7.1 INTRODUCTION

This chapter defines the assessment of climate and weather risk and its importance in agricultural planning to mitigate the impacts of climate variability and extreme events.

The term weather is used to describe day-to-day variations in our atmosphere. This includes precipitation, temperature, humidity and cloud cover, among other variables. Weather forecasts are essentially short-term, as the reliability of forecasts falls off rapidly after five days. Weather is therefore an instantaneous concept. The climate of a region is described by collating the weather statistics to obtain estimates of the daily, monthly and annual means, medians and variability of the weather data. Climate is therefore a long-term average of weather.

Agricultural planning – strategic (long-term) and tactical (<10 days) – needs to weigh climate-related and other risks to attain the producer’s goals and to spell out the sort of information that farmers need to aid their planning, such as climate, technical/managerial, and market data, for example. A key aspect needed in linking climate and weather risk to agricultural planners is an appreciation of the overall management system in question from the decision-makers’ viewpoint. Managers need information for both tactical and strategic decision-making.

As an example, an Australian survey of agricultural planners provided a myriad of planning horizons and key decisions (sometimes referred to as “decision points”) that could be influenced by weather and climate variability at different timescales. In addition, it has been realized that the decision system extends across the whole value chain in agricultural production that is affected by weather and climate variability. The sugar industry can serve as an example that has relevance to many agricultural planning systems: there are decisions at the farm scale (irrigation, fertilization, fallow practice, land preparation, planting, pest management) and at the transportation and milling scale (improved planning for wet season disruption, planning for season start and finish, crop size forecasts, civil works schedules). There are catchment-scale issues (land and water resource management, environmental management), as well as issues at the “marketing scale” (crop size forecasts, planning for high-premium early season supply, shipping and global supply management) and at the policy scale (water allocation planning, planning for extreme events) (Everingham et al., 2002; Stone and Meinke, 2005).

Varying timescales and key agricultural decisions are also important, especially in terms of the need to recognize how different climate and weather systems affect different farming decisions. Table 7.1 provides an example of the complexity inherent in

| Table 7.1. Agricultural decisions at a range of temporal and spatial scales that could benefit from targeted climate forecasts (Meinke and Stone, 2005) |
|--------------------------------------------------|------------------|
| Farming decision type                          | Frequency (years) |
| Logistics (e.g., scheduling of planting/harvest operations) | Intraseasonal (>0.2) |
| Tactical crop management (e.g., fertilizer/pesticide use) | Intraseasonal (0.2–0.5) |
| Crop type (e.g., wheat or chickpeas) or herd management | Seasonal (0.5–1.0) |
| Crop sequence (e.g., long or short fallows) or stocking rates | Interannual (0.5–2.0) |
| Crop rotations (e.g., winter or summer crops) | Annual/bi-annual (1–2) |
| Crop industry (e.g., grain or cotton; native or improved pastures) | Decadal (~10) |
| Agricultural industry (e.g., crops or pastures) | Interdecadal (10–20) |
| Land use (e.g., agriculture or natural systems) | Multidecadal (20+) |
| Land use and adaptation of current systems | Climate change |
matching appropriate climate forecast systems with the farming decision type (from Meinke and Stone, 2005).

7.1.1 **Understanding the climate mechanisms that contribute to climate- and weather-related risks**

Weather and climate variability can result from interactions between the climate system’s various components – the atmosphere, oceans, biosphere, ice layer, land surface and anthropic action.

Article 1 of the United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as: “a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods”. The UNFCCC thus makes a distinction between “climate change” attributable to human activities altering the atmospheric composition and “climate variability” attributable to natural causes.

Climate disasters can be divided into extreme events and regional climate anomalies. Global climate change may produce a larger number of climatic disaster occurrences. This is based on the fact that a linear increase in the average of a climatic variable implies a non-linear increase in the occurrence probability of extreme values of such variable. Also, an increase in its variability means an incremental change in the occurrence probability of extreme values (Cunha, 2003).

A WMO study, *Agrometeorology Related to Extreme Events*, (WMO, 2003a) notes that “Although natural calamities cannot be avoided, their destructive impact, in terms of human losses and animal lives related to ecological equilibrium, could certainly be considerably minimized. Planning and management for the prevention and mitigation of extreme events are matters of vital significance for the safety and well-being of millions of people who inhabit exposed disaster areas. In addition to local and national action, international and regional cooperation should be promoted for an enhanced prevention and mitigation.”

Micro- to large-scale studies have shown anomalies for isolated climatic elements (Grimm et al., 1998; Souza et al., 2000; Garcia et al., 2002; André et al., 1996, 2004; Krishnamurti et al., 2002; Chiang and Sobel, 2002; Su and Neelin, 2003). The vast majority of the Earth’s surface is void of data, however. Moreover, databases are essential for conducting analysis, developing trends and determining anomalies in global and regional climate.

Climate data are essential in planning and reducing the risks associated with climate anomalies. Assessing and forecasting the impacts of short-term climate variability and weather risks, as well as their relationship to extreme events, could help mitigate the effects of climate variability and facilitate the scheduling of agricultural activities.

The definitions of risk, hazard and anomalies differ as follows:

(a) Hazard is an event or process that is potentially destructive; it is the probability of occurrence of a potentially damaging phenomenon within a given time period and location of interest;
(b) Risk is the magnitude of a potential loss (lives lost, persons injured, property damaged, and economic activity disrupted) within the area subject to hazard for a particular location and a reference period;
(c) Anomaly is the deviation of a meteorological quantity value in a given region from the normal (mean) value for the same period.

Impacts from natural disasters on agriculture, rangeland and forestry can be positive or negative. While the impacts are predominantly negative and do affect human society significantly (Joy, 1991), there are some positive impacts or benefits that should be pointed out in any discussion of the impacts of natural disasters.

Positive impacts of natural disasters include increased rainfall to inland areas from tropical cyclones along coastal areas (Ryan, 1993), the fixing of atmospheric nitrogen by thunderstorms, the germination of many native plant species as a result of bushfires, and the maintenance of fertility of flood-plain soils due to flooding (Blong, 2002). The influx of funds into disaster-relief activities after the occurrence of natural disasters can also sometimes be positive for local communities, as was shown for the city of Mobile, Alabama, after Hurricane Frederic (Chang, 1984). Negative impacts will be discussed in detail in this chapter.
CHAPTER 7. CLIMATE AND WEATHER RISK ASSESSMENT FOR AGRICULTURAL PLANNING

7.2 CLIMATIC HAZARDS

7.2.1 Types

7.2.1.1 Extreme events

Extreme events can vary from short-lived, violent phenomena of limited extent such as tornadoes, flash floods and severe thunderstorms, to the effects of large systems such as tropical and extratropical cyclones, and the effects of prolonged drought and floods. Drought and floods are responsible for more significant impacts on human life and property and can affect one area for several months to years. About 65 per cent of the estimated worldwide natural disaster damage is of meteorological origin. Meteorological factors have contributed to 87 per cent of the number of people reported affected by natural disasters and to 85 per cent of related deaths (WMO, 2004). Recent scientific studies also indicate that the number of extreme events and their intensity may increase as the global temperature continues to rise due to climate change.

7.2.1.2 Regional climate anomalies

Mesoscale storms and severe local storms fall into this category. Hail causes millions of dollars of damage to crops and property each year. Tornadoes are among the most feared natural phenomena. More tornadoes occur on the North American continent than anywhere else in the world, though they can affect (and have affected) nearly all regions of the world. Fortunately, their scale is relatively small (diameters range from about 15 m to over 2 km), so they affect a limited area.

Small-scale severe weather phenomena (SCSWP) are weather events that are sparsely dispersed in space and time and may have important impacts on societies, such as loss of life and property damage. Their temporal scales range from minutes to a few days at any location and typically cover spatial scales from hundreds of metres to hundreds of kilometres. The Technical Summary of the Working Group I Report of the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) describes SCSWP as follows: “Recent analyses of changes in severe local weather (e.g., tornadoes, thunderstorm days, and hail) in a few selected regions do not provide compelling evidence to suggest long-term changes. In general, trends in severe weather events are notoriously difficult to detect because of their relatively rare occurrence and large spatial variability” (IPCC, 2001).

7.2.2 Categories

7.2.2.1 Drought

Drought is a shortage of water for essential needs, which for agricultural purposes relates to plant growth. It is also a relative term, however, in that it might be considered a deficiency of water for a few weeks or months in a high rainfall area or a lack of water over several years in arid lands. It also should not be confused with desertification, which is a consequence of human activity, such as overstocking the land relative to its carrying capacity, something that is particularly common in arid lands in times of below-average rainfall. Excessive tillage is another cause of desertification.

Drought differs from other natural hazards in that its effects often accumulate slowly over time, and may linger for years after the termination of the event (Wilhite, 2000). Because of this, drought is often referred to as a creeping phenomenon (Tannehill, 1947).

Droughts must be viewed as an integral part of a natural climatic cycle, even though extreme droughts can have disastrous consequences. Treating drought simply as a disaster that could not be anticipated, with subsequent pleas for national or international assistance, ignores the fact that the impact of all but the most severe droughts can be mitigated through careful planning and risk management (O’Meagher et al., 1998, 2000; Botterill, 2003, 2005). It is also useful to distinguish among meteorological, hydrological and agricultural drought phenomena, in that the severity of these are only partially correlated; the severity of an agricultural drought depends on how deficiency of rainfall and soil moisture is expressed in terms of plant growth, and ultimately in terms of the health and welfare of rural communities (for example, du Pisani et al., 1998; Keating and Meinke, 1998; Stafford Smith and McKeon, 1998; White et al., 1998).

Massive fires can be triggered during and after periods of drought, by lightning or by human actions, in almost every part of the world. These fires destroy forests, grasslands and crops. They also kill livestock and wild animals, damage or destroy settlements, and put the lives of inhabitants at risk (WMO, 2006).

7.2.2.2 Heavy rainfall and floods

According to the WMO publication Working Together for a Safer World, flood hazards represent about 32
per cent of all damage from natural disasters (WMO, 2004). It is estimated that extreme weather events will increase in frequency and severity during the twenty-first century as a result of changes in mean climate and/or climate variability. Changes in temperature and precipitation may lead to dramatic shortening of the return periods of floods. Flood disasters are intensified by environmental degradation, urbanization, demographic shifts and poverty, industrialization and overall economic development.

Prevention of these disasters requires the development of programmes that include the management of the water cycle as a whole, with a view to the adoption of an integrated hazard management approach. WMO and the Global Water Partnership (GWP) are promoting a new concept of Integrated Flood Management (IFM). IFM ensures disaster reduction through the prevention of flooding, mitigation of adverse impacts through appropriate adaptation strategies and preparation of the community to respond appropriately to flood forecasts and warnings.

7.2.2.3 **Strong winds: tornades, storms and tropical cyclones**

Tropical cyclones are among the most destructive of all natural hazards, causing considerable human suffering in about 70 countries around the world. They form over all tropical oceans, with the possible exception of the South Pacific east of about 140° W. In the western North Pacific, mature tropical cyclones are known as typhoons – they are also referred to as hurricanes in the western hemisphere and cyclonic storms or tropical cyclones in other areas. As described in Agrometeorology Related to Extreme Events (WMO, 2003b), tropical cyclones are the offspring of ocean–atmosphere interactions, powered by heat from the sea, steered by the easterly trades and mid-latitude westerlies. An average of 80 tropical cyclones form annually over the tropical oceans, with the typhoon region of the western North Pacific accounting for approximately 30 of these (Obasi, 1997). The impact of tropical cyclones is greatest over coastal areas that bear the brunt of the strong winds and flooding from rainfall. For example, while the annual average for the Bay of Bengal and the Arabian Sea is only five tropical cyclones per year, some of the most destructive tropical cyclones in history have occurred in that region, such as the severe tropical cyclone in Bangladesh in 1970, which claimed 300 000 lives.

El Niño is generally associated with worldwide changes in the patterns of precipitation and temperature, tropical cyclones and hurricane activity, the behaviour of subtropical jet streams, and many other general circulation features over various parts of the world. The magnitude of hurricanes is assessed with the Saffir–Simpson scale, which takes into account maximum sustained winds and minimum storm central pressure.

Losses to agriculture, rangelands and forests from tropical cyclones can be due to direct destruction of vegetation, crops, orchards and livestock; damage to infrastructure such as canals, wells and tanks; and long-term loss of soil fertility from saline deposits over land flooded by seawater. Typhoons can inflict severe damage on agriculture: for example, in southern Hainan on 2 October 1999, some 25 million timber and rubber trees were blown down (WMO, 1994). A typhoon that struck Thailand on 4 November 1989 destroyed some 150 000 ha of rubber, coconut and oil palm plantations and other crops (WMO, 1997).

Not all the impacts of cyclones are negative, however, and some reports cite beneficial effects of tropical cyclones. Ryan (1993) mentions some important benefits of tropical cyclones in Australia. Increased water availability in water-critical regions makes agricultural production less susceptible to the dry season. Researchers estimate that nine major hurricanes in the United States since 1932 terminated dry conditions over an area of about 622 000 km² (Sivakumar, 2005).

7.2.2.4 **Temperature: frost and heatwaves**

A “frost” is the occurrence of an air temperature of 0°C or lower, measured at a height of between 1.25 and 2.0 m above ground, inside an appropriate weather shelter (FAO, 2005). Most frost events occur during clear and calm nights, often preceded by relatively warm and sunny days. This type of frost originates from the reduction of downward long-wave radiation from the atmosphere owing to the absence of, or low, cloud cover, and from the stratification of the air near the ground that develops under weak wind conditions. Because cold air flows downslope, much like water, the valley floors and lower portions of the slopes are colder. This type of frost is classified, in relation to its origin, as a “radiation frost”. Another less common but relevant type of frost is the “advection” or “wind” frost, which originates from the advection of freezing cold air into a region. This type of frost is accompanied by wind and clouds and predominantly affects the higher portions of valleys.
Frost damage is the leading weather hazard, on a planetary scale, as far as agricultural and forest economic losses are concerned. Only a small fraction of the farmland is frost-free and few crops never experience frost damage. Frost reduces substantially the world’s production of vegetables, ornamentals, field and row crops, pasture, forage and silage crops, fruit trees (deciduous and evergreens), vines and berries. Sometimes forest trees are also affected (FAO, 2005).

Frost damage is possible only after the onset of freezing. Thus it is probably more accurate to refer to “freeze damage”. Freezing inside the protoplasts (intracellular freezing) is always lethal, and is most likely due to the disruption of the membrane systems that compartmentalize cells. Fortunately, this type of damage is rare or does not occur in nature (Levitt, 1978). Under natural cooling rates, freezing of the plant tissues starts outside the cells (extracellular freezing) in the intercellular solution, because this solution is more diluted than the solution present in the cytoplasm. As the temperature of the freezing tissue gets lower, the ice masses grow, pulling out water from the protoplast, which shrinks as a result. The driving force behind this water movement is the gradient of vapour pressure, since saturation vapour pressure over ice is lower than over water at the same temperature. The loss of water by the protoplast (that is, desiccation) may or may not affect the viability of the cells, depending on the tissue/plant hardiness. Some tissues cannot recover after any amount of ice has formed extracellularly, but, at the other extreme, there are plants/tissues that can endure freezing down to the temperature of liquid nitrogen (–196°C).

The temperature at which a given level of freeze damage is expected is called a critical temperature. Critical temperatures change with species/variety, phenological stage and a number of hardening factors. For most crops, critical temperatures have been published and compiled (FAO, 2005). Forest trees are mostly affected by frost if there is a deacclimation period and they lose their hardiness prior to a frost event. Nevertheless, there are also published critical temperatures for some forest trees (Larcher, 1982; Tibbitts and Reid, 1987; Ashworth and Kieft, 1995; Ryyppö et al., 1998).

Heatwaves are most deadly for humans in mid-latitude regions, where they concentrate extremes of temperature and humidity over a period of a few days or even weeks in the warmer months. The oppressive airmass in an urban environment can result in many deaths, especially among the very young, the elderly and the infirm. In 2003, much of western Europe was affected by heatwaves during the summer months. In France, Italy, Netherlands, Portugal, Spain and the United Kingdom, they caused some 40 000 deaths. Extremely cold spells cause hypothermia and aggravate circulatory and respiratory diseases (WMO, 2006a).

Others

Duststorms and sandstorms are ensembles of particles of dust or sand lifted to great heights by strong and turbulent wind. They occur mainly in parts of Africa, Australia, China and the United States. They threaten lives and health, especially of persons caught in the open and far from shelter. Transportation is particularly affected as visibility is reduced to only a few metres.

Precipitation in the form of large hailstones can reach diameters of over 10 cm and can fall at speeds of over 150 km/h. Worldwide losses to agriculture in a typical year are more than US$ 200 million. Hailstorms have also caused deaths and great damage to cities around the world. In a matter of minutes, an ice storm can deposit a layer of ice heavy enough to bring down power and telephone lines and snap branches from trees. The ice covers roads, railroad tracks and runways, making driving extremely hazardous, delaying trains and closing airports.

Fog is a suspension of very small, usually microscopic, water droplets in the air. Dense fog has a serious impact on transportation when the visibility is significantly reduced. Highways, airports and ports are closed for safety. Fog can cause considerable economic losses. Smog is a combination of fog and air pollution. It has serious implications for human health.

Pollutants include particulate matter and noxious gases from industry, vehicles and human activities. Smoke and haze result from forest or wildland fires, from slash-and-burn forest or crop clearing, or from ash generated by volcanic explosions in stable air conditions. Smoke, haze and pollution have serious implications for human health – the local population may have to wear gas masks. These conditions reduce visibility, and air and road traffic can be disrupted. Smog, acid rain, the ozone hole and an adverse increase in the greenhouse effect are also caused by air pollution. Stable atmospheric conditions often lead to a concentration of pollutants.

Desert locusts inflict damage in Africa, the Middle East, Asia and southern Europe. When weather and ecological conditions favour breeding, the
insects are forced into a small area. They stop acting as individuals and start acting as a group. Within a few months, huge swarms form and fly downwind in search of food. Swarms can be dozens of kilometres long and can travel up to 200 km a day. A small part of an average swarm (or about one tonne of locusts) eats the same amount of food in one day as 10 elephants, 25 camels or 2 500 people. Swarms jeopardize the lives of millions of farmers and herders in already fragile environments. Locust plagues during or immediately after drought conditions can spell even greater disaster, as was the case in several Sahelian countries in 2005 (WMO, 2006b).

7.3 SCALE STUDIES FOR CLIMATIC ANOMALIES

When investigating climate trends, owing to different force balances, it is important to note that atmospheric motions behave with varying temporal and spatial scales and are often non-linear.

7.3.1 Space

Atmospheric circulation patterns are of critical importance in determining the climate of a location. On a global scale, atmospheric motions transport heat from the tropics towards the poles. Evaporation over the oceans supplies much of the water molecules that support precipitation over land. These circulation patterns are in large part driven by energy differences among regions of the globe. On a smaller scale, precipitation on the lee side of a mountain is typically less than on the windward side. On a still smaller scale, the amount of snow downwind of a snow fence is on average greater than the amount upwind (Ackerman and Knox, 2003). Spatial scales may be classified as follows:

(a) Microclimate – near the ground over a front yard, climate conditions near the surface over distances of a few metres. Large perturbations to the microclimate can rapidly affect plant life;
(b) Mesoclimate – climate conditions over a few square kilometres, for example, climate of a town, valley or beach. Other examples of mesoclimate features are orographic precipitation, lake effects, gravity waves and stratospheric-troposphere exchange through mixing at the top of deep cumulonimbus clouds;
(c) Macroclimate – climate conditions for a state or a country, over scales of approximately 1 000 km or greater;
(d) Global climate – this is the largest spatial scale, since it refers to climate conditions over the entire Earth. Climate change and climate variability, stratospheric dynamics, and the general circulation fit into this category. Energy input from the sun drives global climate. The solar gain is controlled by the orbit of the Earth around the sun and determines the length of seasons. The so-called climatic controls, or factors that produce the observed climate in any given place, are: latitude, distribution of land and water, ocean currents, prevailing winds, position of high- and low-pressure systems, and topography.

7.3.2 Time

Atmospheric fluctuations occur on various timescales. Long-term fluctuations in climate can be caused by changes in ocean circulation or changes in the concentration of greenhouse gases due to human activity, for example. Fluctuations on shorter timescales can be caused by changes in cloudiness and water vapour, for example. Atmospheric timescales are divided as follows:

(a) Microscale – seconds to hours;
(b) Mesoscale – hours to days;
(c) Macroscale – days to weeks;
(d) Global scale – weeks to months or years.

7.3.3 Space–time scales

Figure 7.1 illustrates the energy spectrum in all scales of motion, showing peaks in frequencies of a few days (synoptic scale) or several weeks (planetary scales). There are also peaks at one year, one day and

![Figure 7.1. Mean kinetic energy of the westward-eastward component of the wind in the free atmosphere at 3.2 km (red line) and near the surface of earth (green line)](image-url)
a few minutes. Nevertheless, the spectrum is a continuum.

Orlanski (1975) proposed a set of scales that include the micro-, meso- and macroscales. These three are further subdivided from larger to smaller into $\alpha$, $\beta$ and $\gamma$ scales, as shown in Figure 7.2. As the scale becomes smaller, the effects of some processes become increasingly more difficult to treat explicitly or deterministically. Depending on the horizontal scale of interest, different atmospheric processes become significant. Turbulence, the gustiness superimposed on the mean wind, can be visualized as consisting of irregular swirls of motion called eddies. Eddies produce effects at the microscale. The small-scale phenomena associated with the microscale are so transient in nature that deterministic description and forecasting of individual eddies is virtually impossible.

The scales of atmospheric motions are interconnected and nearly continuous. Macroscale processes drive mesoscale and microscale processes as energy is transferred from larger to smaller scales. Conversely, small-scale processes can organize to develop larger-scale systems, such as convective storms.

Figure 7.3 shows examples of the range and scales of natural hazards that are observed, detected, monitored and forecast by WMO networks (WMO, 2006b).

7.4 AGROMETEOROLOGICAL APPLICATIONS IN THE CHARACTERIZATION OF CLIMATIC HAZARDS – MODELLING AND DATA NEEDS

The Intergovernmental Panel on Climate Change was established in 1988 by WMO and the United Nations Environment Program (UNEP) to assess scientific, technical and socio-economic information relevant to the understanding of climate change, its potential impacts and options for adaptation and mitigation.

Figure 7.2. Scale definitions and different atmospheric processes with characteristic time- and horizontal scales (adapted from Orlanski, 1975). C.A.T. refers to Clear Air Turbulence and I.G.W. to Inertial Gravity Waves (OFCM, 2004).
The IPCC Third Assessment Report (IPCC, 2001), states that “the Earth’s climate system has undergone changes on both global and regional scales since the pre-industrial era”, and “there is newer and stronger evidence that the Earth’s warming observed over the last 50 years is due to human activities”. Among the hazards predicted to occur due to global change, the most threatening for mankind are an increase in the intensity and frequency of storms, floods, droughts and heat waves, and the effects of sea level rise in coastal areas. There is, however, a great deal of uncertainty in these predictions and research that aims to improve climate model predictions is under way in many research centres around the world. A number of empirical mathematical models have also been developed and applied (Long and Drake, 1991; Long, 1991). Predicting how vegetation will respond to climate change is critical to understanding the impacts of atmospheric changes on both natural ecosystems and crop growth.

7.4.1 General circulation models

Characterization of climatic hazards for some crops has been carried out using general circulation models (GCMs) and the confidence in the ability of these models to project future climate has been increasing. The most detailed predictions are based on coupled atmosphere–ocean general circulation models that provide credible simulations of climate, at least for sub-continental scales. Models cannot yet simulate all aspects of climate, however. For example, they still cannot account fully for the observed trend in the temperature difference between the surface and the lower atmosphere. There are also significant uncertainties regarding clouds and their interaction with radiation and aerosols (UNFCCC, 2004).

There are numerous GCMs in use and under construction in research centres around the world. For instance, some of the general circulation models that were used by the IPCC were the French ARPEGE model; the American NASA GEOS-2 and GISS models and NOAA CCM2 models; the German ECHAM model; and the Canadian MAM model, to name a few.

7.4.2 Regional circulation models

Regional Circulation Models (RCMs) are used in many parts of the world to determine specific characteristics of the weather in mesoscale. RCMs have a regional domain, over one state or country, for example, and provide more spatially detailed predictions than those obtained with GCMs. Many RCMs are being adapted and implemented in different parts of the world. The principal RCMs in use are:

(a) RAMS – Regional Atmospheric Modelling System (Pielke et al., 1992);
Climate information can benefit rural producers through the use of seasonal forecasts, and by improving the management of climate variability per se. Significant climate variability implies the likely occurrence of drought and floods.

Historical climate information is crucial to plan the production year. It influences the long-term strategies regarding which crops to grow and when to plant or sow, which for most crops is the primary determinant of when harvesting takes place. Tactical decisions on how much to sow have to be made in relation to climate and market forecasts, along with decisions on when and how much to irrigate, pest control, and crop protection.

Increased self-reliance by rural producers requires the ability to manage both crop and livestock enterprises exposed to a variable climate and to minimize the impact of drought. It also requires the ability to manage risk more effectively; production risk, environmental risk, financial risk and market risk (White, 1997). Improved seasonal outlooks are but one approach to helping farmers become more self-reliant. Ways of offsetting the risks associated with climate variability in order to create opportunities require a systems approach (Hammer and Nicholls, 1996; Hammer et al., 2000).

Climate data have long been invaluable for making farm management decisions, including in areas where seasonal forecasts have proved unreliable. Historical records of rainfall, temperature and even wind speed have been used to determine optimal times for the sowing and harvesting of crops, and for lambing and calving on grassland farms, as well as for irrigation planning.

Ancillary information that can help a producer assess a current season and decide on various tactics includes: rainfall to date (for instance, within a growing season), amount of standing herbage (or crop development), weight of livestock, amount of stored supplements and the capacity to deal with adverse seasons. Weather forecasts (<10 days) are of particular value in making tactical decisions.

A range of decision support systems (DSSs) are available for analysing historical data to determine probabilities of rain, frosts, and the beginning and end of growing seasons. In Australia, for instance, these include Australian Rainman (Clewett et al., 2003), which provides more detailed analysis of rainfall probability distributions, and the MetAccess system (Donnelly et al., 1997) developed by the Commonwealth Scientific and Industrial Research Organization (CSIRO). More complex DSSs and models are able to simulate changes in soil moisture, pasture or crop growth, liveweight change, supplementary feed requirements and cash flow. An example is the “Whopper Cropper” cropping systems DSS, in which the DSS can play a valuable role in encouraging farmers to be more tactical in their decision-making and consider planting a crop when there is adequate stored moisture, or to take a more strategic approach. It can also encourage debate on the design of planned and flexible cropping rotations.

In this respect, the development of DSSs has made it apparent that the best way to obtain an appropriate balance between demand- and supply-driven development of a DSS is via dialogue among the key participants in the decision-making. Including this dialogue in a participatory action research programme suggests that the term “decision support systems” may be better described as “discussion support systems”. Discussion support systems such as “Whopper Cropper”, which can be applied in most agricultural environments, can then provide a complementary vehicle for delivery of agricultural simulation-aided discussions. These systems can also focus on farm management advisers as key intermediary agents, who then act as facilitators in the process (Nelson et al., 2002).

Thus these DSSs, in combination with the findings of field experiments and farm surveys, are useful in determining optimal management strategies (such as long-term stocking rates and cropping rotation strategies) and short-term tactics (such as supplementary feeding, decisions about buying and selling livestock, purchasing grain futures or cheap supplies if available, sowing pastures in spring or sowing summer crops, determining areas for cutting hay for conservation or sale, whether or not to irrigate, and controlling for pests or diseases).

The use of long series of weather data has also helped in determining probabilities and risk associated with frost. The Food and Agriculture Organization of the United Nations (FAO, 2005) published personal computer programs that calculate the probabilities of having a minimum...
temperature lower than a given value in a specified time period, the last spring and first autumn frost dates, length of growing season, and probabilities and risk of frost damage to a specified crop.

7.4.4 Agronomic models

Biophysical models of agricultural systems can provide useful and often necessary information to complement field experimentation and farm surveys, since if properly validated, they enable the system response to be assessed over many locations and seasons. They provide a logical link between climate information and performance of plants and livestock in the field, and can therefore be an effective means of determining the responsiveness of soil moisture, plants and livestock to changing climatic conditions. Since such models should also be realistically responsive to changes in management, the effects of both management and climate can be studied simultaneously. For example, Fouché et al. (1985) used a model to show how the frequency and duration of droughts on the South African veldt increased with stocking rate. The models are also proving to be invaluable for spatial and temporal simulations within Geographical Information Systems (GISs) in terms of drought monitoring, and as mentioned above, in estimating the value of seasonal forecasts for various locations and farming systems.

7.4.4.1 Crop response

Plant growth models need to be sufficiently mechanistic to predict plant responses to changes in the environment. Although considerable attention has been given to defining the appropriate functional forms within vegetation models (Thornley and Johnson, 1990), most models are specific to the major ecosystem in which they have been developed and have an important empirical base. This includes many of the crop models that have been developed to predict grain yield or to evaluate management strategies, such as different sowing dates, and how the efficiency of water use and the use of nitrogen and other fertilizers may be manipulated.

A number of crop models are now being used both in modelling the effects of climate variability on crop production and in determining management strategies to help identify the genotypes and approaches that allow for mitigation of the impact of below-average seasons. Examples of the use of crop models for modelling and forecasting crop production include Keating and Meinke (1998), Stephens (1998), and Potgieter et al. (2005) in Australia, and Lourens and de Jager (1997) and de Jager et al. (1998) for the maize model in Southern Africa.

7.4.4.2 Pasture response

Models of grazing systems, such as GRASP in northern Australia (McKeon et al., 1990) and DYNAMOF (Bowman et al., 1993, 1995) and GrazPlan (Donnelly et al., 1997; Freer et al., 1997; Moore et al., 1997) in southern Australia, are of considerable value in determining appropriate long-term stocking rates, supplementary feeding and other strategies. In other words, they can be of fundamental importance in achieving sustainable grazing systems and in improving the management of climate variability per se.

Such models are of value in assessing the severity and impact of different droughts on grassland and rangelands comprising a range of vegetation types in different locations (Donnelly et al., 1998; Stafford Smith and McKeon 1998; du Pisani et al., 1998; White et al., 1998). The GRASP model has also been incorporated into a GIS-based prototype of a national drought monitoring system in Australia (Carter et al., 2000). Experimentation is under way with an alternative but simpler spatial/temporal model, GrowEst Plus, based on the original model of Fitzpatrick and Nix (1970), to develop indices that may be used to analyse specific events, such as drought, or to characterize the reliability of a growing season as an aid to managing environmental sustainability (Laughlin et al., 2007).

7.4.5 Vegetation suitability maps

Agroecological zoning systems are an example of the use of data and models for the construction of suitability maps. The main system for land resource assessment is the agroecological zoning (AEZ) methodology developed by FAO, along with supporting software packages for application at global, regional, national and sub-national levels. AEZ uses various databases, models and decision support tools, which are described below.

The AEZ concept involves the representation of land in layers of spatial information and the combination of these layers using GIS techniques. The combination/overlay of layers produces agroecological cells. In this way a land resources database is created that contains information on the AEZ cells. AEZ integrates in the database various kinds of geo-referenced datasets, which can include topography; administrative boundaries; road/
communications; towns and settlements; rivers/water bodies; geology; soil; physiography; landforms; erosion; rainfall; temperature; moisture regime; watersheds; irrigable areas; land use/land cover and forest reserves; and population. The AEZ methodology and models have been applied in developing a global digital AEZ land resources database derived from the digitized soil map of the world (DSMW). The database contains information on soil and landforms, temperature regime and length of growing period, agroecological zones, forest and protected areas, and land suitability for about 30 main crops (http://www.fao.org/ag/agl/agll/cropsuit.asp).

7.4.6 Remote-sensing

Remote-sensing can provide useful estimates of vegetation cover and condition, plant water status, and the spatial limits of severe droughts over large areas of land (McVicar and Jupp, 1998; McVicar et al., 2003). Such information is invaluable in monitoring changes in land use, the impact of changing seasons and years on vegetation cover and “greenness”, the beginning and end of growing seasons, the impact of livestock grazing intensity on vegetation, and the extent of erosion and other forms of land degradation. It is also a valuable source of data for validating agronomic models.

McVicar and Jupp (1998) describe four ways in which remote-sensing can assist in mapping and monitoring agronomic conditions in relation to climate variability. These include:

(a) Vegetation condition: monitoring with reflective remote-sensing;
(b) Environmental condition: monitoring with thermal remote-sensing;
(c) Soil moisture: monitoring with microwave remote-sensing;
(d) Environmental stress: combining thermal and reflective remote-sensing.

7.4.6.1 Vegetation indices

Most vegetation indices are derived by combining the red and near-infra-red (NIR) reflective bands recorded by the LANDSAT Thematic Mapper™, the NOAA Advanced Very High Resolution Radiometer (AVHRR) sensors and other remote-sensing instruments used on satellite platforms. Vegetation indices based on satellite data include measurements of leaf area index (LAI) (Tucker, 1979) and plant condition (Sellers, 1985), as well as the simple ratio (NIR/Red) and the Normalized Difference Vegetation Index (NDVI), which is given an extensive review by McVicar and Jupp (1998).

7.4.6.2 Soil moisture index

Thermal remote-sensing is an instantaneous observation of the status of the surface energy balance. This is driven by the net radiation of the surface, which is dominated during the daytime by incoming short-wave radiation from the sun; the amount reflected depends on the albedo of the surface.

The difference between daytime and night-time soil temperatures can be used to monitor changes in superficial soil moisture. McVicar et al. (1992) and Jupp et al. (1998) jointly developed the Normalized Difference Temperature Index (NDTI) to remove seasonal trends from the analysis of daytime land surface temperatures derived from the AVHRR sensor. The NDTI, which is a very close approximation of the moisture availability, has the form:

\[ \text{NDTI} = \frac{(T_\infty - T_s)}{(T_\infty - T_0)} \]  (7.1)

where \( T_\infty \) is a modelled surface temperature if there is an infinite surface resistance, that is, evapotranspiration (ET) is zero; \( T_s \) is the surface temperature observed from the AVHRR sensor, and \( T_0 \) is a modelled surface temperature if there is zero surface temperature resistance; hence ET equals ETp (potential evapotranspiration). As McVicar and Jupp (1998) explain, \( T_\infty \) and \( T_0 \) can be thought of as the physically limited upper and lower temperatures, respectively, for given meteorological conditions and surface resistances. If \( T_0 \) is close to the \( T_\infty \) value, it is an indication that conditions are “wet”, as when soil moisture in surface layers approaches “field capacity”.

7.4.6.3 Drought early warning systems

Drought early warning systems can help achieve a greater level of drought preparedness. Although some of these systems have shortcomings, such as being unreliable, poorly targeted or not user-friendly (Wilhite, 2005), others are proving invaluable at the regional and national levels for monitoring and mitigating the effects of drought.

The integration of spatial datasets, including remotely sensed data, with agronomic models is leading to the development of integrated spatial/temporal systems for both grasslands (du Pisani et al., 1998; Carter et al., 2000; Brinkley et al., 2004) and crops (Lourens and de Jager, 1997; de Jager et al., 1998; Stephens, 1998).
Unit of the Southern African Development Community (SADC) based in Zimbabwe, and the FAO Global Information and Early Warning System on Food and Agriculture (GIEWS)). These often appear to be used primarily to focus reactive relief efforts on “drought disasters”, however, rather than being integral to the implementation of carefully thought out policies aimed at managing for drought and improving the sustainability of agricultural production systems. Furthermore, having such systems in place will be of only limited value if the required transportation and telecommunications infrastructure and extension services are inadequate.

In arid, semi-arid and marginal areas with a probability of drought incidence of at least once in ten years, for example, it is important for those responsible for land-use planning, including agricultural programmes, to seek expert climatological advice regarding rainfall expectations. Drought is often a result of the interaction of human patterns of land use and the rainfall regimes. Thus, there is an urgent need for a detailed examination of rainfall records of these regions. In this regard, the development of methods for predicting the occurrence of rainfall many weeks or months in advance deserves high priority.

Since technological inputs quickly reach an optimum level, more emphasis should be placed on drought management policies, especially in dryland farming areas. Agricultural planning and practices need to be worked out with consideration given to the overall water requirements within an individual agroclimatic zone. Crops that need a short duration to mature and require relatively little water need to be encouraged in drought-prone areas. Irrigation, through canals and groundwater resources, needs to be monitored to ensure optimum utilization, avoiding soil salinity and excessive evaporation loss. A food reserve is needed to meet the emergency requirements of up to two consecutive droughts. A variety of policy decisions on farming, human migration, population dynamics, livestock survival, ecology, and so on must be formulated (Das, 1999).

Sustainable strategies must be developed to alleviate the impact of drought on crop productivity. In areas of recurring drought, one of the best strategies for alleviating drought is to manipulate varieties in such a way as to avoid drought, or to minimize its effects by adopting varieties that are resistant to drought at different growth stages.

If drought occurs during the middle of a growing season, corrective measures can be adopted; these vary from reducing plant population to fertilization or weed management. In high rainfall areas where there are a series of wet and dry spells, rainfall can be harvested in either farm ponds or in village tanks and can be recycled as lifesaving irrigation during a prolonged dry spell. The remaining water can also be used to provide irrigation for a second crop with a lower water requirement, such as chickpea. No one strategy can be adopted universally, however. In fact, all such strategies are dependent upon location, time, crop, crop stage and (to some extent) socio-economic conditions. Developing such strategies for each specific factor can help make agriculture sustainable (Das, 2005).

7.5 METHODS OF RISK ASSESSMENT

7.5.1 Managing risk

Producers recognize risk management as an important activity in their decision-making process. This enables them to manage their businesses more effectively in a physical environment where drought or other extreme events are common, though unpredictable, occurrences. Risk management recognizes that producers also operate in an economic environment of less-than-perfect knowledge. There are three types of risk in agriculture: production risk, financial risk and marketing risk.

Production risk is imposed primarily by seasonal variability. This risk may be reduced by avoiding excessively high stocking rates, developing strategies for reducing stock numbers in the event of abnormally dry conditions, sowing drought-resistant pasture plants and crops, choosing flock and herd structures and dates of lambing and calving that better relate the nutritional demands of the livestock to the available feed supply, providing shelter for livestock, conserving fodder or growing fodder crops, installing irrigation, and diversifying enterprises.

Strategies that are less risky in terms of production may be much more prone to financial risk. For example, low stocking rates may not allow enough income to be generated in the good seasons to enable a farmer to survive the poor seasons (White, 1987). Stocking according to season may result in the purchase of stock at high prices and its sale at low prices (Arnold and Bennett, 1975). Dates of lambing or calving that favour production may not favour marketing. Fodder may be conserved on the farm to support high stocking rates, but with the extra stock numbers, less surplus is available to be conserved (Bishop and Birrell, 1975). Irrigation
schemes will often be unprofitable, even though they reduce the production risk. Diversifying from wool or beef production, for example, into crops or specialist livestock enterprises, such as deer or alpaca farming, may require substantial capital investment and associated financial risk, and farmers who do diversify often do not have the necessary specialist skills.

Climate predictions may be used to reduce risk. For example, farmers planning to prepare land for sowing winter crops might not do so if they were given an adverse forecast in autumn. A farmer in desperate need of cash to meet financial commitments might sow a crop anyway, however, in the hope that the forecast was incorrect. A farmer might decide to feed a “failing” crop to livestock in the spring on the basis of an adverse forecast.

7.5.2 Analyses of long-term weather data to identify occurrence of particular risk

To identify the occurrence of particular risk (such as water stress, heat stress, cold stress – including frosts, freezing, floods and risk of wild fires), it is necessary to analyse long-term weather data. FAO (2005) developed applications and models to compute frost probability and risk of damage. An MS Excel application program (TempRisk.xls) was written, using the approach developed by Haan (1979), to make calculations of the probability and risk that temperatures will fall below a critical value for a user-selected time period. Another application program (FriskS.xls) computes the probability and risk associated with the last spring and first autumn frost dates, and the probabilities for the length of the growing season. A model, the MS Excel Damage Estimator application program (DEST.xls), is used to calculate expected frost damage and crop yield using site-specific maximum and minimum temperature climate data for crops having no protection against frost; it uses up to 11 different frost protection methods. Up to 50 years of maximum and minimum temperature data can be used in the analysis. Critical temperatures associated with 90 per cent and 10 per cent damage are available in the application and correspond to specific phenological dates.

7.5.3 Disaster preparedness on the basis of weather forecasts

One of the most effective measures for disaster preparedness is a well-functioning early warning system that delivers accurate information dependably and in a timely manner. Therefore, it must rely on:

(a) Advanced, accurate, detailed and understandable forecasts of hazardous conditions;
(b) A rapid, dependable distribution system for delivering forecasts, advisories, watches and warnings to all interested parties;
(c) A prompt, effective response to warnings at the national to local levels.

WMO programmes relate to monitoring the atmosphere, oceans and rivers provide the crucial time-sequenced information that underpins the forecasts and warnings of hydrometeorological hazards. The WMO global network of Regional Specialized Meteorological Centres (RSMCs) and World Data Centres (WDCs) supplies critical data, analysis and forecasts that enable the National Meteorological and Hydrological Services (NMHSs) to provide early warning systems and guidelines for various natural hazards, such as tornadoes, winter storms, tropical cyclones, cold waves and heatwaves, floods and droughts.

For example, the WMO network proved to be highly effective in 2004, during one of the most intense hurricane seasons in the Atlantic and Caribbean regions. Atmospheric data collected via in situ and space-based instruments were transmitted to the United States National Hurricane Center, one of the WMO RSMCs (RSMC-Miami), where forecasts and hurricane advisories were developed around the clock. These advisories were transmitted via the Global Telecommunication System (GTS), facsimile and Internet at intervals of three to six hours to the NMHSs of countries at risk. The forecasters at the NMHSs used these hurricane advisories to produce their national hurricane warnings, which were dispatched immediately to newspapers, radio and television stations, emergency services and other users. As a result of this information, many lives were spared through timely evacuations. There is no doubt that much more could be achieved by deploying resources to strengthen further early warning systems. The challenge is to ensure that all countries, particularly the Least Developed Countries, have the systems, infrastructure, human capacity and organizational structures to develop and utilize early warning systems to reduce risks of natural disasters.

7.5.4 Anticipating risk on the basis of seasonal forecasts

Temporal climate risk weighs heavily on many regions. Recent advances in model-based climate forecasting have expanded the range, timeliness and accuracy of forecasts available to
decision-makers whose welfare depends on stochastic climate outcomes. There has consequently been considerable recent investment in improved climate forecasting for the developing world (Lybbert et al., 2003).

The past decade has seen a great deal of progress in the understanding of our climate systems, and in anticipating climate events, particularly El Niño. This has resulted in a cultural change in those countries that experience high climate variability, not only within the meteorological community, but also among many farmers and their advisers. This has been particularly true in north-eastern Australia, where the impact of El Niño has been quite severe, and where many agricultural and other natural resource scientists have gained a significant appreciation of the underlying climatological concepts and have developed tools that would aid rural producers in their farm planning and decision-making. There has also been a major education programme involving the community.

Seasonal forecasts that may cover three or more months are derived in a completely different way from weather forecasts. Weather forecasts rely upon knowledge of the precise conditions of the atmosphere at the time when the forecast begins (initial conditions) in order to make forecasts for one to two weeks into the future. Given the strongly chaotic nature of the atmosphere, however, weather forecasts have virtually no skill after two weeks or so. Forecasts beyond this two-week weather forecast barrier rely on the fact that slowly changing sea surface temperatures (SSTs) or land surface effects (boundary conditions) are driving atmospheric circulations that affect certain regions of the world. Seasonal prediction therefore can be skillful in regions of the globe where the atmosphere is driven by local or remote sea surface temperature or land surface effects. Empirical as well as dynamical tools are used to make seasonal forecasts. Statistical models rely on the fact that the future is driven by past data, and therefore can be skillful in regions where strong relationships exist between the ENSO and local climate (e.g., rainfall in the eastern United States). Empirical tools are based on the past performance of models, and are used to make seasonal forecasts.

Tools

7.5.4.1 Statistical forecasts

In 1989 the Australian Bureau of Meteorology began issuing seasonal outlooks for the next three months, based primarily on the Southern Oscillation Index (SOI). Since 1997, this initial approach has been replaced by a method based on Pacific Ocean and Indian Ocean sea surface temperature patterns, although methods and systems using the SOI (or SOI “phases”) remain popular in eastern Australia, where strong relationships exist between the SOI and key rainfall periods for agriculture and variables such as the start and finish of the frost season. In addition, methods based on the SOI have proven more amenable to incorporation into crop and pasture simulation models, thereby providing increased capability for uptake by agricultural planners. The SOI is based on the long-term trend in the differences in atmospheric pressure between Darwin and Tahiti, and has proven to be a reasonably reliable indicator over much of eastern Australia, and elsewhere, with respect to winter, spring and summer rainfall (McBride and Nicholls 1983; Stone et al., 1996). Such information is used in other countries susceptible to the influence of the El Niño–Southern Oscillation (ENSO) effect, including Southern Africa, parts of South America, Indonesia, and India.

More recently a new forecast system has been developed on the basis of near-global patterns of sea surface temperatures. The system shows more skill than the former SOI-based system and is now in operation in some countries. The phase of the SOI (Stone et al., 1996) is proving to be another valuable tool for producing seasonal outlooks. Both rainfall-forecast methodologies (ENSO and SOI phases) were applied in the Pampas, located in central-eastern Argentina, one of the world’s leading areas in terms of agricultural and farming potential (Penalba et al., 2005). A lead time of three to six months, especially for November (0), appears to be feasible. The lead time found in the SOI phases methodology, however, does not improve the “forecast” provided by the ENSO methodology occurrence, given that the ENSO event has already entered into the development stage.

North-east Brazil is noteworthy as a region of the world where remarkable skill has been achieved for the seasonal prediction of wet-season rainfall anomalies. These forecasts are based on the observation that wet-season (February to May) rainfall in North-east Brazil is strongly affected by sea surface temperature anomalies in the Atlantic and Pacific oceans in the previous months (November through January). Statistical, real-time predictions of North-east Brazil wet-season rainfall have been issued by the British Met Office since the early 1990s, following the work of Ward and Folland (1991).
7.5.4.2 **General circulation models (GCMs)**

Forecast lead times in terms of years rather than months are needed to attain significant financial benefits in many pastoral systems. Therefore there is a robust case for further research to extend seasonal forecasts to annual timescales and beyond.

Coupled ocean-atmosphere GCMs of the global climate have been shown to offer more promise in extending forecasts from 3 to 12 months than the statistical SOI methods, particularly because they directly forecast changes in SSTs in the central and eastern tropical Pacific. Such longer lead times would certainly be more useful to livestock producers. GCMs have yet to be properly tested for rainfall prediction, although their SST predictions can be used statistically to estimate changes in the SOI and rainfall with reasonable success.

Generally speaking, dynamical seasonal forecasts require the performance of large ensembles of GCM simulations and an analysis of the results to look for regions where most simulations produce similar results. In such regions, atmospheric circulations may be more strongly driven by slowly varying ocean or land effects and therefore the prospect for making skillful seasonal predictions is improved. Our experience with seasonal forecasting has shown that, in general, the tropical regions of the world present more promise for seasonal predictability than extra-tropical regions, although when seasonal climate forecast systems can be integrated into agricultural simulation models, an increase in applicability of seasonal forecasting systems appears possible in extra-tropical regions and even some high-latitude locations (Meinke and Stone, 2005).

### 7.5.4.2 Accuracy, timeliness and value

The forecasts can influence decisions on when and what area to sow and whether to irrigate and/or fertilize a crop. Accuracy of forecasting does not necessarily equate with its value to resource managers. Obviously, if the information is not used, even though it may have value, no benefit is obtained. If the forecast is inaccurate, the information is likely to have negative value in the current season. Even accurate information can be of limited value, however, if the lead time is only three months, for example, since many livestock producers require lead times in excess of six months or even a year.

The value of seasonal forecasts to crop producers can be significant, but it varies with management and initial conditions, as well as with cropping systems and location (for example, Hammer et al., 2000; Marshall et al., 1996).

Preliminary studies of the value of seasonal forecasts using models of grassland systems have shown that the financial benefits may not be easily realized based on existing skill levels, lead times (three months, for example) and decision points within a calendar year. These analyses also demonstrate, however, that the same level of cash flow could be achieved for a much lower risk of environmental degradation with the use of climate forecasting (Stafford Smith et al., 2000). In some areas, even high skill levels appear to offer low financial benefits in the medium term, despite increased animal welfare and protection for soils and vegetation (Bowman et al., 1995). This highlights the need for further research to determine whether and how the management of many grassland systems and the timing of the relevant decisions should be modified to take advantage of forecast information.

### 7.6 Example of Risk Assessment for Particular Weather and Climate Events from Literature

In north-western China, informal herder groups counteract risk and manage disaster situations by jointly preparing emergency plans and organizing pasture movements should an emergency situation, such as a snowstorm, occur (Yongong et al., 1999). “According to the herders, village leaders and production team leaders are the most active persons in dealing with the risk management... They even fulfill extension tasks, since there are no township and village extension line agencies... In those townships which have no concentrated village settlement pattern, there is another non-governmental informal organization locally called ‘zhangquan’ situated between the production team and households. A ‘zhangquan’ normally comprises about 4-5 herder’s households on average. In general, ‘zhangquan’ are comprised of families or of neighbouring families settled in the same area. Generally, these individuals collaborate as unofficially formed herders groups. Such groups jointly organize the grazing, they exchange their labour force, share information, protect animals from theft, address risk avoidance, organize meetings and make decisions together” (Yongong et al., 1999).

Synoptic and mesoscale predictions of minimum temperature are usually undertaken by national or regional weather services, using large amounts of
equipment and manpower. These are usually public institutions that release frequent updates at no cost to the public. Local (microscale) forecasts are typically unavailable unless provided by private forecast services. At the microscale, complex energy-balance models have been used to predict short-range minimum temperature, with uncertain results (Sutherland, 1980; Cellier, 1982, 1993; Kalma et al., 1992). Simple empirical models calibrated locally, however, often give satisfactory results in the prediction of minimum temperature in a given day. FAO (2005) presents an empirical forecast model “FFST.xls”, which can be easily calibrated for local conditions. The model uses historical records of air and dewpoint temperature at two hours past sunset and observed minimum temperatures to develop site-specific regression coefficients needed to accurately predict the minimum temperature during a particular period of the year. This model will only work during radiation-type frost events in areas with limited cold air drainage.

In coastal Asia where flood risk is severe, for example in Bangladesh and Cambodia, several projects have been built specifically focusing on people’s perception of flood risk, the purpose and tools of community flood risk assessment, the strategies for community organization, and resource mobilization and capacity-building. In these cases, the underlying rationale can be traced back to the sequencing of disaster risk management activities, with an emphasis on local scoping studies and capacity-building that are to precede community interventions.

In India, following the cyclone of 1971 (which took the lives of 10 000 people), the government of the state of Orissa prepared a report outlining a series of measures to be taken to prepare for future cyclones, which later led to the Orissa Relief Code. This code provides the basic framework for the implementation of emergency measures under all types of emergency situations, as it details the specific responsibilities of the state’s Special Relief Commissioner and its different line ministries. During the latest cyclone of 1999, planning responses were still hindered by a lack of updated and available vulnerability maps and databases on conditions on the coast.

In Nicaragua, the Asociación de Consultores para el Desarrollo de la Pequeña, Mediana y Microempresa (ACODEP), one of the largest microfinance institutions (MFIs) in the country, has been learning from the experience of Hurricane Mitch in 1998 and more recent disasters. The association has developed a “disaster prevention plan” whose objectives are to identify, prepare for and mitigate natural and man-made disasters in order to protect the institution, its clients and staff from possible losses. The plan is quite comprehensive, including measures to safeguard the institution’s staff, portfolio, facilities, equipment and information systems and records, as well as measures to better respond to the many disasters that affect Nicaragua. The plan recognizes that priority should be given to assisting clients in finding medical aid, contacting relief organizations and joining food for work (FFW) programmes, but, in keeping with the sector’s orthodox “best practices”, it does not consider that the institution should provide relief directly.

Hurricane Michelle, the most powerful storm since 1944, ripped through Cuba in November 2001. But, in contrast to the 20 000 victims of Hurricane Mitch in Honduras, just five people died in Cuba. Successful civil defence and Red Cross planning ensured that 700 000 people were evacuated to emergency shelters in time. Search-and-rescue and emergency health care plans swung into action. In Havana, electricity and water supplies were turned off to avoid deaths from electrocution and sewage contamination. Cuba’s population was advised in advance to store water and clear debris from streets that might cause damage (FAO, 2003).

The severity of the El Niño/La Niña phenomenon of 1997–1998 led to the establishment of the Andean Regional Programme for Risk Prevention and Reduction (PREANDINO), with the objective of promoting the development of disaster risk prevention and mitigation policies and new institutional arrangements aimed at incorporating prevention into development planning.

The Lempira Sur rural development project in the south of Honduras has promoted improved agricultural practices, river basin management, ecological sustainability, increases in on- and off-farm incomes, and economic resilience among poor families. This has been achieved with the introduction and appropriation of improved land-use practices, water management schemes, maintenance of biodiversity, local credit schemes, and the strengthening of local government and the ability to plan urban and rural development. The notion of disaster risk reduction was never considered in the project document. The project demonstrates, however, how ecologically sustainable, best-practice agriculture will lead to reductions in disaster risk, although this was not a defining characteristic of the project as such. Hazard reduction associated with flooding and landslides has been achieved, along with increases in the resil-
ience of the local population when faced with extreme conditions. During Hurricane Mitch, the area covered by the project suffered little damage thanks to the types of land-use and slope-stabilization methods that were utilized, and it was able to provide food assistance to other areas severely damaged by the hurricane.

An efficient telecommunication system is a prerequisite for an effective typhoon warning system. The Global Telecommunication System was developed by WMO under the World Weather Watch (WWW) Programme to collect data from the national observing stations and exchange these data with other countries. This elaborate telecommunication system also allows for the prompt dissemination of typhoon warnings, as well as the transmission of data for the monitoring of typhoons (Lao, 2006).

### 7.7 EXTREME CASES

Although there is a great deal of uncertainty involved in the assessment of climate-related human health risk, visible progress is being made. Climate-related health risks range from the direct effects of extreme temperature and flooding, which every year cause deaths and the spread of infectious diseases, to the more indirect effects of climate variability on the global distribution of infectious diseases such as malaria, dengue fever, cholera, Rift Valley fever, and hantavirus, among many others.

The role of climate and the environment in human disease dynamics has been clearly demonstrated for the case of cholera, an acute intestinal infection caused by the bacterium *Vibrio cholerae*. The dynamics of cholera outbreaks involve the *V. cholerae* bacterium and plankton in such a way that during periods of warm sea surface temperatures, *V. cholerae* is active and abundant and the number of cholera cases in certain geographical areas is elevated (Colwell, 1996). On a global scale, the clear link between cholera epidemics and climate variability phenomena, such as El Niño, offers the possibility of creating an early-warning system that could help prevent future cholera epidemics given reliable climate prediction.

Climate change can affect agriculture in many ways, for example: (a) through soil–plant processes, with an increase in soil water deficits caused by changes in soil water balance; (b) in the area of crop development, since crops will be affected by temperature and soil humidity changes; (c) by contributing to the formation of weeds, pests and diseases (weeds are expected to benefit from higher CO$_2$ concentration, increases in precipitation and temperature are favourable to the development of early crop diseases, and the risk of crop damage by pests and diseases increases in all regions under climate warming); and (d) through economic and social effects. Rosenzweig and Liverman (1992) observed that the tropical regions could also be more vulnerable to climate change because of economic and social disparities. Greater economic and individual dependence on agriculture, widespread poverty, inadequate technologies and lack of political power are likely to exacerbate the impacts of climate change in tropical regions.

A number of global assessments of the impacts of climate change in agriculture and agricultural markets have been produced (Rosenberg and Crosson, 1991; Rosenzweig and Hillel, 1998; Mendelsohn and Neumann, 1999; Siqueira et al., 1999; Salinger et al., 2001; Reilly et al., 2001; Das, 2003a). It is expected that the concentration of atmospheric CO$_2$ will rise from its current level of 354 ppm to 530 ppm by the year 2050, and to 700 ppm by the year 2100 (Watson et al., 1990). Changes in the concentration of the infra-red absorbing gases in the atmosphere are expected to produce a general warming of the global surface ranging from 3°C–4°C by the year 2100 (Bretherton et al., 1990). According to Marengo (2001), in most of Latin America there are no regional studies that show conclusive effects of climate change. Some changes in atmospheric circulation at the regional level, however, were detected for precipitation and hydrological cycles in the Amazon region, for example (Marengo et al., 2001; Costa and Foley, 1999; Curtis and Hastenrath, 1999), and for temperature, including several Brazilian regions (Victoria et al., 1998; Marengo and Rogers, 2001).

*Catarina*, a powerful storm that affected parts of Santa Catarina and Rio Grande do Sul states in Brazil in March 2004, may be an early example of the effect of climate change in the South Atlantic Ocean. A technical note published by the Brazilian Centre for Weather Forecasting and Climate Studies (CPTEC) and the Brazilian National Institute of Meteorology (INMET) reports that the storm formed as a cyclone in the South Atlantic Ocean, acquiring hurricane characteristics while moving towards the South American continent. The storm (with winds of up to 180 km/h, which had never before been observed in the South Atlantic Ocean) caused unprecedented destruction.
in that region. Damages were in excess of US$ 350 000 000.

Climate change may therefore result in an increase in climate variability and climate extremes. Such climate changes will most certainly affect crop growth and productivity. There is not enough information about the potential impact of climate change in agriculture, however, because of the complex response of plant and soil processes to several weather variables.

Climatologists at the NOAA National Climatic Data Center in Asheville, North Carolina, have selected some of the most notable floods, typhoons, hurricanes, droughts, heatwaves, tornadoes, winter storms, blizzards and other climate events of the twentieth century. Factors taken into consideration included the event’s magnitude and meteorological uniqueness, as well as its economic impact and death toll (NOAA, 1999). The list includes:

(a) Recurring floods that occur in the middle and lower reaches of the major rivers in China and kill from several thousand to several hundred thousand people. During the last century, major flooding disasters occurred in 1900, 1911, 1915, 1931, 1935, 1950, 1954, 1959, 1991 and 1998, mainly in the Yangtze River Valley.

(b) Yangtze River Flood, 1931. The summer flood along the Yangtze in July–August 1931 was the most severe, with over 51 million people affected (one fourth of China’s population). Some 3.7 million people perished due to disease, starvation or drowning during what is considered the greatest disaster of the twentieth century. This flood was preceded by a prolonged drought in China during the period between 1928 and 1930.

(c) Flood in Vietnam, 1971. Heavy rains caused severe flooding in North Vietnam, killing 100 000 people.

(d) Great Iran Flood, 1954. A storm over Iran produced flooding rains resulting in approximately 10 000 deaths.

Many of the devastating floods that occur in parts of South-East Asia are also associated with typhoons or tropical systems. (See the typhoon section for more information.) In contrast, the United States Midwest Flood of 1993 caused 48 deaths.

Among the most devastating hurricanes of all time were Hurricane Georges (September 1998) and Hurricane Mitch (October 1998). A Category 5 hurricane, Mitch was one of the most powerful Atlantic hurricanes on record. With 290 km/h winds, a minimum storm pressure of 0.1 mPa, and quite a long lifespan (14.5 days), Hurricane Mitch turned out to be the deadliest of the century. It caused loss of life, destruction of property and damage to food production, food reserves and transportation systems, as well as increased health risks.

Deadly typhoons and killer cyclones strike coastal areas along the Bay of Bengal with periodic frequency, much like the floods along the Yangtze River in China. They historically have also devastated the Chinese coast, Korea, Japan, the Philippines and South-East Asia. The list includes:

(a) Bangladesh Cyclone, November 1970. The greatest tropical system disaster of the last century occurred in Bangladesh in November 1970. Winds coupled with a storm surge killed between 300 000 and 500 000 people. These cyclones usually cause the most devastation, loss of life, and suffering in low-lying areas of Bangladesh and coastal India.

(b) Bangladesh Cyclone 02B, April 1991. Another cyclone struck the Chittagong region in Bangladesh in 1991, killing over 138 000 people and causing damage in excess of US$ 1.5 billion. The tropical cyclone devastated the coastal area south-east of Dacca with winds in excess of 200 km/h and a 6 m storm surge

(c) China typhoons, early half of last century. Several typhoons also struck the eastern China coast during the early half of the last century, causing great hardship. Deaths from some of the storms ran into the tens of thousands. For example, typhoons striking the China coast in August 1912 and August 1922 resulted in fatality counts of 50 000 and 60 000, respectively.

(d) Hurricane Mitch, November 1998. One of the strongest late-season hurricanes on record formed in the western Caribbean in October 1998. Although the system eventually weakened before landfall, its slow passage westward over the mountainous regions of Central America unleashed precipitation amounts estimated as high as 1.9 m. The resulting floods devastated the entire infrastructure of Honduras and also had a severe impact on other countries in the area. The final estimated death toll was 11 000, the greatest loss of life from a tropical system in the western hemisphere since 1780.

(e) Typhoon Vera, September 1958. This typhoon’s passage over Japan in 1959 caused Japan’s greatest storm disaster. The death toll reached nearly 5 000, with 1.5 million left homeless. Typhoon Vera dealt a staggering blow to Japan’s economy, with tremendous damage
to roads, bridges and communications from wind, floods and landslides.

(f) Typhoon *Thelma*, October 1991. *Thelma* was one of the most devastating tropical systems to affect the Philippines in the last century. Reports indicated that 6 000 people died as a result of catastrophic events, including dam failure, landslides and extensive flash flooding. The death toll exceeded that of the Mount Pinatubo eruption. The highest casualties occurred on Leyte Island, where widespread logging in recent years had stripped the hills above the port city bare of vegetation.

(g) Hurricane *Katrina*, August 2005. *Katrina* was the deadliest hurricane to hit the United States since 1928, killing more than 1 400 people. *Katrina* inundated 80 per cent of the city of New Orleans and caused damages of over US$ 70 billion.

Table 7.2 shows typhoon damages in North Central Viet Nam and Table 7.3 shows disaster impacts in the same area.

Losses from a single tropical cyclone may therefore run into the billions of dollars and such losses are forecast to rise due to the ever-increasing numbers of people living in coastal areas. For example, in 1998, El Niño-related weather phenomena caused US$ 6.6 billion in damages in Argentina, Peru and Ecuador, while Hurricane *Georges* alone caused US$ 2.1 billion in damages in the Dominican Republic, and Hurricane *Mitch* resulted in damages of US$ 2.4 billion in Honduras and Nicaragua (Charveriat, 2000).

In May 2002, the cyclone *Kesiny* hit Madagascar, affecting more than half a million people and leaving them homeless or in need of emergency food, shelter and drinking water. Up to 75 per cent of the crops were destroyed, 20 people died and 1 200 were injured (CIDI, 2002).

The cyclone on 17–18 October 1999 and the one following it on 29–30 October in Orissa, India, caused devastating damage. The second cyclone, with wind speeds of 270–300 km/h for 36 hours, was accompanied by torrential rain ranging from 400 to 867 mm over a period of three days. The two cyclones together severely affected around 19 million people in 12 districts (Roy et al., 2002). Sea waves reaching 7 m rushed 15 km inland. Some 2.5 million livestock perished and a total of 2.1 million ha of agricultural land was affected.

Table 7.2. Typhoon damages in North Central Viet Nam, 15° N to 20° N (Van Viet, 1999)

<table>
<thead>
<tr>
<th>Year</th>
<th>No. of deaths</th>
<th>Value of losses (US$ million)</th>
<th>Paddy fields submerged (in 1,000 ha)</th>
<th>Houses flooded (in 1,000)</th>
<th>No. of boats sunk</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>57</td>
<td>106.3</td>
<td>139</td>
<td>131</td>
<td>528</td>
</tr>
<tr>
<td>1996</td>
<td>499</td>
<td>720</td>
<td>590</td>
<td>829</td>
<td>741</td>
</tr>
<tr>
<td>1997</td>
<td>63</td>
<td>16</td>
<td>82</td>
<td>43</td>
<td>54</td>
</tr>
<tr>
<td>1998</td>
<td>214</td>
<td>104</td>
<td>461</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 7.3. Disaster impacts in North Central region of Viet Nam, 1979–1998 (Van Viet, 1999)

<table>
<thead>
<tr>
<th></th>
<th>Total killed</th>
<th>Typhoons</th>
<th>Floods</th>
<th>Flash floods</th>
<th>Tornadoes</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>%</td>
<td>No.</td>
<td>%</td>
<td>No.</td>
<td>%</td>
</tr>
<tr>
<td>People killed</td>
<td>2 642</td>
<td>100</td>
<td>1 769</td>
<td>67</td>
<td>592</td>
</tr>
<tr>
<td>Houses collapsed</td>
<td>417 941</td>
<td>100</td>
<td>306 646</td>
<td>73</td>
<td>46 829</td>
</tr>
<tr>
<td>Paddy crop unharvested</td>
<td>399 531</td>
<td>100</td>
<td>253 775</td>
<td>64</td>
<td>52 583</td>
</tr>
<tr>
<td>Money loss (in 1 000 million vnd)</td>
<td>2 736</td>
<td>100</td>
<td>1 890</td>
<td>69</td>
<td>728</td>
</tr>
</tbody>
</table>
The effects of droughts, famines and heatwaves are much harder to quantify. The effects are devastating and impacts can span just a couple of months or stretch to a decade or more. Some historical drought/famines with loss of life are described below.

Numerous drought-related disasters have occurred over the Asian mainland during the last century. The most notable Asian droughts include:

(a) Indian drought of 1900 – between 250 000 and 3.25 million people died due to drought, starvation and disease;
(b) Chinese famine of 1907 – Over 24 million perished from starvation;
(c) Chinese famine from 1928 to 1930 – Over 3 million perished in north-west China;
(d) Chinese famine of 1936 – 5 million Chinese died in what is called the “New Famine”;
(e) Chinese drought from 1941 to 1942 – Over 3 million perished from starvation;
(f) Indian drought from 1965 to 1967 – Over 1.5 million perished in India;
(g) Drought in the Soviet Union (Ukraine and Volga regions) from 1921 to 1922 – between 250 000 and 5 million perished.


The American Dust Bowl of the 1930s lasted almost an entire decade and covered virtually the entire United States Great Plains. The Dust Bowl drought and associated high temperatures, strong winds, duststorms and insect infestations resulted in an agricultural depression that further aggravated the country’s Great Depression of the 1930s, affecting the livelihood and health of millions of people. The rainfall deficits that caused the Dust Bowl are the result of natural cycles of the atmosphere in the Great Plains. In fact, paleoclimatic evidence points to the occurrence of multi-year droughts in the Great Plains at a rate of one or two per century, with even longer droughts, or mega-droughts that last for many decades, occurring at a rate of one to three per thousand years (Overpeck, 2000). Although the rainfall deficits during the Dust Bowl years were caused by natural variability of the atmosphere, poor land management and agricultural practices during the 1920s further aggravated the situation by making the Great Plains more vulnerable to wind erosion, depletion of soil moisture and nutrients, and drought. The Dust Bowl event highlights the importance of assessing risk on a regional basis and putting in place land management and agricultural practices that will help mitigate the possibly devastating effects of drought (Warrick, 1980).

Severe and damaging tornadoes are mainly a North American phenomenon. The United States is the “tornado capital of the world” and has more tornadoes annually than any other country on the globe. Two notable outbreaks include the “Super Tornado Outbreak of 1974” (315 deaths) and the “Tri-State Tornado of 1925” (695 deaths).

A blizzard in Iran in February 1972 ended a four-year drought, but the weekend cold and snow caused the deaths of approximately 4 000 people.

The European storm surge during the winter months of January and February 1953 was one of Europe’s greatest natural disasters. Violent winter storms caused storm surges, which resulted in flooding in areas of the Netherlands and the United Kingdom. Almost 2 000 people perished due to these storm surges.

The Great Smog of London occurred in December 1952. Stagnant air due to an inversion combined with industrial and residential emissions to create an air pollution episode without parallel in this century. Casualties, attributed to the poisonous air, rose to 4 000, with 4 000 additional fatalities due to related causes.

Significant El Niño effects were seen in 1982 and 1983. El Niño and La Niña events tend to alternate within every three to seven years. The time from one event to the next can vary from 1 to 10 years, however. The economic impacts of the 1982–1983 El Niño were huge. Along the west coast of South America, the losses exceeded the benefits. The fishing industries in Ecuador and Peru suffered heavily when their anchovy harvest failed and their sardines unexpectedly moved south into Chilean waters. Changed circulation patterns also steered tropical systems off their usual tracks to islands such as Hawaii and Tahiti, which are usually unaffected by such severe weather. They caused the monsoon rains to fall over central parts of the Pacific Ocean instead of the Western Pacific. The lack of rain in the Western Pacific led to droughts and disastrous forest fires in Indonesia and Australia. Winter storms battered Southern California and caused widespread flooding across the southern United States, while unusually mild weather and a lack of snow was evident across much of the central and north-eastern portion of the United States. Overall, the loss to the world economy in 1982–1983 as a result of the climate...
7.8 DEVELOPING AND IMPLEMENTING POLICY TO REDUCE THE RISK AND IMPACT OF EXTREME EVENTS

The Typhoon Committee, the first of the five tropical cyclone regional bodies, was established under the auspices of WMO and the United Nations Economic and Social Commission for the Pacific (ESCAP) in 1968. The Committee continues to work towards the reduction of damage caused by typhoons and floods in the western North Pacific and South China Sea region. In its more than 40 years of existence, substantial advances have been made by National Meteorological Centres in the region towards meeting their responsibilities for providing warnings of tropical cyclones and storms surges (Lao, 2006).

Public and private-sector institutions servicing government and rural communities have a role to play in helping rural producers cope with climate variability and extreme climate and weather events in terms of policy and implementation, and in preparing for and mitigating the impacts of these events. Specific ways in which they can be of assistance include:

(a) Development of policy, implementation plans and infrastructure (related to meteorology, agriculture and natural resources);
(b) Ensuring ready access to global, regional, national and local warning systems and broad dissemination of warnings (the tsunami in December 2004 is a case in point);
(c) Understanding climate variability, preparing for and managing drought at national and regional levels, and mitigating the impact of drought, flood and wildfire (public awareness, training and education).

Drought planning is an integral part of drought policy (Wilhite, 1991, 2005). A generic set of planning objectives has been developed that could be considered as part of a national, state/provincial or regional planning effort (Wilhite, 2000). These include:

(a) Establishing criteria for declaring drought and triggering various mitigation and response activities;
(b) Providing an organizational structure that assures information flow among and within levels of government, as well as with non-governmental organizations, and defining the duties and responsibilities of all agencies with respect to drought;
(c) Maintaining a current inventory of drought assistance and mitigation programmes used in assessing and responding to drought emergencies, and providing a set of appropriate action recommendations;
(d) Identifying drought-prone areas and vulnerable sectors, population groups and environments;
(e) Identifying mitigation actions that can be taken to address vulnerabilities and reduce drought impacts;
(f) Providing a mechanism to ensure timely and accurate assessment of drought’s impacts on agriculture, livestock production, industry, municipalities, wildlife, health, and other areas, as well as specific population groups;
(g) Collecting, analysing and disseminating drought-related information in a timely and systematic manner;
(h) Keeping the public informed of current conditions and mitigation and response actions by providing accurate, timely information to media in print and electronic form;
(i) Establishing a set of procedures to continually evaluate, exercise or test the plan, and to periodically revise the plan so that it remains responsive to the needs of the people and government ministries.

Drought plans in which mitigation is a key element should have three principal components: monitoring, early warning, and prediction; risk and impact assessment; and mitigation and response. A description of each of these components follows.

(a) Production monitoring – remote-sensing, ground validation field observations, agronomic models;
(b) Policies to promote land care and minimize soil erosion, weed invasion and salinization; likewise with water – safeguarding flows, minimizing algal blooms, deciding whether to dam or not to dam, improving water use efficiency, and the like;
(c) Mitigating the effects of extreme events – for instance, by implementing a policy to limit grazing pressure and wind and water erosion, promoting the use of seasonal forecasts, promoting on-farm self-reliance and risk management, cultivating drought-resistant plants, and so on.

Owing to major advances in technology and notable progress in scientific understanding, the accuracy and timeliness of weather and flood warnings have significantly improved over the
last few decades. The accuracy of forecasts of large-scale weather patterns for seven days is today the same as those for two days in advance only 25 years ago (Obasi, 1998). Forecasts up to 10 days are nowadays showing remarkable accuracy, and there is now the capability to provide some skilful information on expected weather patterns several seasons in advance. For example, early information on El Niño episodes is now allowing advanced national planning, with considerable advantage in many sectors of the economy, such as in water resources management, tourism, and fisheries and agricultural production (Obasi, 1996). In the case of the 1997–1998 El Niño event, advances in El Niño-related science and in monitoring the sea surface temperatures in the Pacific Ocean enabled scientists to predict its formation further in advance than any of the previous events. With recent developments in communication technology, including the use of the Internet, information on El Niño was disseminated in a rapid and timely manner throughout the world. This enabled many governments to take appropriate measures and stimulated international cooperation and integrated efforts to address the associated impacts.

The accuracy of tropical cyclone track forecasts and the timeliness of warnings have also been steadily improving in the past few years. Global efforts, especially within the context of the WMO Tropical Cyclone Programme, have resulted in a noticeable improvement in the warning systems in many parts of the world and have helped to save many lives and limit property damage. For example, the decrease in the death toll in Bangladesh caused by similar tropical cyclones in 1991 and 1994, from about 130 000 to 500, respectively, was attributed by government sources in large part to improvements in early warning and evacuation systems (Obasi, 1997).

The evolving Internet has proven to be an invaluable tool in facilitating the exchange of global and regional climate monitoring and prediction information. Many users require assistance in the selection, interpretation and application of appropriate information, however. Effective early warning systems, coupled with community education for protective action, have reduced the potential human loss from these events. Because they represent disaster risk, floods also lend themselves well to both structural and legislative preparedness measures (land-use laws, zoning plans and urbanization). Preparedness in terms of life-saving techniques and evacuation plans should be promoted actively in these high-risk zones (Sivakumar, 2005).

7.9 ON-FARM PLANNING TO REDUCE THE RISK AND IMPACT OF EXTREME EVENTS

Stigter et al. (2003) have emphasized the importance of on-farm preparedness.

7.9.1 Crop selection and cropping sequence

The method of selecting crop varieties based on agroclimatic requirements consists of comparing, on the one hand, the regional availability of agroclimatic resources and, on the other, the climatic requirements of certain crop varieties on the basis of which the selection is to be made. The selection of varieties of plants at local or regional levels should be based on agroclimatic studies carried out to determine the climatic requirements of the different crop varieties. Agroclimatic characterization of crops includes solar radiation, temperature, humidity and photoperiod, among the most important climatological factors.

There are large differences in sensitivity to frost damage among crops. On a farm scale, frost-sensitive species should, if at all, be planted on middle slopes. Valley floors and locations where cold air can flow should be avoided. Planting deciduous crops on slopes facing away from the sun delays springtime bloom and often provides protection. Subtropical trees are best planted on slopes facing the sun where the soil and crop can receive and store more direct energy from sunlight. Rootstock often influences how early deciduous fruit trees flower and therefore potential frost damage. On evergreen fruit trees, rootstock may be also related to frost hardiness. For example, navel oranges are more frost hardy when grown on trifoliate rootstock than they are when grown on sweet orange rootstock (FAO, 2005).

7.9.2 Selection of varieties

Intraspecific variability for resistance to drought, frost and heat stress is often large. Hence, there is often room for plant breeding for resistance to these risks. For example, in citrus growing, frost may not be avoidable; however, selecting for tolerance to sub-zero temperatures is a valuable option (Ikeda, 1982). The selection of an appropriate variety for a
given area should take into account the frost hardiness of the varieties in the species.

7.9.3 **Land preparation**

As far as frost protection is concerned, deep ploughing has about the same effect as shallow ploughing on heat transfer, since the layer of soil that is involved in heat transfer to the surface by conduction, on a daily basis, is not thicker than about 0.3 m.

With regard to tillage methods, cultivation should be avoided during periods when frost is likely to occur, because it increases porosity of the soil and may contribute to more evaporation in the top layer. Since air is a poor heat conductor, when compared to soil matrix and water, cultivation reduces the amount of heat stored in the soil during the day and transferred to the surface during the cold night. If cultivation cannot be avoided, a roll should be used to compact the soil to counteract the increase in air space generated by the mobilization of the soil.

7.9.4 **Crop management**

With regard to irrigation management from a frost protection perspective, soils should be moist before a frost period is likely to occur. Hence, irrigation one or two days in advance of a frost night brings the soil to near field capacity, which results in an increased soil heat flux during a subsequent frost night. Various irrigation methods are also used during a frost night (namely, as active methods), with the objective of using the heat liberated as the water cools and freezes. For details see FAO (2005).

In terms of fertilizer management, the use of fertilizers, and in particular nitrogen, accelerates crop growth and helps crops develop profuse root systems, thus making plants more capable of withstanding drought. The time and method of application are important. Nitrogen and other nutrients are known to affect frost sensitivity. In general, nitrogen may reduce frost resistance, and phosphorus and potassium are likely to increase it (WMO, 1978). New growth is more sensitive to frost, because it tends to have less solute content in the tissues. Therefore, management should minimize new growth in frost-prone periods. Nitrogen may result in increased frost resistance, however, if the biophysical effect of a bigger canopy offsets the physiological effect (FAO, 2005).

As for weed management, during a dry spell or under water stress conditions, weed competition is a problem for crops because weeds also use the little moisture that is available. In dryland crops sown in line, weed control through interculture operations is found to be beneficial under water stress conditions. Cover crops and weeds in orchards tend to trap air and thus reduce heat diffusivity of the ground. Hence, under these circumstances, minimum temperature is lower and frost risk increases. Mowing the plants, without removing them, or cultivation to remove them, has little if any effect on minimum temperature. Spraying with herbicide has a substantial positive effect on minimum temperature, however. It is possible that the presence of cover crops or weeds has a negative effect on frost resistance that results from a higher concentration of ice-nucleation active (INA) bacteria that is known to occur on cover crops and weeds. Fruit trees, namely citrus and grapevines, are known to have lower INA bacteria concentrations (FAO, 2005).

Early or delayed harvesting is a practical method to avoid frost damage that many farmers adopt to ensure that crops are harvested before a frost period is likely to occur. This is in general feasible on small farms, but often impossible on larger ones.

7.9.5 **Pasture and livestock management**

7.9.5.1 **Preparing for and managing through drought**

An essential part of farming in a variable climate is anticipating and preparing for the next drought. This needs to be incorporated into a farm’s long-term management strategy, and a good manager should be cognizant of those factors that threaten the sustainability and long-term financial viability of the property.

At the farm level, it is essential that sustainable systems be developed and implemented to minimize the impact of drought on the soils and vegetation, and livestock need to be humanely cared for or disposed of as well. The well-being of farming families will also be enhanced through better financial and risk management. Although the threat of drought cannot be removed, its impact on the community and on soils, vegetation and livestock may be reduced.

Conditions conducive to soil erosion by wind and water are more prevalent in drought periods (Marshall, 1973). The area of bare ground within a pasture increases with stocking rate, particularly in adverse seasons (White et al., 1980). This is caused by the associated reduction in vegetative cover and the drying out of the surface soil. The decision to retain stock during drought may therefore intensify
the degradation of vegetative cover (Morley and Daniel, 1992). Wind velocity near the ground increases considerably when vegetation is removed. Further degradation can therefore follow, with soil erosion exacerbated by the action of wind or intensive drought-breaking rains on bare soil.

Self-reliant drought management is inextricably linked to the concept of economic and environmental sustainability. Rangelands and improved pastures should be managed so that degradation of soils and vegetation is minimized. This requires the choice of an appropriate long-term stocking rate and strategy for grazing management, destocking early in drought (Morley and Daniel 1992), and possibly planting perennial fodder trees. Only a nucleus of productive and breeding stock should be fed, and wethers and steers and the eldest age groups of breeding ewes and cows should be sold or destroyed, depending on the most profitable options. Failed crops can be harvested for grain, cut for hay or used for grazing.

7.9.5.1.1 Planning for management in the face of uncertainty (with respect to climate)

Budgeting is a vital part of managing risk and preparing for drought. At a minimum it involves planning for the year ahead based on assumptions of both an average or better season and a drought year, and then applying a probability to each. This can then be extended to a two- or even a five-year estimate of cash flow, possibly including a wider range of seasons. Where seasonal forecasts are being used, one can include the probability that a drought or an average or better season will be forecast, but then one must also include the probabilities that these forecasts will be perceived as being wrong (Table 7.4). It is essential that all possible outcomes be budgeted for in advance.

Meinke et al. (2003) point out, however, that management decisions based on seasonal forecasts will have positive outcomes in some years and negative outcomes in others. This should not be regarded as either a “win” or a “failure” of the strategy employed using seasonal forecasts, since each season or year is only a sample of one of a “not very well-defined distribution of possible outcomes”. They add that assessing the true value of this type of probabilistic information requires a comparison of results in each season against outcomes that would have been achieved in the absence of such information. A large part of the perceived problem in the use of seasonal forecasts appears to stem from the fact that as a consequence of the delivery of weather forecasts, prediction information was initially issued as a deterministic forecast. Murphy (1993) stresses the need for uncertainties that are inherent in judgements to be properly reflected in climate forecasts.

Financial strategies identified by Blackburn (1992) as leading to greater self-reliance are summarized in Table 7.5. When frost protection is likely to be necessary, the appropriate method(s) to be used must be selected based both on the physical and economic risk. An MS Excel application (FrostEcon.xls), programmed in VBA, was developed by FAO (2005) to help farmers anywhere in the world conduct the cost-effectiveness and risk analyses essential to making wise financial decisions concerning the adoption of frost protection methods.

<table>
<thead>
<tr>
<th>Table 7.4. Determining seasonal probabilities when seasonal forecasts are available</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forecast –</td>
</tr>
<tr>
<td>Good season –</td>
</tr>
</tbody>
</table>

7.9.5.1.2 Stocking rate and carrying capacity of the land

Long-term stocking rates should be both biologically and financially sustainable after allowing for drought (Morley, 1981; White 1987). Stocking rates that fail to sustain pastures or viable vegetation are not economically feasible in the long term. In this regard, the sustainability of agricultural systems in some areas may need to be reassessed, given the underlying capacity of the land.

7.9.5.1.3 Adaptation of livestock

A variety of management adaptations are available for livestock production systems. For example, Hahn and Mader (1997) outline a series of proactive management countermeasures that can be taken during heatwaves (for instance, shades and/or sprinklers) to reduce excessive heat loads. Historical success in coping with climate variability suggests that livestock producers are likely to adjust to climate change successfully. Johnson (1965) provides examples from advances in genetics and breeding as related to the environment. These capabilities should allow adaptation to changing, less favourable circumstances associated with projected rates of climate change. Coping can entail significant dislocation costs for certain producers, however. For individual producers, uncertainties associated with potential climate change imply additional risks related to how and when to adapt current production practices (Lewandrowski and Schimmelpfennig, 1999).
Confidence in the foregoing projections of the ability of livestock producers to adapt their herds to the physiological stresses of climate change is difficult to judge. The general lack of simulations of livestock adaptation to climate change is problematic, and the absence of a well-developed livestock counterpart to crop modelling of adaptation assessments suggests a major methodological weakness. Hence, we give only low-to-moderate confidence in projections of successful livestock adaptability (IPCC, 2001).

7.10 SIGNIFICANCE OF CLIMATE CHANGE

7.10.1 Climate is always changing

Better understanding of weather and climate requires monitoring and analysis of the climate signals at different timescales. These include:

(a) The Madden–Julian (30–50 day) Oscillation, or Intraseasonal Oscillation, which increases the likelihood of rain every time it passes over northern Australia;

(b) The Quasi-Biennial Oscillation (QBO), a quasi-periodic stratospheric oscillation that affects the distribution of stratospheric ozone and monsoon precipitation, for example;

(c) The El Niño-Southern Oscillation (ENSO), a global coupled ocean–atmosphere phenomenon that has a cycle of about three to seven years and has profound effects on global climate;

(d) The Pacific Decadal Oscillation (PDO), a decadal oscillation of Pacific Ocean sea surface temperatures that affects climate in the northern hemisphere;

(e) A 50–80 year variability associated with the tilt of the Earth’s axis (hemispheric);

(f) Milankovitch cycles (ice ages; inter-glacial periods) based on variation of the Earth’s orbit around the sun.

The overriding certainty is that climate has always changed and will continue to change. Whether climate change is natural or anthropogenic is relevant here only in the context of the likely direction and rate of change. The important issue at stake is the capacity of farmers and ranchers to adapt the management of crops, rangeland and grassland ecosystems to a changing climate so as to minimize adverse consequences.

Climate change will include changes in rainfall, temperature and atmospheric CO₂ concentrations. For instance, in Australia, which has the highest climate variability of any continent in the world, comparable with Southern Africa, it is anticipated

<table>
<thead>
<tr>
<th>Table 7.5. Financial strategies to aid drought preparedness and management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-drought</td>
</tr>
<tr>
<td>Build up cash reserves during good years</td>
</tr>
<tr>
<td>Budget each year assuming both normal and drought years</td>
</tr>
<tr>
<td>Stabilize income through off-farm investments</td>
</tr>
<tr>
<td>Drought forecast</td>
</tr>
<tr>
<td>Budget for a long-range forecast that is either (a) right or (b) wrong</td>
</tr>
<tr>
<td>Unload prime or surplus livestock before prices drop</td>
</tr>
<tr>
<td>Identify least-cost feed supplements</td>
</tr>
<tr>
<td>Purchase fodder before its value increases</td>
</tr>
<tr>
<td>Budget to compare feeding and selling strategies</td>
</tr>
<tr>
<td>Sensitivity – drought duration, feed costs, stock prices</td>
</tr>
<tr>
<td>Evaluate alternative strategies, such as droving, agistment</td>
</tr>
<tr>
<td>Budget for selling all stock and investing off-farm</td>
</tr>
<tr>
<td>Drought</td>
</tr>
<tr>
<td>Minimize financial losses to facilitate post-drought recovery</td>
</tr>
<tr>
<td>Continue comparison of feeding and selling strategies</td>
</tr>
<tr>
<td>Consider raising capital by selling off-farm investments</td>
</tr>
</tbody>
</table>
that the most noticeable changes will be an increase in rainfall intensity and variability and an increased frequency of extreme high temperatures, with a likelihood of more severe droughts and a greater fire risk (Jones et al., 2000).

Some of the consequences of climate change are likely to be beneficial. For example, increased atmospheric CO$_2$ concentrations can offset the detrimental effects of drier seasons through increased water use efficiency and yields. For grassland systems, particularly those based on C$_4$ species, this can be reflected in higher carrying capacities and less variability in the stocking rate from year to year (Howden et al., 1999; Reyenga et al., 1999).

7.10.2 Adaptation to climate change

Knowledge of climate variability can assist in adapting to climate change. In eastern Australia there is a strong correlation between the Southern Oscillation Index in winter and spring and subsequent spring and summer rainfall (McBride and Nicholls, 1983; Stone et al., 1996; Nicholls, 1998). If producers stock their land in response to changes in the SOI, and if climate change leads to either drier or wetter summer seasons, they will ipso facto adjust their stocking rates accordingly (McKeon et al., 1993). This of course assumes that the prevailing relationship between the SOI and summer rainfall remains unchanged, which may not be the case (Walsh et al., 1999). Other indices such as sea surface temperatures in the equatorial Pacific and Indian oceans could similarly be used.

Climate may also change outside the range of previous experience, especially with regard to the severity and frequency of extreme conditions. Longer-term adaptation will require some foreknowledge of the nature of the climate change, not simply reliance on recent experience.
REFERENCES


Queensland Department of Primary Industries.


Larcher, W., 1982: *The Environmental, Economic and Social Significance of Drought*. Sydney, Angus and Robertson.


Roy, B.C., Mruthyunjaya and S. Selvarajan, 2002: Vulnerability to climate-induced natural disasters with special emphasis on coping strategies of the rural poor in Coastal Orissa, India. Paper presented at the UNFCCC COP 8, 23 October–1 November 2002, New Delhi, India.


FURTHER READING


