased electric cooling demand and reduced energy supply reliability
Higher (increasing) minimum temperatures; fewer cold days, frost days, and cold waves[d] over nearly all land areas (Very Likely[a])	• Decreased cold-related human morbidity and mortality • Decreased risk of damage to a number of crops, and increased risk to others • Extended range and activity of some pest and disease vectors • Reduced heating energy demand
More intense precipitation events (Very Likely[a] over many areas)	• Increased flood, landslide, avalanche, and mudslide damage • Increased soil erosion • Increased flood runoff could increase recharge of some floodplain aquifers • Increased pressure on government and private flood insurance systems and disaster relief
Complex Extremes	
Increased summer drying over most mid-latitude continental interiors and associated risk of drought (Likely[a])	• Decreased crop yields • Increased damage to building foundations caused by ground shrinkage • Decreased water resource quantity and quality • Increased risk of forest fire
Increase in tropical cyclone peak wind intensities, mean and peak precipitation intensities (Likely[a] over some areas)[e]	• Increased risks to human life, risk of infectious disease epidemics, and many other risks • Increased coastal erosion and damage to coastal buildings and infrastructure • Increased damage to coastal ecosystems such as coral reefs and mangroves
Intensified droughts and floods associated with El Niño events in many different regions (Likely[a])	• Decreased agricultural and rangeland productivity in drought- and flood-prone regions • Decreased hydro-power potential in drought-prone regions
Increased Asian summer monsoon precipitation variability (Likely[a])	• Increase in flood and drought magnitude and damages in temperate and tropical Asia
Increased intensity of mid-latitude storms (little agreement between current models)[d]	• Increased risks to human life and health • Increased property and infrastructure losses • Increased damage to coastal ecosystems

[a] Likelihood refers to judgmental estimates of confidence used by TAR WGI: very likely (90-99% chance); likely (66-90% chance). Unless otherwise stated, information on climate phenomena is taken from the *Summary for Policymakers, TAR WGI*.

[b] These impacts can be lessened by appropriate response measures.

[c] Based on information from chapters in this report; high confidence refers to probabilities between 67 and 95% as described in *Footnote 6* of *TAR WGII, Summary for Policymakers*.

[d] Information from *TAR WGI*, *Technical Summary*, *Section F.5*.

[e] Changes in regional distribution of tropical cyclones are possible but have not been established.

Annex A.4.3. Coping range structure and dynamics

The coping range is a conceptual framework that provides a structure for showing how a system, or an activity, has coped historically and how it copes now, e.g., how has the system responded to past and present climate risk. If the team is to use the coping range they first need to be aware of its basic dynamics, in order to be able to adapt it to the specific circumstances of an assessment. The coping range, response relationships and thresholds can be constructed independently of climate change scenarios, and that information will continue to be relevant even if projections of climate change alter.

Climate–society relationships, and by implication coping ranges, are dynamic. The coping range has two main dynamic influences that can affect the sensitivity of the system:

- Changes in climate drivers can change the frequency and magnitude of hazards, and
- Changes in socio-economic drivers can alter the capacity of the system to cope with hazards.

If a system moves beyond its coping range, the level of harm suffered can threaten sustainability in a number of ways. People may be harmed through loss of livelihood, injury or death. An activity could cease, the coping range may narrow through reduced socio-economic capacity, system sensitivity may increase, or adaptive capacity may be reduced (i.e., the system survives the current stress but its ability to adjust to future change is reduced).

The climatic phenomena used to describe coping range may be simple (as in a single driver such as average temperature or total rainfall), a combination of factors influencing a process (e.g., temperature, rainfall, photosynthetically active radiation and CO_2 for crop production) or indirect variables that can be linked to climate (such as stream flow or crop yield). The coping range can be expressed in a number of ways, ranging from narrative to mathematical. Graphically, one climate or climate-related driver can be shown as a time series, two drivers can be expressed on a response surface, and three in three-dimensional charts.

Within the coping range, an activity is resistant – able to withstand stress – or resilient – able to weather stresses without undergoing significant change). Beyond this range is a zone of vulnerability. Some losses may be so large that people's livelihoods are threatened by losses to environmental security. In many systems, this may take several seasons of loss to occur, and in the most vulnerable systems, only one season. Often, when people are coping poorly, they have lost environmental security through previous events that may, or may not be, climate related.

There are several ways to show outcomes in terms of the coping range. They can be portrayed in terms of continuous output, such as the relationship between crop yield and climate. They can be segmented into good, moderate or poor outcomes; or we can choose trigger points, or thresholds, where either the system changes, or a change in management is indicated. For example, drought policy may stipulate a level of rainfall, or an aridity index, and if conditions remain below these levels for a sustained period, drought conditions are declared. These outcomes can become the criteria for a risk assessment where changes in the frequency of drought declarations over time are measured. It is also possible to use a critical threshold to measure risk. This is the point where the level of harm is too high to be tolerated and a system moves beyond the coping range into a state of vulnerability.

The width of the coping range is a function of historical adaptation. For developing countries, in cases where the capacity to adapt has been limited by factors such as access to technology and financial resources, climate variability is large and the reliance on climate is high (e.g., Ogallo et al., 2000), the coping range may be small compared to the range of climate variability. Small coping ranges are likely to be breached by numerous single events. Large coping ranges, typical of developed countries where resilience is high, may experience a sequence of extreme events such as a string of droughts before impacts become unacceptable (e.g., Smit et al., 1999)[4]. Historical adaptation influences the behaviour upon which any response to climate change will be based. Adaptation to current climate stress is influenced by past behaviour (Glantz, 1996; Parry, 1986; Warrick et al., 1986). Adaptive capacity is the ability to adjust to change through adaptation, and is thus a potential that can be brought into play by an experience of stress or information about a potential future stress. The level of adaptive capacity will influence the evolution of the coping range.

Relationship between coping range and adaptive capacity

Adaptive capacity is a measure of the potential to adapt (TP7). When realised, it becomes coping capacity or the ability to cope. Adaptive capacity describes the potential of the coping range to expand or contract in response to autonomous (unplanned) or planned changes to the environment. Most systems affected by climate will also be affected by other drivers of change. For example, as well as climate, farming systems are affected by land tenure, cost structure and commodity prices and trade relationships. These can be independent of climate or can interact with climate in complex ways affecting the dynamics of adaptive and coping capacity. This is true of many other systems where natural resources are being managed, and for health, where complex social interactions can affect climate-driven exposure to disease (e.g., mosquito vectors).

Figure A-4-3-1 shows four different relationships between climate variability and coping capacity that can be called Decreasing Resilience, Increasing Resilience, Suffering Climate Shocks and Responding to Climate Shocks. Graphs 1 and 2 rep-

[4] This is a generalisation that is consistent with the overall findings of the IPCC Third Assessment Report. However, some coping ranges in developing countries are substantial and some coping ranges in developed countries are extremely limited. Each situated needs to be assessed individually.

resent autonomous changes occurring independently of climatic responses. For example, environmental degradation may make people more vulnerable to climate extremes, and economic diversification may make them less vulnerable. Graphs 3 and 4 show where the coping range changes directly in response to climate extremes. In graph 3, where adaptive capacity is low to non-existent, the coping range will decrease in response to climate shocks. In graph 4, where adaptive capacity is moderate to high, the coping range will increase in response to climate shocks. In most systems, all four of these influences are likely to be interacting, and

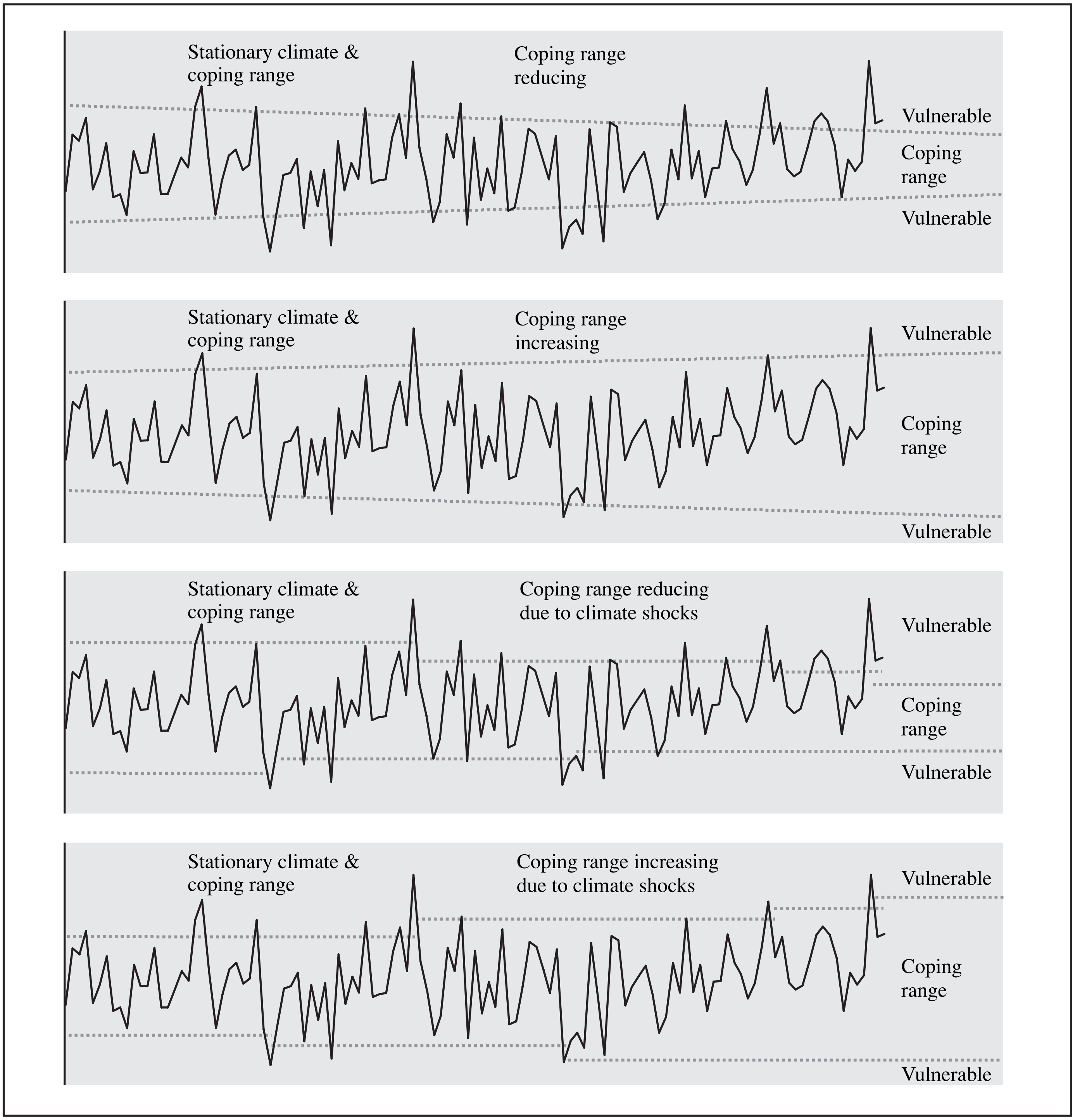

Figure A-4-3-1: Schematic diagram showing the relationship between variability in a stationary climate and the coping range, showing four different mechanisms that can be called (1) decreasing resilience, (2) increasing resilience, (3) suffering climate shocks and (4) responding to climate shocks. Graph 1 shows gradual decreases in coping capacity over time; Graph 2 shows gradual increases in coping capacity over time; Graph 3 shows climate shocks reducing coping capacity over time (adaptive capacity here would be low to non-existent); and Graph 4 shows climate shocks producing an increase in coping capacity (where adaptive capacity is high). See also de Vries (1985) and Smit and Pilifosova (2002).

analysis needs to identify the over-riding determinants of changing responses. This is the “bumpy road” of irregular socio-economic change mentioned in TP6. Not shown are dynamics, where following a change, conditions relax back to the original situation (e.g., where water conservation measures are gradually discarded following a period of enforced restrictions).

The coping range can be utilised in various ways. One is to assess vulnerability assuming the climate will change, while holding the ability to cope constant, to test what adaptation may be needed in response to climate change. Another way is to change climate and the coping range according to expectations of adaptive capacity being developed and generating an adaptive response to climate. This is a more dynamic situation where both climate and the coping range change over the time.