Drought monitoring and early warning:

concepts, progress and future challenges

Weather and climate information for
sustainable agricultural development

World
Meteorological
Organization
Weather • Climate • Water

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Cover illustration: Maasai tribesman walking through drought-stricken landscape, Kenya. © Jonathan and Angela (Getty Images)

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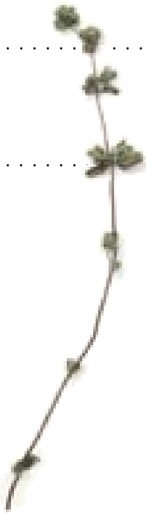

FOREWORD

Throughout the course of human history, drought has been a problem affecting our welfare and food security. Of all human endeavours, agriculture was perhaps the first sector for which humans recognized the strong relationships between crops and weather. Short-term rainfall deficits prompted early humans to find alternative food crops. However, even a single year with a severe drought during the rainy season resulted in crop failures, which most likely led to humans migrating to other areas. Therefore, in early human history, even limited droughts had large impacts.

M. Jarraud, Secretary-General

In recent times, short-term drought adaptation mechanisms have improved, but extended periods of drought are now the main concern for human welfare and food security. These periods of dryness, when coupled with other climatic factors, such as extreme rainfall and wind events or unsustainable agricultural and development patterns, can result in land degradation and, if unchecked, in increases in desert land areas or desertification. During the 1970s and 1980s, West Africa experienced an extended period of drought that led to widespread concern about these issues The aggregate impact of drought can be quite negative on the economies of developing countries, in particular. For example, GDP fell by 8 to 9 per cent in Zimbabwe and Zambia in 1992 and 4 to 6 per cent in Nigeria and Niger in 1984. Over 250 million people are directly affected by land degradation and desertification. In addition, some one billion people in over 100 countries are at risk. They include many of the world's poorest and most marginalized citizens. Hence, combating desertification is an urgent priority in the global efforts to ensure food security and the livelihoods of millions of people who inhabit the drylands.

As vulnerability to drought has increased globally, greater attention has been directed to reducing the risks associated with its occurrence through the introduction of planning to enhance operational capabilities such as climate and water supply monitoring and building institutional capacity, and mitigation measures that are aimed at reducing the impacts of drought.

Important components of effective drought management are improved drought monitoring and early warning systems. The fight against drought and desertification receives a high priority in WMO's Strategic Plan, particularly under the Agricultural Meteorology Programme, the Hydrology and Water Resources Programme and the Technical Cooperation Programme. WMO actively involves the National Meteorological and Hydrological Services (NMHSs), the regional and sub-regional meteorological centres and other bodies in the improvement of hydrological and meteorological networks for systematic observations and exchange and analysis of data. WMO also works closely with other UN agencies and international organizations to develop long-term strategies aimed at promoting meteorological and hydrological activities that contribute to better drought monitoring and use of medium- and long-range weather forecasts and to assist in the transfer of knowledge and technology.

At its 58th ordinary session, the United Nations General Assembly declared 2006 to be the International Year of Deserts and Desertification (IYDD). In doing so, the General Assembly underlined its deep concern for the exacerbation of desertification, particularly in Africa, and noted its far-reaching implications for the implementation of the Millennium Development Goals (MDGs), which are to be met by the year 2015. The IYDD presents a golden opportunity to convey the message strongly and effectively in the sense that issues of drought, land degradation and desertification are global problems that must be addressed. It also provides an impulse to strengthen the visibility and importance of the drylands issue on the international environmental agenda, while providing a timely reminder to the international community of the huge challenges that still lie ahead.

The United Nations Convention to Combat Desertification (UNCCD) and WMO have been longstanding partners in developing and promoting the issues related to drought monitoring, preparedness, mitigation, land degradation and desertification. As part of its implementation activities for IYDD, WMO has prepared this brochure to explain the various concepts and challenges of drought monitoring and early warning systems. This brochure also details the considerable progress that has been made on these issues in some drought-prone countries by highlighting several case studies from around the world.

I wish to thank Mr Donald Wilhite, Director of the National Drought Mitigation Center and Professor of the School of Natural Resources of the University of Nebraska (USA), for preparing this informative brochure. We hope that this document will be useful to countries looking to develop or enhance their own drought monitoring and early warning capabilities.

(M. Jarraud)
Secretary-General

INTRODUCTION

Drought is an insidious natural hazard characterized by lower than expected or lower than normal precipitation that, when extended over a season or longer period of time, is insufficient to meet the demands of human activities and the environment. Drought is a temporary aberration, unlike aridity, which is a permanent feature of climate. Seasonal aridity, that is, a well-defined dry season, also needs to be distinguished from drought, as these terms are often confused or used interchangeably. The differences need to be understood and properly incorporated in drought monitoring and early warning systems and preparedness plans.

Drought must be considered a relative, rather than an absolute, condition. It occurs in both high and low rainfall areas and virtually all climate regimes. Drought is often associated only with arid, semi-arid and sub-humid regions by scientists, policymakers and the public. In reality, drought occurs in most countries, in both dry and humid regions. Drought is a normal part of climate, although its spatial extent and severity will vary on seasonal and annual timescales. In many countries, such as Australia, China, India and the United States of America, drought occurs over a portion of the country each year. Owing to the frequent occurrence of drought and the profound impacts associated with it, governments should devote more attention to the development of a national strategy or policy to reduce its economic, social and environmental consequences. A critical component of that strategy is a comprehensive drought monitoring system that can provide early warning of drought's onset and end, determine its severity and deliver that information to a broad clientele in many climate- and water-sensitive sectors in a timely manner. With this information, the impacts of drought can be reduced or avoided in many cases.

Drought is a regional phenomenon and its characteristics differ from one climate regime to another. A few examples of the contrasting temperature and precipitation regimes of various regions are shown in Figure 1. Drought occurs in each of these locations, but characteristics such as frequency and duration vary appreciably. New Delhi's precipitation pattern is distinctly monsoonal, with maximum precipitation occurring from June to October, with the greatest concentration in July, August and September. Tunis has a distinctly Mediterranean-type (dry summer) climate regime. Nairobi's precipitation distribution is distinctly bi-modal, with peak rainfall expected from March through May and a second concentration in November and December. London's precipitation is evenly distributed throughout the year. In each example, a significant departure from these regimes for an extended period of time will result in impacts in climate- and water-sensitive sectors. Impacts are also

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regional in nature, reflecting exposure to the hazard and the vulnerability of society to extended periods of precipitation deficits. Impacts are a measure of vulnerability. Risk is a product of exposure to the hazard and societal vulnerability.

Drought by itself is not a disaster. Whether it becomes a disaster depends on its impact on local people, economies and the environment and their ability to cope with and recover from it. Therefore, the key to understanding drought is to grasp its natural and social dimensions. The goal of drought risk management is to increase society's coping capacity, leading to greater resilience and a reduced need for government or donor interventions in the form of disaster assistance. Drought monitoring and early warning are major components of drought risk management.

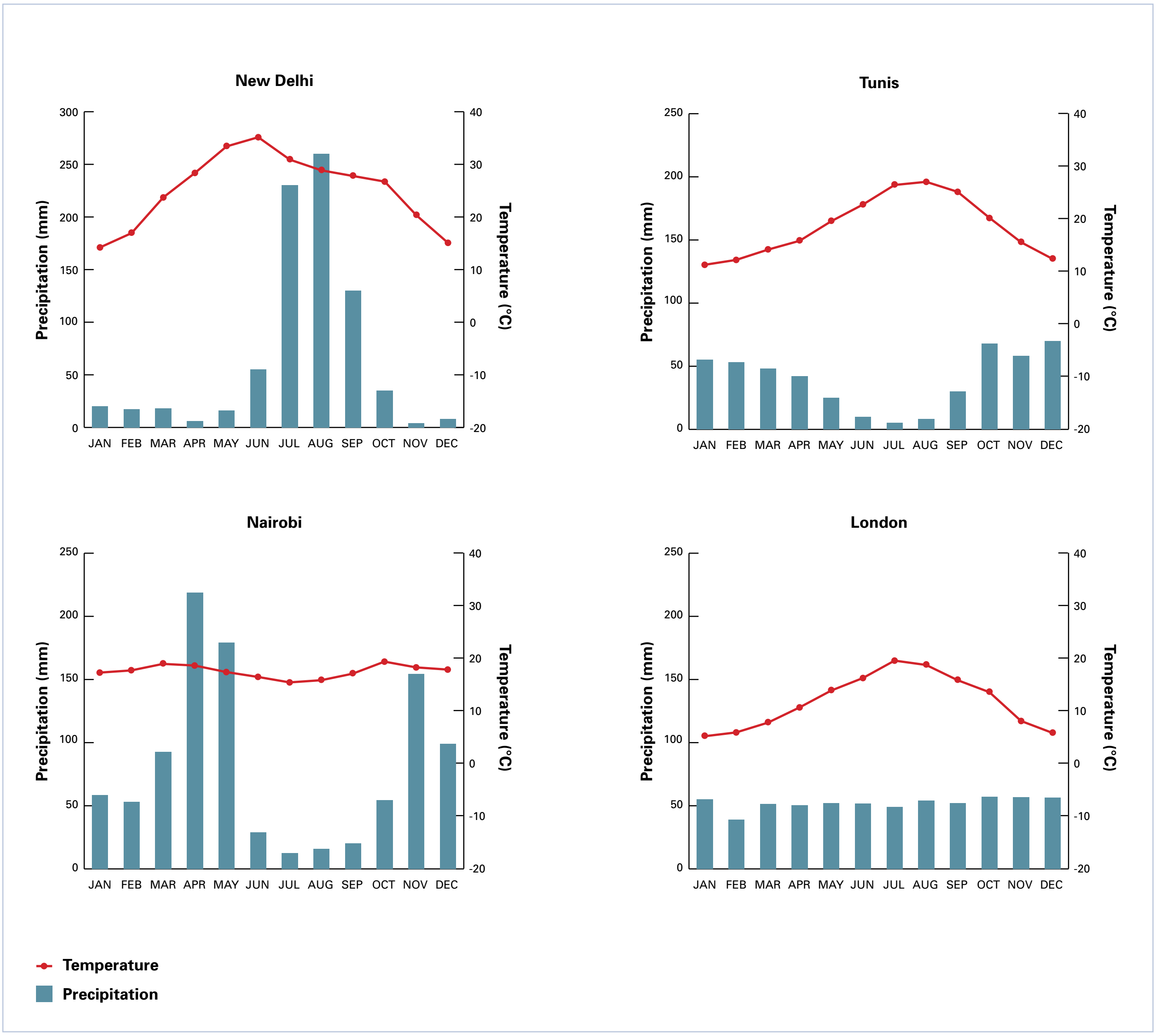

Figure 1. Climographs illustrating monthly temperature and precipitation regimes for New Delhi, Tunis, Nairobi and London. (Source: National Drought Mitigation Center, University of Nebraska–Lincoln, USA)

DROUGHT AS A HAZARD: CONCEPTS AND DEFINITIONS

Drought differs from other natural hazards in various ways. Drought is a slow-onset natural hazard that is often referred to as a creeping phenomenon. It is a cumulative departure from normal or expected precipitation, that is, a long-term mean or average. This cumulative precipitation deficit may build up quickly over a period of time, or it may take months before the deficiency begins to appear in reduced stream flows, reservoir levels or increased depth to the groundwater table. Owing to the creeping nature of drought, its effects often take weeks or months to appear (Figure 2). Precipitation deficits generally appear initially as a deficiency in soil water; therefore, agriculture is often the first sector to be affected.

It is often difficult to know when a drought begins. Likewise, it is also difficult to determine when a drought is over and according to what criteria this determination should be made. Is an end to drought heralded by a return to normal precipitation and, if so, over what period of time does normal or above normal precipitation need to be sustained for the drought to be declared officially over? Since drought represents a cumulative precipitation deficit over an extended period of time, does the precipitation deficit need to be erased for the event to end? Do reservoirs and groundwater levels need to return to normal or average conditions? Impacts linger for a considerable period of time following the return of normal precipitation. Therefore, is the end of drought signalled by meteorological or climatological factors, or by the diminishing negative impact on human activities and the environment?

Another factor that distinguishes drought from other natural hazards is the absence of a precise and universally accepted definition. There are hundreds of definitions, adding to the confusion about the existence of drought and its degree of severity. Definitions of drought should be region and application specific or impact specific. Droughts are regional in extent and, as previously stated, each region has specific climatic characteristics. Droughts that occur in the North American Great Plains will differ from

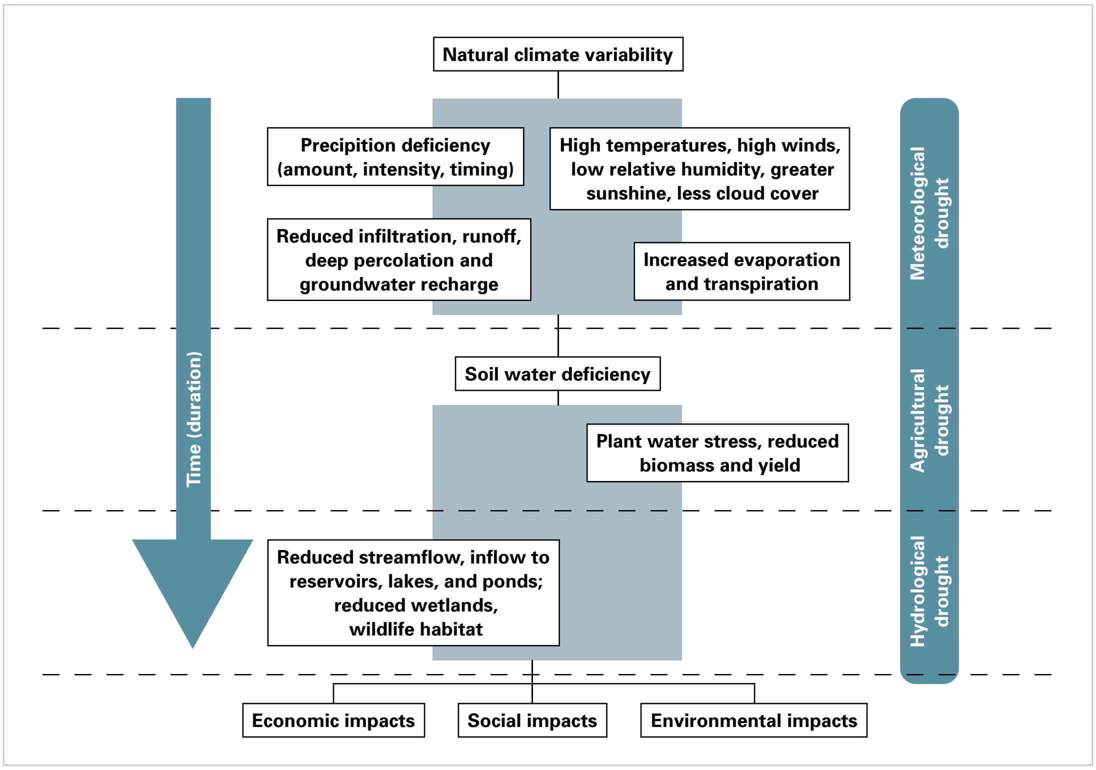

Figure 2. Sequence of drought occurrence and impacts for commonly accepted drought types. All droughts originate from a deficiency of precipitation or meteorological drought but other types of drought and impacts cascade from this deficiency. (Source: National Drought Mitigation Center, University of Nebraska–Lincoln, USA)

CARLO SCHERER

those in Northeast Brazil, southern Africa, Western Europe, eastern Australia or the North China Plain. The amount, seasonality and form of precipitation differ widely between each of these locations.

Temperature, wind and relative humidity are also important factors to include in characterizing drought from one location to another. Definitions also need to be application specific because drought impacts will vary between sectors. Drought conjures different meanings for water managers, agricultural producers, hydroelectric power plant operators and wildlife biologists. Even within sectors, there are many different perspectives of drought because impacts may differ markedly. For example, the effects of drought on crop yield may vary considerably for maize, wheat, soybeans and sorghum because they are planted at different times during the growing season and do not have the same water requirements and sensitivities to water and temperature stress at various growth stages.

Drought impacts are non-structural and extend over a larger geographical area than damages that result from other natural hazards such as floods, tropical storms and earthquakes. This, combined with drought's creeping nature, makes it particularly challenging to quantify impacts and even more challenging to provide disaster relief for drought than for other natural hazards. These characteristics have hindered the development of accurate, reliable and timely estimates of the severity and impacts, such as drought early warning systems and ultimately, the formulation of drought preparedness plans. Similarly, it is difficult for disaster officials tasked with responding to drought to deal with the large spatial coverage usually associated with its occurrence.

TYPES OF DROUGHT

Droughts are commonly classified by type as meteorological, agricultural, hydrological and socio-economic.

Meteorological drought is usually defined by a precipitation deficiency threshold over a predetermined period of time. The threshold chosen, such as 75 per cent of normal precipitation, and duration period, for example, six months, will vary by location according to user needs or applications. Figure 3 illustrates three characterizations of drought for three different countries based on precipitation departures from normal, deciles and the Standardized Precipitation Index (SPI). Meteorological drought is a natural event and results from multiple causes, which differ from region to region. Agricultural, hydrological and socio-economic drought, however, place greater emphasis on the human or social aspects of drought, highlighting the interaction or interplay between the natural characteristics of meteorological drought and human activities that depend on precipitation to provide adequate water supplies to meet societal and environmental demands.

Agricultural drought is defined more commonly by the availability of soil water to support crop and forage growth than by the departure of normal precipitation over some specified period of time. There

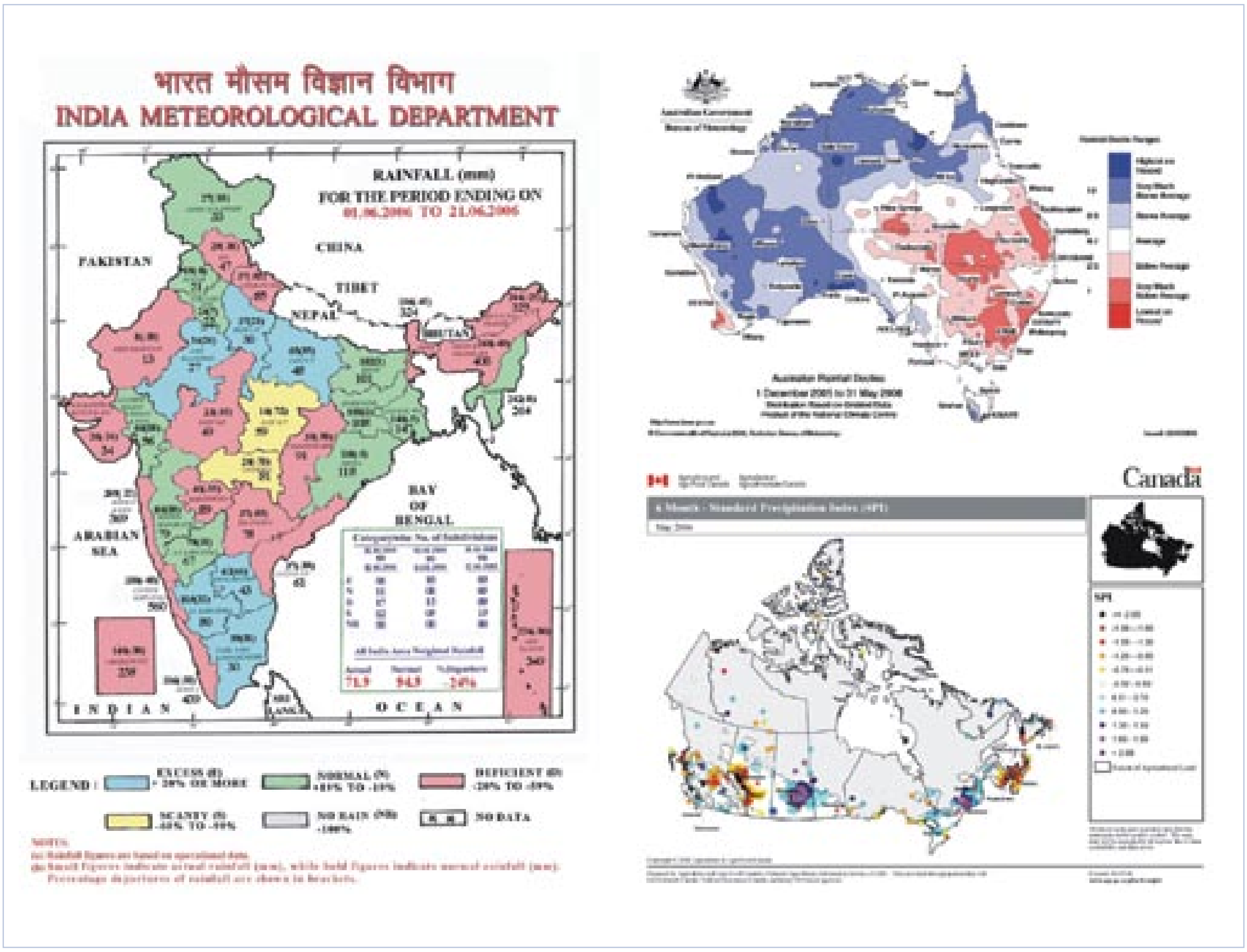

Figure 3. Meteorological drought expressed as percentage departure from normal precipitation for India, precipitation deciles for Australia and the Standardized Precipitation Index for Canada. (Sources: Indian Meteorological Department, Australian Bureau of Meteorology and Prairie Farm Rehabilitation Administration and Agriculture Canada, respectively)

is no direct relationship between precipitation and infiltration of precipitation into the soil. Infiltration rates vary, depending on antecedent moisture conditions, slope, soil type and the intensity of the precipitation event. Soil characteristics also differ: some soils have a high water-holding capacity while others do not. The latter are more prone to agricultural drought.

Hydrological drought is even further removed from the precipitation deficiency since it is normally defined by the departure of surface and subsurface water supplies from some average condition at various points in time. Like agricultural drought, there is no direct relationship between precipitation amounts and the status of surface and subsurface water supplies in lakes, reservoirs, aquifers and streams because these hydrological system components are used for multiple and competing purposes, such as irrigation, recreation, tourism, flood control, transportation, hydroelectric power production, domestic water supply, protection of endangered species and environmental and ecosystem management and preservation. There is also a considerable time lag between departures of precipitation and the point at which these deficiencies become evident in surface and subsurface components of the hydrologic system. Recovery of these components is slow because of long recharge periods for surface and subsurface water supplies. In some drought-prone areas, such as the western United States, snow pack accumulated during the winter months is the primary source of water during the summer. Reservoirs increase the resilience of this region to drought because of their ability to store large amounts of water as a buffer during single- or multi-year drought events.

Socio-economic drought differs markedly from the other types of drought because it reflects the relationship between the supply and demand for some commodity or economic good, such as water, livestock forage or hydroelectric power, that is dependent on precipitation. Supply varies annually as a function of precipitation or water availability. Demand also fluctuates and is often associated with a positive trend as a result of increasing population, development or other factors.

The interrelationship between these types of drought is illustrated in Figure 4. Agricultural, hydrological and socio-economic drought occur less frequently than meteorological drought because impacts in these sectors are related to the availability of surface and subsurface water supplies. It usually takes several weeks before precipitation deficiencies begin to produce soil moisture deficiencies leading to stress on crops, pastures and rangeland. Continued dry conditions for several months at a time bring about a decline in stream flow and reduced reservoir and lake levels and, potentially, a lowering of the groundwater table. When drought conditions persist for a period of time, agricultural, hydrological and socio-economic drought occur, producing associated impacts. During drought, not only are inflows to recharge surface and subsurface supplies reduced but demand for these resources increases dramatically as well. As shown in Figure 4, the direct linkage between the main types of drought and precipitation deficiencies is reduced because water availability in surface and subsurface systems is affected by how these systems are managed. Changes in the management of these water supplies can either reduce or aggravate the impacts of drought. For example, the adoption of appropriate tillage practices and planting more drought-resistant crop varieties can diminish the impact of drought significantly by conserving soil water and reducing transpiration.

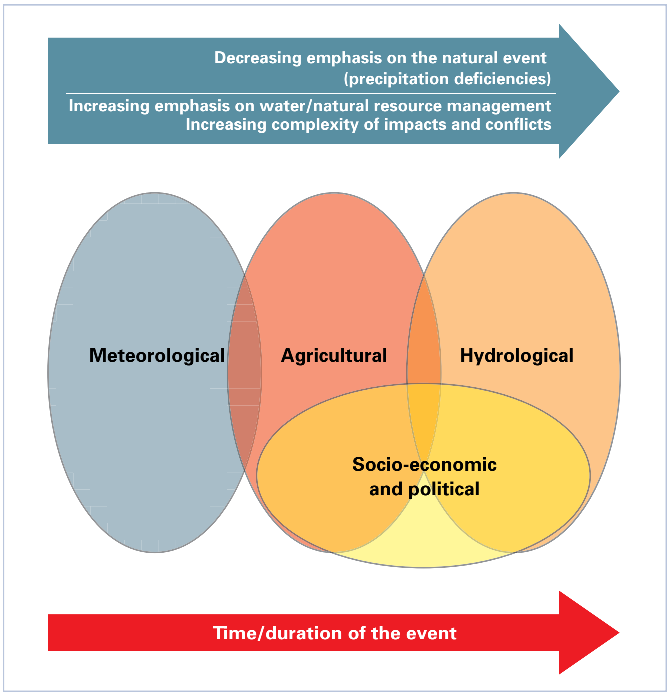

Figure 4. Interrelationships between meteorological, agricultural, hydrological and socio-economic drought. (Source: National Drought Mitigation Center, University of Nebraska–Lincoln, USA)

CHARACTERIZING DROUGHT AND ITS SEVERITY

Droughts have three distinguishing features: intensity, duration and spatial coverage. Intensity refers to the degree of the precipitation shortfall and/or the severity of impacts associated with the shortfall. It is generally measured by the departure from normal of a climatic parameter such as precipitation, an indicator such as the reservoir level or an index such as SPI.

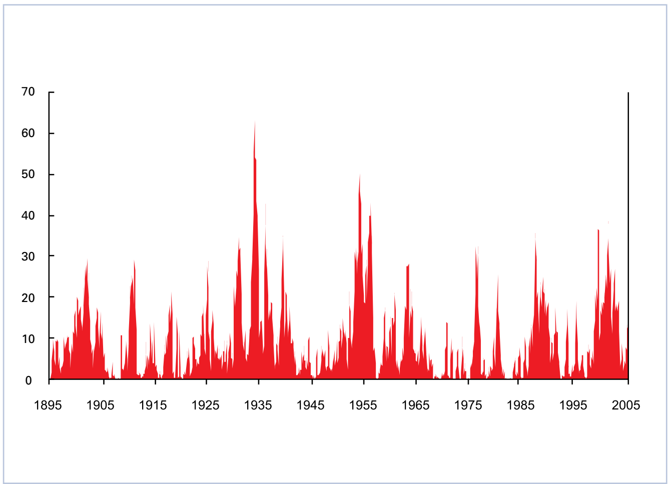

Figure 5. Percentage of the United States affected by severe to extreme drought, January 1895 to May 2006.
(Source: National Drought Mitigation Center, University of Nebraska–Lincoln, USA; based on data from the National Climatic Data Center/NOAA)

Another essential characteristic of drought is its duration. Droughts can develop quickly in some climatic regimes, but usually require a minimum of two to three months to become established. Once a drought begins, it can persist for months or years. The magnitude of drought impacts is closely related to the timing of the onset of the precipitation shortage, its intensity and the duration of the event. For example, a dry winter may have few impacts in many middle latitude, temperate climates because of the reduced demand for water during those months. Developing a better understanding of the frequency, duration and spatial extent of drought from the paleo-record, for example, tree rings or lake sediments, can be very instructive because it provides planners with critically important information from periods outside of the instrumental period of record.

Droughts also differ in their spatial characteristics. The areas affected by severe drought evolve gradually, and regions of maximum intensity, such as epicentres, shift from season to season and year to year in the event of multi-year droughts. In larger countries, such as Brazil, China, India, the United States or Australia, drought would rarely, if ever, affect the entire country. During 1934, one of the most severe drought years in United States' history, 65 per cent of the country was affected by severe or extreme drought (Figure 5). That was the maximum spatial extent of drought between 1895 and 2005.

PIERRE GAZIN (IRD)

THE CHALLENGES OF DROUGHT MONITORING AND EARLY WARNING

A drought early warning system is designed to identify climate and water supply trends and thus to detect the emergence or probability of occurrence and the likely severity of drought. This information can reduce impacts if delivered to decision makers in a timely and appropriate format and if mitigation measures and preparedness plans are in place. Understanding the underlying causes of vulnerability is also an essential component of drought management because the ultimate goal is to reduce risk for a particular location and for a specific group of people or economic sector.

There are numerous natural drought indicators that should be monitored routinely to determine the onset and end of drought and its spatial characteristics. Severity must also be evaluated on frequent time steps. Although all types of droughts originate from a precipitation deficiency, it is insufficient to rely solely on this climate element to assess severity and resultant impacts because of factors identified previously. Effective drought early warning systems must integrate precipitation and other climatic parameters with water information such as stream flow, snow pack, groundwater levels, reservoir and lake levels, and soil moisture into a comprehensive assessment of current and future drought and water supply conditions.

JEAN-PIERRE MONTOROI (IRD)

Monitoring drought presents some unique challenges because of its distinctive characteristics. Some of the most prominent challenges are as follows:

- Meteorological and hydrological data networks are often inadequate in terms of the density of stations for all major climate and water supply parameters. Data quality is also a problem because of missing data or an inadequate length of record;
- Data sharing is inadequate between government agencies and research institutions, and the high cost of data limits their application in drought monitoring, preparedness, mitigation and response;
- Information delivered through early warning systems is often too technical and detailed, limiting its use by decision makers;
- Forecasts are often unreliable on the seasonal timescale and lack specificity, reducing their usefulness for agriculture and other sectors;
- Drought indices are sometimes inadequate for detecting the early onset and end of drought;
- Drought monitoring systems should be integrated, coupling multiple climate, water and soil parameters and socio-economic indicators to fully characterize drought magnitude, spatial extent and potential impact;
- Impact assessment methodologies, a critical part of drought monitoring and early warning systems, are not standardized or widely available, hindering impact estimates and the creation of regionally appropriate mitigation and response programmes;
- Delivery systems for disseminating data to users in a timely manner are not well developed, limiting their usefulness for decision support.

INTEGRATED DROUGHT MONITORING AND DELIVERY: THE WAY FORWARD

A comprehensive and integrated approach is required to monitor drought more effectively and provide early warning. The collection of climatic and hydrologic data is fragmented between many agencies or ministries in most countries. Often these data are not reported in a timely fashion. Automating the data collection process can substantially improve the timeliness and reliability of drought monitoring and early warning systems.

The analysis of climate and water data is most effective when it is coordinated under a single authority. This authority could be an agency or ministry or an inter-agency authority and would be responsible for analysing data and producing useful end products or decision-support tools for delivery to end users. Stakeholders must be involved from the early stages of product development to ensure that the information will serve their varied timing and content needs. A delivery system should reflect the needs of this diverse clientele. The Internet is the most cost-effective way to deliver information, but it is inappropriate in many settings. A combination of Internet, extension, print and electronic media delivery may be required in many instances.

To date, monitoring and early warning systems have been based on a single indicator or climatic index. Recent efforts to improve drought monitoring and early warning in the United States and other countries have provided new early warning and decision-support tools and methodologies in support of drought preparedness planning and policy development. The lessons learned can be helpful models for other countries to follow as they try to reduce the impacts of future droughts. An effective monitoring, early warning and delivery system continuously tracks key drought and water supply indicators and climate-based indices and delivers this information to decision makers. This allows for the early detection of drought conditions and timely triggering of mitigation and emergency response measures, the main ingredients of a drought preparedness plan.

Until recently, a comprehensive, integrated drought monitoring, early warning and delivery system did not exist in the United States. Between 1996 and 2006, severe droughts have been widespread in their occurrence and have affected most of the country, reinforcing the need for a more highly integrated monitoring and early warning system. During this period, many regions have been affected over several consecutive years and on more than one occasion. Some regions of the country have experienced as many as five to seven consecutive years of drought. These drought events have highlighted the deficiencies of the nation's drought monitoring efforts and the need to develop a more coordinated approach that would make optimum use of the Internet for data sharing and analysis, communication and product delivery. In 1999 the National Oceanic and Atmospheric Administration (NOAA), the United States Department of Agriculture (USDA) and the National Drought Mitigation Center (NDMC) at the University of Nebraska–Lincoln formed a partnership aimed at improving the coordination and development of new drought monitoring tools. The United States Drought Monitor (USDM) became an operational product on 18 August 1999. USDM is maintained on the NDMC website (http://www.drought.unl.edu/index.htm), which has become a web-based portal for drought and water supply monitoring (Figure 6).

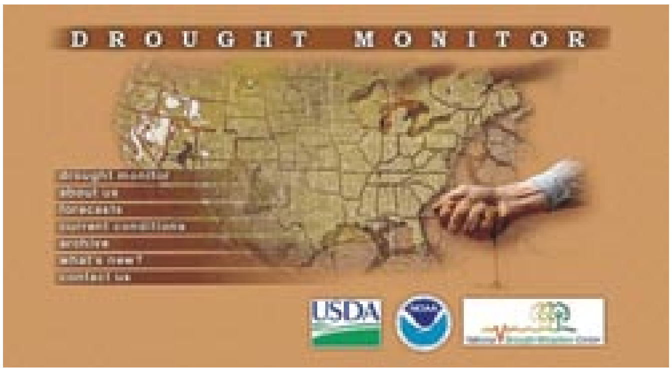

Figure 6. US Drought Monitor website. (Source: National Drought Mitigation Center, University of Nebraska–Lincoln, USA, http://www.drought.unl.edu/dm)

USDM successfully integrates information from multiple parameters—climate indices and indicators—and sources to assess the severity and spatial extent of drought in the United States on a weekly basis. It is a blend of objective analysis and subjective interpretation. This map product has been widely accepted and is used by a diverse set of users to track drought conditions across the country. It is also used for policy decisions on eligibility for drought assistance. USDM represents a weekly snapshot of current drought conditions. It is not intended to be a forecast. This assessment includes the 50 US states, Pacific possessions and Puerto Rico. The product

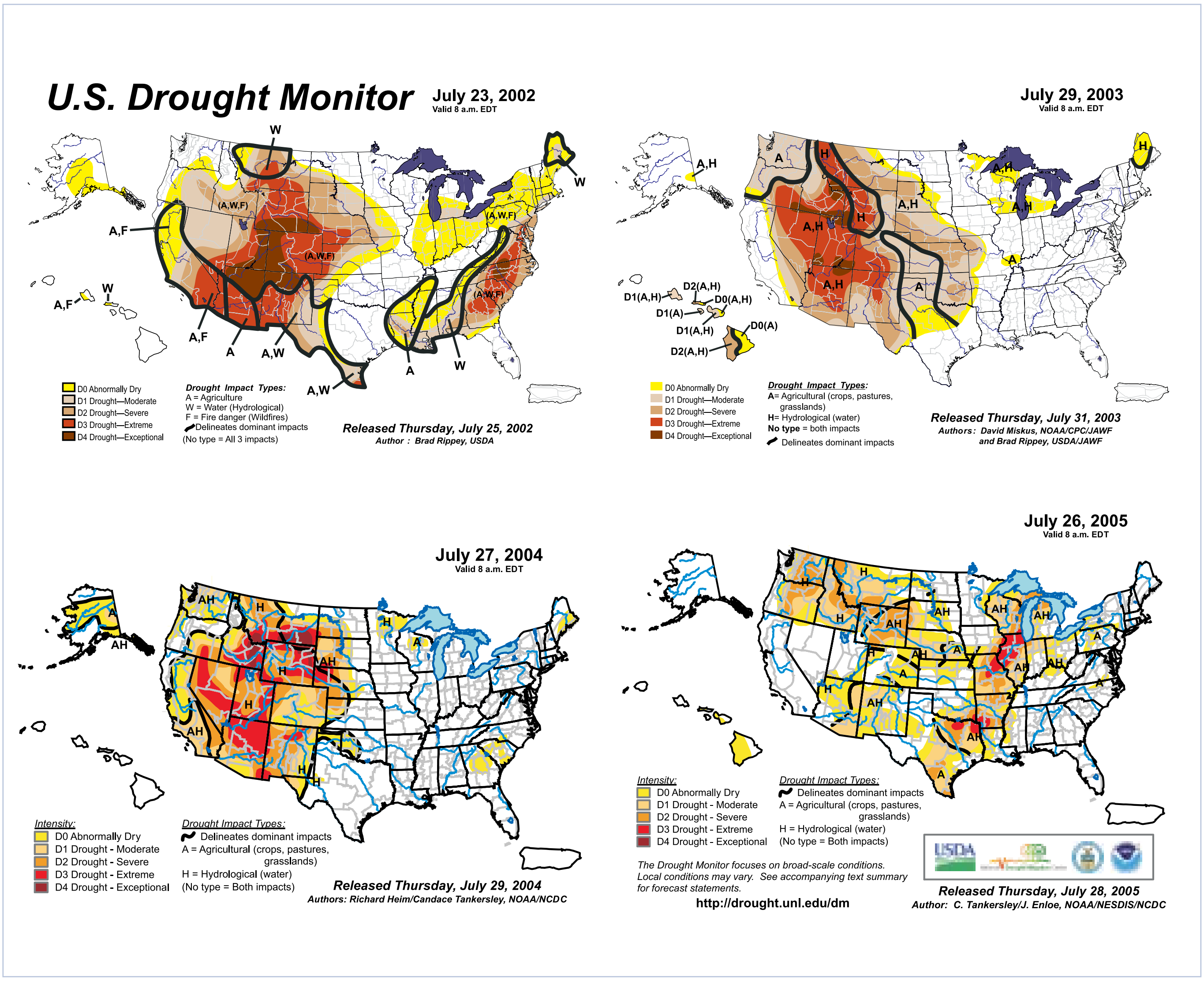

Figure 7. Spatial extent and severity of drought conditions in the United States, 2002 to 2005, as per the US Drought Monitor. (Source: http://www.drought.unl.edu/dm)

consists of a colour map, showing which parts of the United States are suffering from various degrees of drought, and accompanying text. The text describes the drought's present impacts, future threats and prospects for improvement. USDM is by far the most user friendly national drought monitoring product available in the United States today. The Internet is currently the primary distribution vehicle, although the map also appears in local and national newspapers and on television. Figure 7 illustrates the pattern of drought conditions across the United States from 2002 to 2005. A single weekly map illustrates the drought pattern in each year. All USDM maps since 1999 are archived on the website and available to users for comparison.

Since no single definition of drought is appropriate in all situations, agricultural and water planners and others must rely on a variety of data or indices that are expressed in map or graphic form. The USDM authors rely on several key indicators and indices, such as the Palmer Drought Severity Index (PDSI), the Standardized Precipitation Index, stream flow, vegetation health, soil moisture and impacts. Ancillary indicators such as the Keetch-Byram Drought Index, reservoir levels, Surface Water Supply Index, river basin snow water equivalent, and pasture and range conditions from different agencies are integrated to create the final map. Electronic distribution of early drafts of the map to field experts throughout the country provides excellent ground truth for the patterns and severity of drought illustrated on the map each week.

USDM classifies droughts on a scale from one to four (D1–D4), with D4 reflecting an exceptional drought event such as a 1 in 50-year event. A fifth category, D0, indicates an abnormally dry area. The USDM map and narrative identify general drought areas, labelling droughts by intensity from least to most intense. D0 areas are either heading into drought or recovering from drought but still experiencing lingering impacts.

USDM also shows which sectors are presently experiencing direct and indirect impacts, using the labels A (agriculture: crops, livestock, pasture and grasslands), and H (hydrological) and/or W (water supplies). For example, an area shaded and labelled as D2 (A) is in general experiencing severe drought conditions that are affecting the agricultural sector more significantly than the water supply sector. The map authors are careful not to bring an area into or out of drought too quickly, recognizing the slow-onset characteristics of drought, the long recovery process and the potential for lingering impacts.

The methodology associated with USDM has now been applied to the production of the North American Drought Monitor (NADM), a collaborative project between the United States, Mexico and Canada. The partnership began in 2002 in an attempt to map drought severity and spatial patterns across the North American continent. Figure 8 illustrates the NADM for May 2006. Multiple indices and indicators are used to map drought conditions, similar to the procedure used to generate the USDM. Responsibility for this product is shared between NOAA's National Climatic Data Center, the US Department of Agriculture and the National Drought Mitigation Center at the University of Nebraska–Lincoln in the United States; the National Water Commission in Mexico; and Environment Canada and Agriculture and Agri-Food Canada. This product is prepared on a monthly basis and is an excellent example of international drought monitoring cooperation.

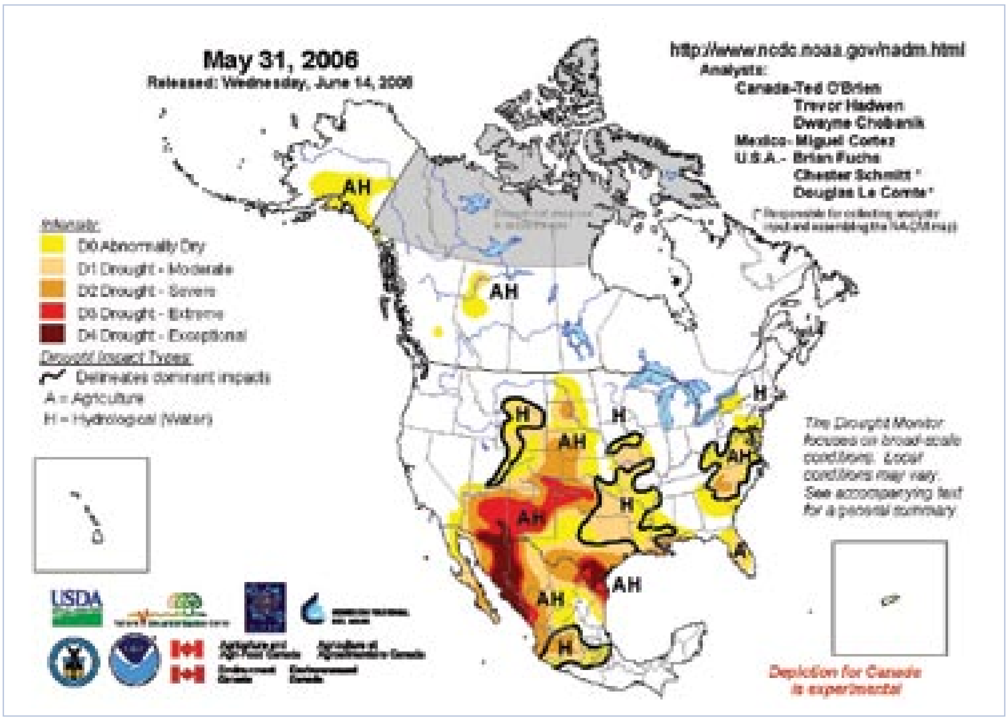

Figure 8. North American Drought Monitor, May 2006. (Source: North American Drought Monitor, http://www.ncdc.noaa.gov/oa/climate/monitoring/drought/nadm/index.html)

DROUGHT MONITORING ACTIVITIES: CASE STUDIES

Considerable progress is being made in drought monitoring and early warning systems in many countries. The increased emphasis on improving these systems is largely the result of the mounting impacts of drought, reflecting greater societal vulnerability. Heightened monitoring capability, including the expansion of automated weather station networks and satellites and the Internet are contributing to such improvements. The Internet allows for improved access to critical data and information to assist in climate and drought assessments and the delivery of this information through a wide range of tools or decision-support products to users in many sectors. A few examples from various countries are included to illustrate some of the approaches being taken in drought-prone regions.

CHINA

The authority that monitors drought development in China is the Beijing Climate Center (BCC) of the China Meteorological Administration (CMA). BCC has used the Standardized Precipitation Index since 1995 to monitor drought occurrence and development in China on a 10-day basis. The monitoring results are published in the China Drought Monitoring Bulletin issued by BCC. Between 1995 and 1999, a Chinese

SHUPING YANG

drought monitoring and early warning system was developed and put into operation on a daily basis in 1999. This system provides accurate information on drought to various related governmental agencies and to the general public, which helps in the development of measures to mitigate the impacts of drought. The core of the system is a Comprehensive Index (CI) for drought monitoring developed by BCC as a result of its long experience in drought monitoring and impact assessment.

CI is a function of the last 30-day and 90-day SPI and the corresponding potential evapotranspiration. Based on CI and soil moisture monitoring from an agricultural meteorological station network and remote-sensing-based monitoring from CMA's National Satellite Meteorological Center, a number of drought monitoring products have being produced:

- Bulletin of China Drought Monitoring, which targets governmental agencies and is published at varying intervals;
- A drought monitoring and impact assessment briefing, broadcast on CCTV every Wednesday since 2004;
- Daily drought monitoring maps, which have been available on the BCC homepage since February 2003 (http://www.bcc.cma.gov.cn/en).

Figures 9 to 11 provide examples of drought monitoring products such as drought monitoring maps, soil moisture assessment and remote-sensing-based products. Spring drought in Ningxia province in 2006 had a significant impact on the winter wheat crop.

MICHEL DUKHAN (IRD)

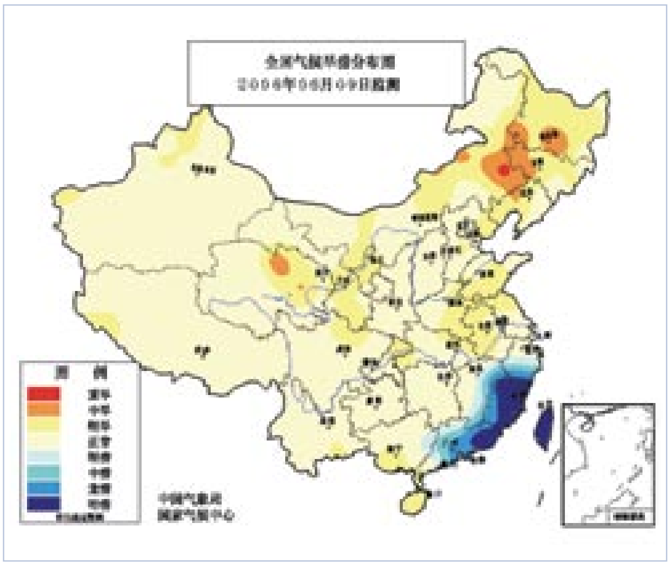

Figure 9. Drought monitoring for China, 9 June 2006; the colour scale from eggshell (in the middle) to red indicates increasing drought severity. (Source: China Meteorological Administration)

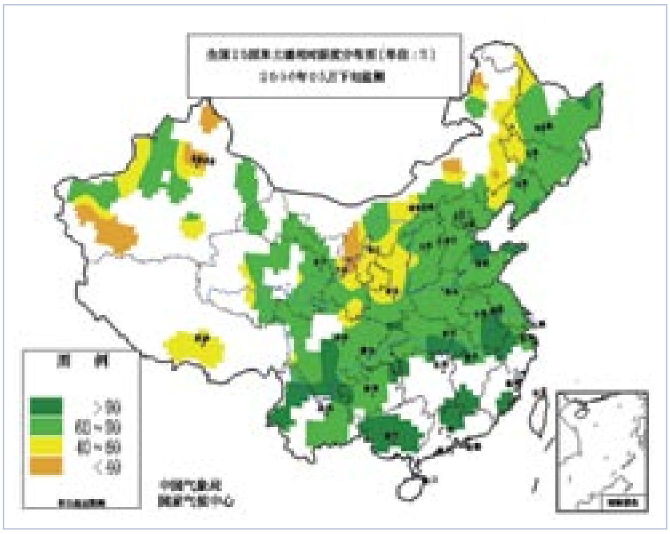

Figure 10. Soil moisture monitoring of the top 20 cm of soil from 21 to 31 May 2006. The higher the values, the wetter the soil. (Source: China Meteorological Administration)

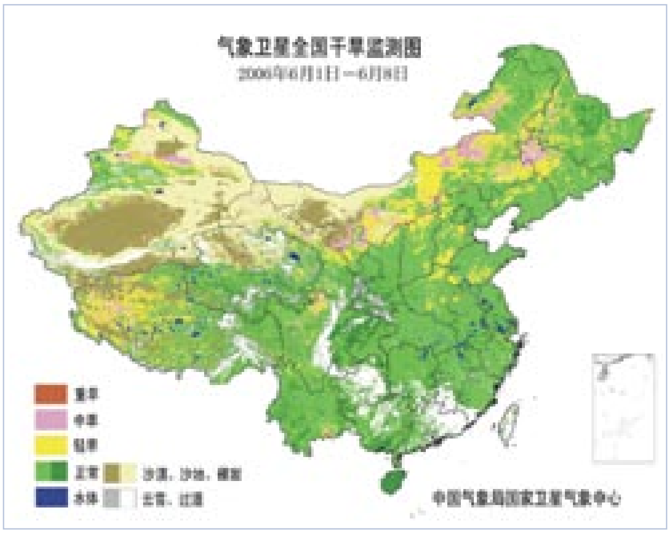

Figure 11. Remote-sensing-based drought monitoring for 1 to 8 June 2006. The colour scale on the left from blue to brown indicates the degree of drought severity. (Source: China Meteorological Administration)

IGAD CLIMATE PREDICTION AND APPLICATIONS CENTRE (ICPAC)

The Greater Horn of Africa, like many parts of the tropics, is prone to extreme climate events such as droughts and floods. In an effort to minimize the negative impacts of extreme climate events, WMO and the United Nations Development Programme established the regional Drought Monitoring Centre (DMC) in Nairobi and a sub-centre in Harare in 1989 covering 24 countries in the eastern and southern African subregion. In 2003, DMC Nairobi became a specialized institution of the Intergovernmental Authority on Development (IGAD) and was renamed the IGAD Climate Prediction and Applications Centre (ICPAC). The participating countries of ICPAC are Burundi, Djibouti, Eritrea, Ethiopia, Kenya, Rwanda, Somalia, Sudan, Uganda and United Republic of Tanzania. The Centre is responsible for climate monitoring, prediction, early warning and applications for the reduction of climate-related risks in the Greater Horn of Africa.

ICPAC's main objective is to contribute to climate monitoring and prediction services for early warning and mitigation of the adverse impacts of extreme climate events on various socio-economic sectors in the region, such as agricultural production and food security, water resources, energy and health. The early warning products enable users to put mechanisms in place for coping with extreme climate- and weather-related risks in the Greater Horn of Africa. The Centre also promotes capacity-building for both climate scientists and users.

ICPAC provides regular regional climate advisories, including 10-day, monthly and seasonal climate bulletins as well as timely early warning information on evolving climate extremes and associated impacts. Regional Climate Outlook Forums are also being held before the onset of the major rainfall seasons to provide consensus climate outlooks and to develop mitigation strategies. Below are some of the activities undertaken by ICPAC:

- Development and archiving of regional and national quality-controlled climate databanks;
- Data processing, including development of basic climatological statistics;
- Timely acquisition of near real-time climate and remotely sensed data;
- Monitoring space-time evolutions of weather and climate extremes over the region;
- Generation of climate prediction and early warning products;
- Delineation of risk zones of extreme climate-related events;
- Timely dissemination of early warning products;
- Conducting capacity-building activities in the generation and application of climate products;
- Organization of climate outlook forums for the countries in the Greater Horn of Africa;
- Enhancement of interactions with users through user workshops and pilot application projects;
- Climate change monitoring, detection and attribution.

Figures 12 to 14 illustrate a range of climate- and drought-related products produced by ICPAC (http://www.icpac.net). The products depict cumulative rainfall deviations from the mean for Marsabit, Kenya; a regional climate outlook map; and a map illustrating the food security outlook for the countries in the Greater Horn of Africa, respectively.

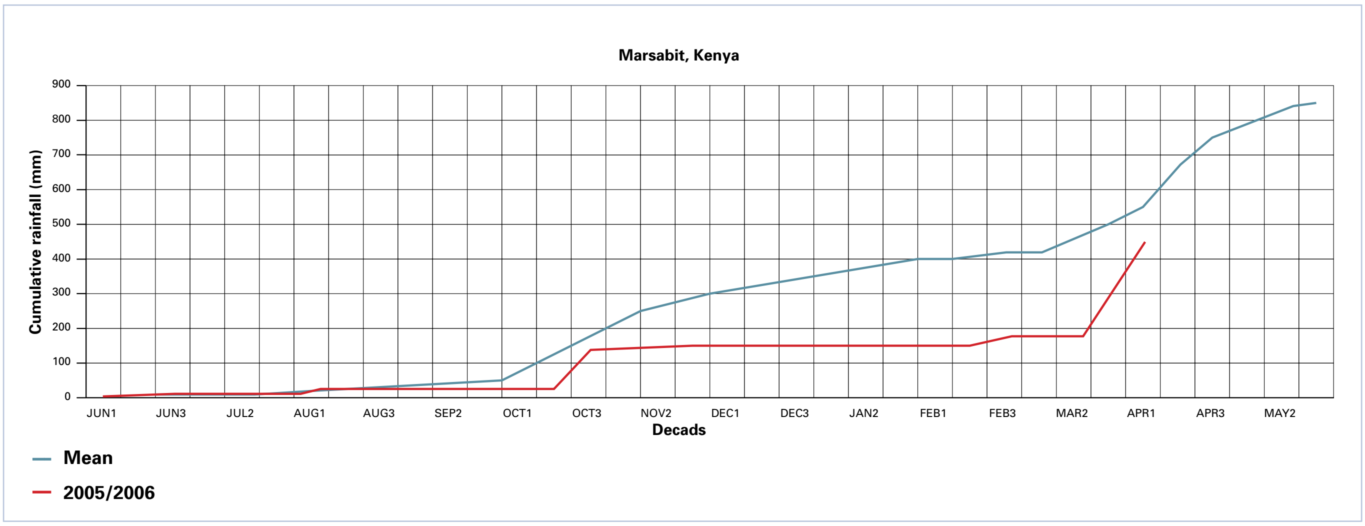

Figure 12. Examples of cumulative decadal rainfall over parts of Kenya from June 2005 to early April 2006. (Source: ICPAC)

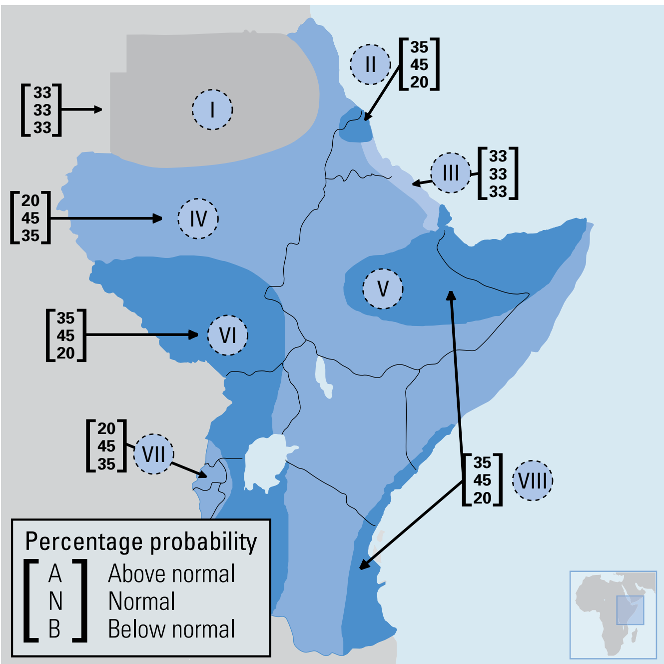

Figure 13. Climate outlook for the Greater Horn of Africa, March to May 2006. (Source: ICPAC)

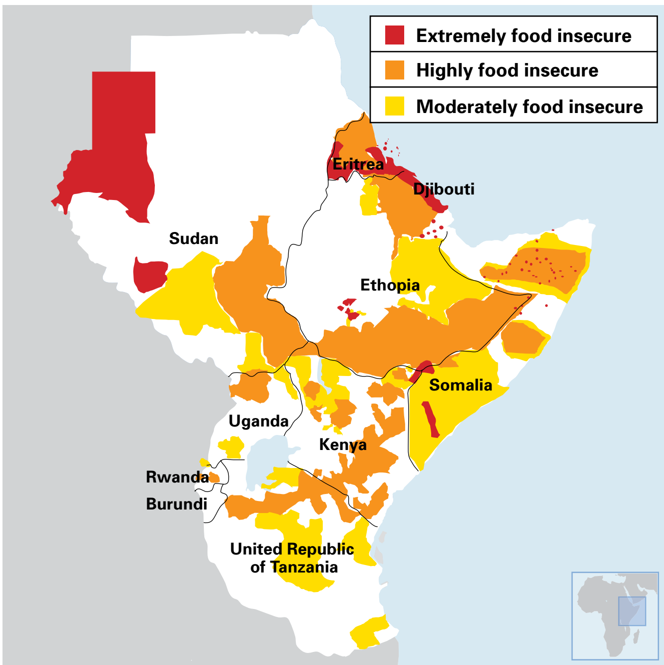

Figure 14. Food security outlook for the Greater Horn of Africa, September to December 2005. (ICPAC)

SOUTH AFRICA

Drought is a normal, recurrent feature of the South African climate. Droughts have in the past resulted in significant economic, environmental and social impacts and highlight the country's continuing vulnerability with regard to this natural phenomenon. During low rainfall periods, policymakers, agriculturalists, businesses and the general public often require additional rainfall data for decision-making and planning.

In response to recurring drought in South Africa, the South African Weather Service (SAWS) established a drought monitoring desk where information regarding observed rainfall and long-range forecasts could be presented in one place for easy access. It also provides an opportunity for people to compare the current year's rainfall with amounts from previous dry periods to assist them in their decision and planning practices.

Neither the percentage of normal nor the decile-based drought indices can assist decision makers with the assessment of the cumulative effect of reduced rainfall over various time periods. Neither of these indices can describe the magnitude of the drought compared with other drought events. SPI can alleviate both of these principal shortcomings while at the same time being less complex to calculate than some of the other drought indices now in use at the South African Weather Service. SPI is an index based on the probability of rainfall for any timescale; it can be useful in assessing the severity of drought and can be calculated at various timescales that reflect the impact of the drought on the availability of water resources. The SPI calculation is based on the distribution of rainfall over long time periods, preferably more than 50 years. The long-term rainfall record is fit to a probability distribution, which is then normalized so that the mean SPI for any place and time period is zero. SPI values above zero indicate wetter periods and values less than zero indicate drier periods.

On 23 November 2005, the Department of Agriculture issued a report indicating that eight of South Africa's nine provinces were being severely affected by drought, the exception being the densely populated Gauteng province, a minor player in agriculture. At that time, the northernmost province, Limpopo, had had districts flagged as disaster areas since 2003 and 2004, with 27 of its 37 municipalities affected. The dams of the province were at their lowest levels, an average of 36 per cent of capacity, compared with 64 per cent the previous year.

The severity of the situation was clearly reflected in the different timescales of the SPI maps on the SAWS Drought Monitoring Page (http://www.weathersa.co.za/DroughtMonitor/DMDesk.jsp), updated at the beginning of December 2005. A very dry winter and the lack of good spring rains exacerbated the dry conditions in some areas.

The main rainfall features in November 2005 were near normal rainfall over most of South Africa, but wet conditions over parts of the Western Cape, the Eastern Cape,

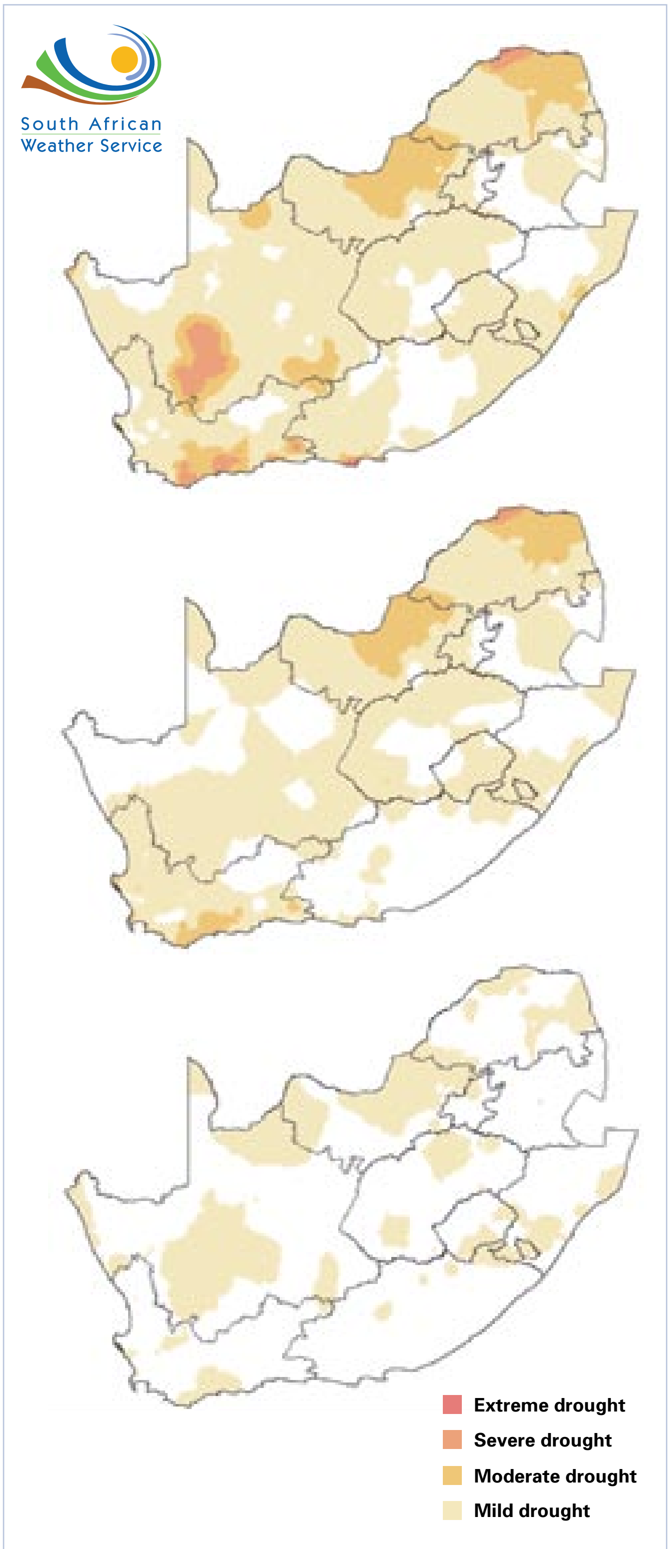

Figure 15. Standardized Precipitation Index (SPI) for South Africa, November 2005 (top); September to November 2005 (middle); June to November 2005 (bottom). (Source: South African Weather Service)

KwaZulu-Natal and Mpumalanga (Figure 15, top). According to available data, no part of the country received rainfall much below the normal value for the month.

From September to November 2005, there was some alleviation of the dry conditions in the northern provinces as well as the far south (Figure 15, middle). However, some dryness remained in the northernmost province, Limpopo.

The rainfall for the six-month period, as shown by the SPI map for June to November 2005, shows near normal conditions over the largest part of South Africa, but moderate to very dry conditions in several areas, most notably in the Southern Cape, southern parts of the Northern Cape and the far north (Figure 15, bottom). Even though some parts of Limpopo received good rains during November 2005, there was still a strain on water resources.

PORTUGAL

The Palmer Drought Severity Index is used to characterize drought in Portugal. This index has been adapted and calibrated to the specific climatic conditions of mainland Portugal. The PDSI performs a parameterized computation of the soil water balance and compares the estimated soil moisture content with its climatological mean.

Evolving drought patterns are presented in monthly PDSI maps that show the spatial distribution of drought in Portugal. These maps are used to monitor spatial and temporal variations in drought across mainland Portugal, which is helpful in delineating potential disaster areas for agriculture and other sectors, allowing for improved on-farm decisions to reduce impacts.

The 2004–2005 hydrological year began with favourable amounts of precipitation in October, except in the southern region, where it was dry to normal. The months that followed were dry to extremely dry, resulting in the development of a very intense drought. Figure 16 and Table 1 show the monthly PDSI variations expressed as percentages of area affected in mainland Portugal. In addition, they reveal a deterioration of drought conditions during the winter months, with some attenuation in March because of the occurrence of precipitation in the country's northern and inner regions. During June, July and August, the drought situation worsened. These months normally contribute, on average, only 6 per cent of the annual precipitation. Precipitation received during the first 15 days of September lessened the severity of drought in the northern and central regions.

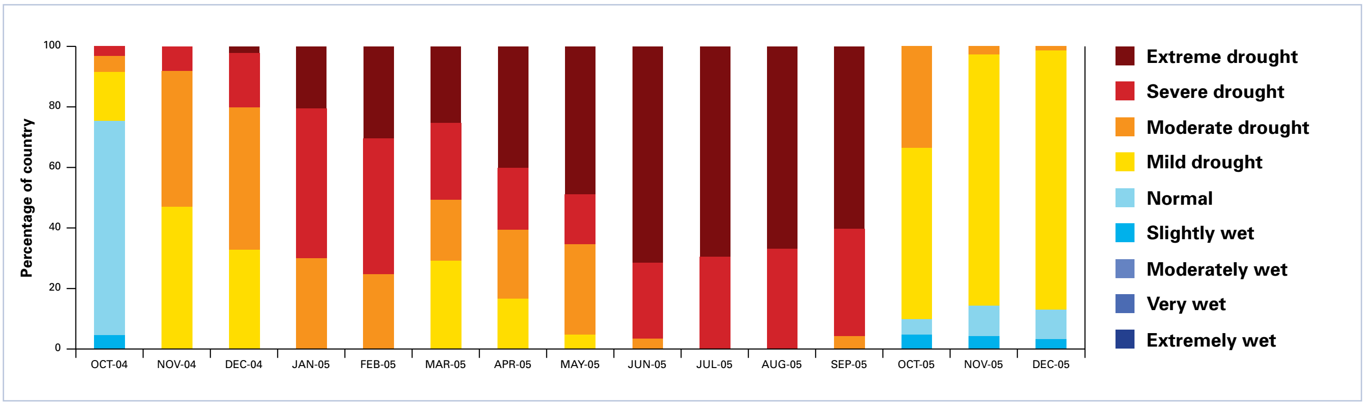

Figure 16. Percentage of Portugal affected by drought, October 2004 to December 2005. (Source: Instituto de Meteorologia, I.P., Portugal)

Palmer Drought Severity Index (PDSI)	Area affected by drought in 2004–2005 (per cent)														
	2004			2005											
	31 Oct	30 Nov	31 Dec	31 Jan	28 Feb	31 March	30 April	31 May	30 June	31 July	31 Aug	30 Sept	31 Oct	30 Nov	31 Dec
Moderately wet	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Slightly wet	47	0	0	0	0	0	0	0	0	0	0	0	6	5	5
Normal	22	1	0	0	0	0	0	0	0	0	0	0	6	12	11
Mild drought	20	47	30	0	0	26	15	4	0	0	0	0	52	81	83
Moderate drought	5	47	48	25	23	22	22	28	3	0	0	3	36	2	1
Severe drought	1	5	20	53	44	28	20	20	33	27	29	36	0	0	0
Extreme drought	0	0	2	22	33	24	43	48	64	73	71	61	0	0	0

Table 1. Percentage of mainland Portugal affected by drought in 2004 and 2005. (Source: Instituto de Meteorologia, I.P., Portugal)

Figure 17 shows the number of consecutive months in severe and extreme drought through the end of September 2005.

The impacts of the drought on agriculture, energy and urban water supply were significant. Figure 18 illustrates these impacts on the urban water supply. The number of people affected by drought from April to December 2005, as shown in Table 2, is also a good indicator of the widespread impacts associated with this drought event.

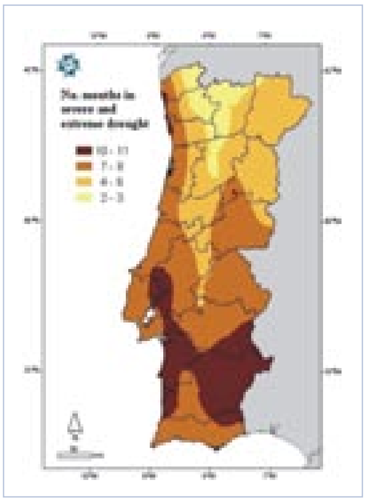

Figure 17. Spatial representation of consecutive months in severe and extreme drought situations in Portugal, October 2004 to September 2005. (Source: Instituto de Meteorologia, I.P., Portugal)

Period	Affected population	
	With supplemented water	With cuts/reduction in supply
1st half April	14 175	213
1st half May	8 395	2635
1st half June	26 500	26 781
2nd half June	23 440	25 217
1st half July	26 004	26 350
2nd half July	54 831	53 312
1st half August	48 500	60 061
2nd half August	94 372	100 500
1st half September	73 097	66 127
2nd half September	69 588	39 429
2nd half October	48 883	30 083
2nd half November	11 921	13 354
2nd half December	10 238	13 445
Maximum	**94 372**	**100 500**

Table 2. Number of people affected directly or indirectly by drought in Portugal, 2005. (Source: Instituto de Meteorologia, I.P., Portugal)

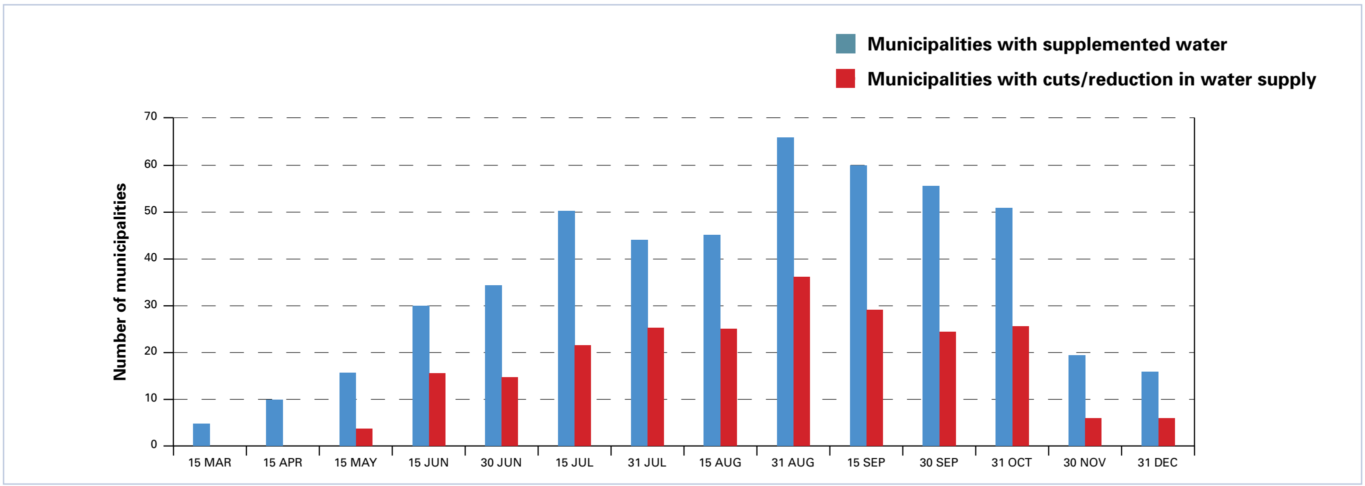

Figure 18. Number of municipalities with supplemented water (blue) or cuts/reduction in household supply (red). (Source: Instituto de Meteorologia, I.P., Portugal)

AUSTRALIA

The island continent of Australia straddles the southern subtropical zone, with its mainland extending from around 11°S across the "Top End" to 39°S in the south-east. The northern regions are seasonally tropical while the eastern, south-eastern and south-western coasts and near inland regions are generally well watered but prone to high interannual and seasonal variability in their rainfall. The more inland regions range from arid to semi-arid. Droughts, sometimes covering vast tracts of the continent, are a recurring feature of Australia's climate. Many of the more severe and widespread droughts are associated with El Niño events.

Given that rainfall is by far the dominant factor determining the success or failure of the growing season across Australia, drought monitoring has for many years been synonymous with the monitoring of rainfall deficiencies. The Australian Bureau of Meteorology's Drought Watch Service, in operation since 1965, has used accumulated rainfall percentiles over successive months to identify regions of rainfall deficit and excess. Areas with rainfall accumulations below the 10th or 5th percentile for periods of three months or more are referred to as being seriously or severely in deficit, respectively. Figure 19 shows the extent of serious or worse rainfall deficiencies at the peak of the last El Niño-related drought during 2002–2003.

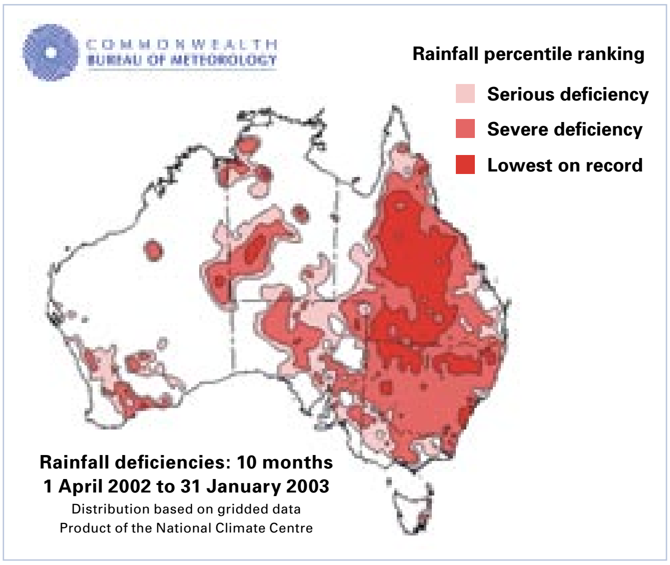

Figure 19. The extent of serious or worst rainfall deficiencies at the peak of the last El Niño-related drought in 2002 and 2003. (Source: Australian Bureau of Meteorology)

Although an extended period of rainfall deficiency in any area is virtually a prerequisite for drought, there is widespread recognition in Australia that the formal declaration of a drought is a more complex issue. It involves consideration not only of the rainwater supply but also the subsequent uses for that rainfall once it has fallen onto farmlands, runs into streams and rivers, is stored in dams, is used to drive hydro-electric power stations and is supplied to cities and towns across the nation. Furthermore, given the size and geographical location of Australia, it is unusual for there not to be one or more areas of varying size at any given time experiencing serious or severe rainfall deficiencies. Whether or not such areas are declared drought stricken and then whether the drought is of sufficient intensity, duration and extent for those affected to be eligible for government relief involves a complex series of assessments by national and state authorities.

The recognition that drought is a "normal" feature of Australia's natural, economic, and social environments has led the national and state governments to agree that climate-sensitive industries and enterprises must learn to manage drought risk, along with all the other attendant and ongoing risks that they face. Nonetheless, the governments do recognize that, from time to time, some droughts become so severe, chronic or widespread that there is a need to offer support to those worst affected. Such occurrences in Australia are called "exceptional circumstances".

In 2002–2003 Australia experienced an especially severe and widespread drought, accompanied by record high temperatures in many regions. At the peak of the drought, 57 per cent of the Australian mainland had registered 10 months or more of serious to severe cumulative rainfall deficits, and 90 per cent, below the median (Figure 19). With the experience of the drought fresh in mind, and also recognizing the need for a more objective, fair and transparent process underpinning the declaration of exceptional circumstances, the Primary Industries Ministerial Council of Australia in 2005 commissioned the establishment of the National Agricultural Monitoring System (NAMS).

NAMS was developed over the next 12 months under the leadership of the Bureau of Rural Sciences in collaboration with the Bureau of Meteorology and the Commonwealth Scientific and Industrial Research Organization (CSIRO). The outcome is a freely accessible website containing current maps, graphs and reports on the state of the climate system across Australia, and information on production for major dryland broad-acre agricultural systems. As well as current data, NAMS also contains historical information on measured and modelled production, financial impacts, remote-sensing indices and climate.

The NAMS website presents information on screen and in the form of printable reports, providing general background, current climatic conditions and production and resource statistics for regions that can be specified by the user. Regions can range in size from the entire country to individual local government areas or the statistical local areas used for summarizing Australian census data.

Collectively, NAMS information shows the status of current conditions for the major agricultural production systems and production prospects for the upcoming growing season. NAMS is initially directed at monitoring and supplying data for dryland broad-acre industries, with plans to extend the system to cover the extensive irrigated regions of Australia and also for more intensive industries such as horticulture.

As NAMS draws on a common information database for the entire country, it will facilitate a more consistent approach to the drought declaration process through the use of the following:

- A common template and language for describing drought in terms of probabilities;
- A common set of declaration criteria;
- A common process for the subjective "on-ground" assessment of drought impacts.

The NAMS website is at http://www.nams.gov.au. Detailed information on Australia's national drought assistance measures, including the declaration of exceptional circumstances, can be found at http://www.daff.gov.au/droughtassist, while information on the rainfall deficiency monitoring system can be found at http://www.bom.gov.au/climate/drought/drought.shtml.

CONCLUSION

Drought affects more people than any other natural disaster and results in serious economic, social and environmental costs. The development of effective drought monitoring, early warning and delivery systems has been a significant challenge because of the unique characteristics of drought. Significant strides have been made in recent years to improve the effectiveness of these systems. With the increasing frequency and severity of drought in many regions of the world and increased societal vulnerability, more emphasis is now being placed on the development of drought preparedness plans that are proactive rather than reactive and emphasize risk-based management measures. Improved drought monitoring is a key component of a drought preparedness plan and a national drought policy. Early warning systems can provide decision makers with timely and reliable access to information on which mitigation measures can be based. There are many challenges to improving these systems, but a comprehensive, integrated approach to climate and water supply monitoring is proving to be successful in many countries.