WORLD METEOROLOGICAL ORGANIZATION

TECHNICAL NOTE No. 201

AGROMETEOROLOGY RELATED TO EXTREME EVENTS

by

H.P. Das, T.I. Adamenko, K.A. Anaman, R.G. Gommes and G. Johnson

(CAgM-XI Working Group on Agrometeorology Related to Extreme Events)

WMO-No. 943

Secretariat of the World Meteorological Organization - Geneva - Switzerland

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* On 1 July 2002

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2003

ISBN: 92-63-10943-5

NOTE

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FOREWORD

Extreme events affect human society and cause suffering, damage to infrastructure worth billions of dollars each year, loss of life and deterioration of the environment, substantially exceeding normal expectations. In recent decades, people throughout the world have become increasingly concerned by extreme meteorological and hydrological events, which are becoming more frequent and more destructive. The extreme events that affect agriculture are mainly those that are related to weather and climate such as drought, floods, extreme hot and dry weather, frost, excessive rainfall, tropical cyclones, storm surges, high winds, hailstorms, heat stress and cold injuries.

Indeed few communities are immune to these events although some communities are more vulnerable to particular events than others. In the developing world, some of the impacts that can accompany extreme meteorological and hydrological events include the decline in agricultural production and destruction of food reserves and damage to or loss of water supplies through drought or through pollution of traditional water sources during floods. The extension of cultivation into less suitable climates also increases the risk of damage.

Accurate information on extreme meteorological and hydrological events can therefore help farmers take preventive steps to limit damage and increase agricultural output. The information is also useful for several other purposes including modification of the crop environment, protection from frost and strong winds and also for irrigation scheduling. Prediction and early warning with good lead times are vital not only for enhancing food and agricultural production, but also in the utilization and management of fresh water, energy and other natural resources that are sensitive to extreme weather and climate events.

Over the past years, WMO has been assisting Member countries through its Agricultural Meteorology Programme to enhance the application of science and technology for improved agricultural production. The provision of scientifically based forecasts and warnings, as well as improved agrometeorological information and services, has enabled every nation in the world to forewarn and protect their communities from the threat of tropical cyclones, floods, droughts and desertification, locust invasion, forest fires, severe storms and other weather-induced natural disasters.

Given the significance of the impact of extreme meteorological and hydrological events on agriculture, the Commission for Agricultural Meteorology (CAgM) at its eleventh session held in Havana in February 1995 invited Dr H.P. Das (India/Chairman), Dr K. Anaman (Australia), Ms T.I. Adamenko (Ukraine), Ms B. Cusursuz (Romania), Dr G. Johnson (United States) and Mr R.G. Gommes (FAO) to serve as members of a working group to survey and summarize existing knowledge on the application of agrometeorological information needed to better cope with extreme events. The group was also asked to provide examples of the operational use of such information for Member countries and to prepare guidance material for training purposes; to coordinate the design and establishment of a database of extreme events which have significant social and economic impacts on agriculture, foresty and fisheries; and to examine the methods used for assessing the economic impacts of extreme meteorological events on agricultural production.

The report of the group addresses these issues which are of great interest to all nations and in particular to the developing countries. I believe that the publication of this report as a WMO Technical Note will contribute to the development of sustainable agricultural strategies by WMO Members. It is therefore with much pleasure that I take this opportunity to express the gratitude of the World Meteorological Organization to all members of the working group who contributed to the report.

(G.O.P. Obasi)
Secretary-General

SUMMARY

This technical note demonstrates the effects of extreme meteorological events on agricultural production and summarizes existing knowledge on the application of agrometeorological information needed to better cope with extreme meteorological events.

Chapter 1 (*Introduction*) deals with the definition and type of extreme climatic events with emphasis on the requirements of an adequate database to estimate the risk of extreme events in quantitative terms. The impact of climatic extremes on agricultural production and the socio-economic consequences are discussed in general with a focus on disaster prevention, preparedness and rehabilitation.

Chapter 2 (*Agrometeorological aspects of drought and desertification*) deals with the concept, definitions and causes of drought and desertification. Spatial and temporal aspects of drought and their impact on agriculture are explained with particular reference to socio-economic implications. Forecasting, monitoring, early warning of drought and its adaptation and management are well documented in the context of agricultural production. Distribution and trends of desertification, with particular reference to agrometeorological aspects, are also included, along with the methods of its control, monitoring and prevention.

Chapter 3 (*Incidence, prediction, monitoring and mitigation measures of tropical cyclones and storms surges*) describes the geographical distribution and related characteristics of tropical cyclones with emphasis on prediction, monitoring and mitigation aspects. Storm surges, often associated with tropical cyclones, are also discussed. Agrometeorological losses associated with some of the worst cyclones are illustrated with examples. The chapter ends with a description of cyclone warning systems and disaster management.

Chapter 4 (*Assessing the economic and social impacts of extreme events on agriculture and use of meteorological information to reduce adverse impacts*) looks at the economic and social costs extreme events can have in relation to agriculture and agricultural communities. Data, information and services are considered as economic resources for analysis and discussed at length.

Chapter 5 (*Assessing the impact of extreme weather and climate events on agriculture, with particular reference to flooding and heavy rainfall*) presents a synopsis of responses to a survey on extreme weather and climate events. The impacts of flooding and heavy rainfall on agriculture are brought out in this chapter.

Chapter 6 (*Hail, high winds and cold injury*) highlights the effects of some local extreme weather events on agriculture. It shows how hail, high winds and extreme cold weather, including cold injury, affect agricultural production in Ukraine.

Chapter 7 (*Locusts*) describes some principal pests including locusts, grasshoppers and army worms, the devastation they cause to crops and how their migration is largely controlled by agrometeorological, climatological and synoptic conditions.

Chapter 8 (*Specification for a database of extreme agrometeorological events*) is an attempt to design a specification for a database of extreme agrometeorological events. It provides the component, methodology and structure of a database of agricultural disasters resulting from extreme geophysical and man-made factors with an atmospheric component.

Chapter 9 (*Conclusions and recommendations*) highlights the impact extreme agrometeorological events have around the world. Recommendations regarding information systems; monitoring, early warning and remedial measures; training and awareness raising; and global cooperation are provided.

Noting that extreme agrometeorological events continue to occur in many parts of the world with negative impacts on agricultural production, it is recommended that the Commission for Agricultural Meteorology continues to study this subject with renewed terms of reference.

RÉSUMÉ

La présente note technique confirme les effets des phénomènes météorologiques extrêmes sur la production agricole et fait le point sur les connaissances actuelles concernant l'application de l'information agrométéorologique nécessaire pour mieux faire face à ces phénomènes.

Le chapitre 1 (*Introduction*) traite de la définition et du type des phénomènes climatiques extrêmes, et en particulier de la nécessité de disposer d'une base de données convenable pour évaluer les risques de tels phénomènes sur le plan quantitatif. L'incidence des extrêmes climatiques sur la production agricole et les conséquences socio-économiques sont examinées d'un point de vue général, l'accent étant mis sur la prévention des catastrophes, la préparation à ces catastrophes et la réhabilitation.

Le chapitre 2 (*Aspects agrométéorologiques de la sécheresse et de la désertification*) porte sur le concept et la définition de la sécheresse et de la désertification ainsi que sur leurs causes. Les éléments spatiaux et temporels de la sécheresse et leur incidence sur l'agriculture sont examinés, notamment du point de vue des conséquences socio-économiques. Les aspects relatifs à la prévision, à la surveillance, à l'annonce précoce et à la gestion des phénomènes de sécheresse ainsi qu'à l'adaptation à leurs effets sont largement abordés, toujours dans le contexte de la production agricole. Les questions de la répartition et de l'évolution de la désertification, eu égard en particulier aux aspects agrométéorologiques, sont également abordées, de même que celles qui concernent les méthodes employées pour lutter contre ce phénomène et en assurer le suivi et la prévention.

Le chapitre 3 (*Incidence, prévision et surveillance des cyclones tropicaux et des marées de tempête et mesures d'atténuation de leurs effets*) décrit la distribution géographique et les caractéristiques connexes des cyclones tropicaux, l'accent étant mis sur la prévention et la surveillance de ces phénomènes et sur l'atténuation de leurs effets. Les marées de tempête, dont s'accompagnent souvent les cyclones tropicaux, sont également mentionnées. Les pertes agrométéorologiques dues à quelques-uns des cyclones les plus dévastateurs sont illustrées par des exemples. Le chapitre se termine par une description des systèmes d'avis de cyclone et par des considérations sur la gestion des catastrophes.

Le chapitre 4 (Evaluation des répercussions économiques et sociales des phénomènes extrêmes sur l'agriculture et utilisation de l'information météorologique pour en atténuer les effets néfastes) porte sur les coûts économiques et sociaux que peuvent avoir les phénomènes extrêmes en ce qui concerne l'agriculture et les communautés agricoles. Les données, les informations et les services sont considérés comme des ressources économiques aux fins d'analyse et font l'objet d'un examen approfondi.

Le chapitre 5 (*Evaluation de l'incidence des phénomènes météorologiques et climatiques extrêmes sur l'agriculture, notamment pour ce qui concerne les inondations et les fortes pluies*) présente un résumé des réponses obtenues dans le cadre d'une enquête sur les phénomènes météorologiques et climatiques extrêmes. On attire en particulier l'attention sur les conséquences des inondations et des fortes pluies pour l'agriculture.

Le chapitre 6 (*Grêle, vents forts et dégâts dus au froid*) insiste sur les effets de certains phénomènes météorologiques extrêmes sur l'agriculture. On y décrit la manière dont la grêle, les vents forts et les périodes de froid extrême (y compris les dégâts dus au froid) ont des effets négatifs sur la production agricole en Ukraine.

Le chapitre 7 (*Criquets*) donne la description de certains des principaux ravageurs (criquets, sauterelles, chenilles légionnaires, etc.) et des dégâts qu'ils causent aux cultures et précise le rôle déterminant que jouent les conditions agrométéorologiques, climatiques et synoptiques dans leur migration.

Le chapitre 8 (*Spécifications d'une base de données sur les phénomènes agrométéorologiques extrêmes*) est une tentative d'élaboration de spécifications pour une base de données sur les phénomènes agrométéorologiques extrêmes. On y précise les composantes, la méthodologie et la structure d'une base de données sur les catastrophes agricoles qui résultent de facteurs géophysiques et anthropiques extrêmes et qui présentent un élément atmosphérique.

Le chapitre 9 (*Conclusions et recommandations*) insiste sur les répercussions qu'ont les phénomènes agrométéorologiques extrêmes dans le monde entier. On y formule en outre des recommandations concernant les systèmes d'information; les systèmes de surveillance et d'alerte précoce et les mesures correctives ; la formation et la sensibilisation; et la coopération à l'échelle du globe.

Etant donné que les phénomènes agrométéorologiques extrêmes continuent d'avoir des effets néfastes sur la production agricole dans de nombreuses régions du globe, il est recommandé que la Commission de météorologie agricole continue d'étudier cette question dans le cadre d'un mandat renforcé.

РЕЗЮМЕ

В настоящей технической записке демонстрируется воздействие экстремальных метеорологических явлений на сельскохозяйственное производство и содержится резюме существующих знаний по применению агрометеорологической информации, необходимой для того, чтобы лучше противостоять экстремальным метеорологическим явлениям.

Глава 1 (*Введение*) содержит определения и описание видов экстремальных климатических явлений с упором на потребности в адекватной базе данных для оценки риска экстремальных явлений в количественном выражении. Излагаются также вопросы воздействия экстремальных климатических явлений на сельскохозяйственное производство и их социально-экономические последствия в целом с упором на предотвращение последствий стихийных бедствий, подготовку к ним и устранение ущерба.

Глава 2 (*Агрометеорологические аспекты засухи и опустынивания*) рассматривает концепцию определения и причин засухи и опустынивания. Пространственные и временные аспекты засухи и воздействие засух на сельское хозяйство освещается с особым упором на социально-экономические последствия. Прогнозирование, мониторинг, заблаговременное предупреждение засухи и адаптация к условиям засухи и борьба с ней хорошо излагаются в контексте сельскохозяйственного производства. Вопросы распространения и тенденции опустынивания с особым упором на агрометеорологические аспекты также раскрываются в этой главе наряду с методами борьбы с засухой, мониторинга и предотвращения засухи.

Глава 3 (*Появление, предсказание, мониторинг и меры по смягчению последствий тропических циклонов и штормовых нагонов*) описывает географическое распространение и соответствующие характеристики тропических циклонов с упором на прогноз, мониторинг и аспекты смягчения последствий. Излагаются также вопросы, касающиеся штормовых нагонов, которые часто связаны с тропическими циклонами. Например, иллюстрируются потери в плане ухудшения агрометеорологических условий в связи с некоторыми самыми сильными циклонами. Глава заканчивается описанием систем предупреждений о циклонах и изложением вопросов обеспечения готовности к стихийным бедствиям.

Глава 4 (*Оценка экономических и социальных последствий экстремальных явлений для сельского хозяйства и использование метеорологической информации для уменьшения негативных воздействий*), в которой рассматриваются социально-экономические потери в финансовом плане от экстремальных явлений, которые могут иметь отношение к сельскому хозяйству и сельскохозяйственным общинам. Данные, информация и обслуживание рассматриваются как экономические ресурсы для анализа, и эти вопросы излагаются достаточно подробно.

Глава 5 (*Оценка воздействий экстремальных погодных и климатических явлений на сельское хозяйство с особым упором на затопления и ливневые осадки*) представляет собой совокупность ответов на обзор по экстремальным погодным и климатическим явлениям. В этой главе рассматривается воздействие затоплений и ливневых осадков на сельское хозяйство.

Глава 6 (*Град, сильные ветры и повреждения низкими температурами*) освещает воздействие некоторых локальных экстремальных погодных явлений на сельское хозяйство. В ней описывается то, каким образом град, сильные ветры и экстремально холодная погода, включая повреждения низкими температурами, влияют на сельскохозяйственное производство на Украине.

Глава 7 (*Саранча*) описывает некоторых основных вредителей, включая саранчу, кузнечиков и гусениц, опустошительный ущерб, который они могут наносить сельскохозяйственным культурам, и то, каким образом их миграция в основном обусловлена агрометеорологическими, климатологическими и синоптическими условиями.

Глава 8 (*Спецификация базы данных экстремальных агрометеорологических явлений*) представляет собой попытку составить спецификацию для базы данных экстремальных агрометеорологических явлений. В ней содержится описание методологии и структуры базы данных сельскохозяйственных бедствий, являющихся результатом экстремальных геофизических и антропогенных факторов, включая атмосферный компонент.

Глава 9 (*Выводы и рекомендации*) освещает воздействие экстремальных агрометеорологических явлений по всему земному шару. Содержит рекомендации, касающиеся информационных систем, мониторинга, заблаговременного предупреждения и мер по устранению последствий; обучения и повышение уровня осведомленности; и касается также вопросов глобального сотрудничества.

Принимая во внимание, что экстремальные агрометеорологические явления будут продолжать иметь место во многих частях земного шара с негативными последствиями для сельскохозяйственного производства, рекомендуется, чтобы Комиссия по сельскохозяйственной метеорологии продолжала изучать эти вопросы при обновленном круге своих обязанностей.

RESUMEN

En esta nota técnica se demuestran los efectos de los fenómenos meteorológicos extremos sobre la producción agrícola y se resumen los conocimientos existentes acerca de la aplicación de la información agrometeorológica necesaria para poder hacer frente más eficazmente a los fenómenos meteorológicos extremos.

En el Capítulo 1 (*Introducción*) se abordan la definición y el tipo de los fenómenos climáticos extremos, prestando especial atención a los requisitos de una base de datos adecuada para la estimación de los riesgos de los fenómenos extremos en términos cuantitativos. Se examinan en general los efectos de los extremos climáticos sobre la producción agrícola y sus consecuencias socioeconómicas, prestando especial atención a la prevención de desastres, las medidas de preparación y la rehabilitación.

El Capítulo 2 (*Aspectos agrometeorológicos de la sequía y la desertificación*) trata del concepto, las definiciones y las causas de la sequía y la desertificación. Se explican los aspectos espaciales y temporales de la sequía y sus efectos sobre la agricultura, con especial referencia a las implicaciones socioeconómicas. La predicción, la vigilancia, la alerta temprana de la sequía y las medidas de adaptación y gestión están bien documentadas en el contexto de la producción agrícola. Se incluyen también la distribución y las tendencias de la desertificación, con particular referencia a los aspectos agrometeorológicos, así como los métodos de control, vigilancia y prevención.

En el Capítulo 3 (*Incidencia, predicción, vigilancia y medidas de mitigación de los ciclones tropicales y de las mareas de tempestad*) se describen la distribución geográfica y las características conexas de los ciclones tropicales, poniéndose énfasis en los aspectos de predicción, vigilancia y mitigación. Se estudian también las mareas de tempestad que a menudo acompañan los ciclones tropicales. Se presentan casos ilustrativos de las pérdidas agrometeorológicas asociadas con algunos de los ciclones que han causado mayores destrozos. El capítulo concluye con una descripción de los sistemas de alerta ciclónica y gestión de desastres.

En el Capítulo 4 (*Evaluación de los efectos económicos y sociales de los fenómenos extremos en la agricultura y la utilización de la información meteorológica para reducir los impactos adversos*) se examinan los costos económicos y sociales de los fenómenos extremos en relación con la agricultura y las comunidades agrícolas. Los datos, la información y los servicios se consideran recursos económicos para el análisis y son objeto de un estudio pormenorizado.

El Capítulo 5 (*Evaluación de los efectos de los fenómenos meteorológicos extremos y de los fenómenos climáticos en la agricultura, con particular referencia a las crecidas y a las precipitaciones intensas*) presenta una sinopsis de las respuestas a una encuesta sobre fenómenos meteorológicos y climáticos extremos. En ese capítulo se abordan los efectos de las inundaciones y de las precipitaciones intensas sobre la agricultura.

En el Capítulo 6 (*Granizo, vientos fuertes y daños causados por el frío*) se subrayan los efectos de algunos fenómenos meteorológicos extremos para la agricultura. Se explica cómo el granizo, los vientos fuertes y el frío extremo, incluidos los daños causados por el frío, afectan la producción agrícola en Ucrania.

El Capítulo 7 (*Plagas de langostas*) describe algunas de las principales plagas, incluidas las langostas, los saltamontes y las orugas negras, sus devastadores efectos sobre los cultivos y la manera en que su migración está controlada mayormente por las condiciones agrometeorológicas, climatológicas y sinópticas.

En el Capítulo 8 (*Especificaciones para una base de datos sobre fenómenos agrometeorológicos extremos*) es un esbozo de diseño de una especificación para una base de datos sobre fenómenos agrometeorológicos extremos. Se presentan los componentes, la metodología y la estructura de una base de datos sobre desastres agrícolas que obedecen a factores geofísicos extremos y antropogénicos con componente atmosférico.

El Capítulo 9 (*Conclusiones y recomendaciones*) subraya las repercusiones de los fenómenos agrometeorológicos extremos en todo el mundo. Se presentan recomendaciones relativas a los sistemas de información, vigilancia, alerta temprana y medidas correctivas; capacitación y elevación de la concienciación, y cooperación a escala mundial.

Teniendo presente que en muchas partes del mundo siguen ocurriendo fenómenos agrometeorológicos extremos que tienen efectos negativos en la producción agrícola, se recomienda que la Comisión de Meteorología Agrícola continúe estudiando estos temas con un mandato renovado.

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CHAPTER 1

INTRODUCTION
(by H.P. Das)

1.1 DEFINITION OF EXTREME EVENTS

Extreme events are infrequent meteorological phenomena that surpass a defined threshold. The perceived severity depends on the vulnerability of the natural environment and human society to that event. This implies that the definition of an extreme event can depend strongly on location. Susman, *et al.* (1983) described a disaster as “the interface between an extreme physical event and a vulnerable human population”. In the same way, an extreme agrometeorological event is the interaction between a vulnerable agricultural system and extreme weather conditions. However, the definition of extreme agrometeorological events is broader, as it also includes weather conditions conducive to the development of agents such as pests and diseases that adversely affect all aspects of agriculture including livestock and pasture, forests and fisheries (Gommes, 1997).

One important aspect of extreme events is the apparent randomness and abruptness with which they arrive. Global changes in air pollution, acid deposition, desertification, water shortages, salt water intrusion and soil degradation are also serious but tend to arrive slowly enough that regional, national and local authorities can adopt successful long-term counter-measures.

1.2 TYPES OF EXTREME CLIMATIC EVENTS

Generally, plants exhibit particular thresholds for the various climatic variables determining plant growth and development. The optimum values for plant growth may not necessarily be those for its development. The climatic events which adversely affect agricultural production may be linked to an extreme value of one parameter or another. Some of the important extreme climatic events from an agriculture and livestock point of view are:

(*a*) Tropical storms (cyclones, hurricanes, typhoons, etc.) associated with high winds, flooding and storm surges;
(*b*) Floods (other than those related to tropical storms), heavy rains during monsoon and waterlogging;
(*c*) Severe thunderstorms, hailstorms, tornadoes and squalls;
(*d*) Drought and heatwaves;
(*e*) Cold spell, low temperature, frost, snow and ice storms;
(*f*) Dust storms and sand storms;
(*g*) Weather conducive to fires (lightning); and
(*h*) Weather encouraging pests and diseases of crops and livestock.

Besides the above climatic events, the following geological/geophysical extreme events are also hazardous to society at large:

(*a*) Volcanic eruptions;
(*b*) Earthquakes and tsunamis;
(*c*) Avalanches; and
(*d*) Landslides and mudslides.

1.3 AGROMETEOROLOGICAL DATA RELATED TO EXTREME EVENTS

The first and the most basic requirement in agrometeorological hazard assessment for extreme events is an adequate database. If sufficient quality data are available, it may be feasible to estimate the risk of the extreme events and their damage in quantitative terms. An overall assessment will include information not only on meteorological and hydrological aspects but also on social, economic, geographical and other factors. The evaluation of risk or the investigation of disaster potential can generally be done in a fairly straightforward way, using the long-term meteorological and hydrological records of the country, supplemented, if necessary, by data available from neighbouring countries. Analysis of these data may be helpful in making decisions on social, economic, regional and other considerations and to plan and organize protective measures.

As a first step, the climatological records should be analyzed in order to discover how often an extreme event, say tropical cyclones of various intensities, strike different areas or regions of the country. All possible sources should be considered in order to build up the most complete data possible. Old records in libraries and newspaper offices often furnish valuable information.

While measures to optimize an extreme events database should be vigorously pursued, it must be recognized that basic data collection, processing and storage, remain the cornerstone of any research and of operational aspects of extreme events. For each extreme event, the database should include location, time and details about the severity of the phenomenon and the extent of damage or injury, preferably quantitatively.

Accurate information on extreme meteorological events is extremely important to farmers in maximizing their production. The information is also useful for modifying the crop environment, protection from frost and strong winds and also for irrigation scheduling. The extension of cultivation into less suitable climates increases the risk of damage by the climate, particularly meteorological extremes. The successful development of a country's agricultural economy is, therefore, to a large extent, dependent on the use of climatic information, especially on adverse agrometeorological factors. To examine the effect of agroclimatic extreme events, all aspects of the climatology of the locality must be considered.

Observation systems must be devised in anticipation of damage from the extreme weather. The nature of the observation for each extreme agrometeorological event will vary with the type of hazard. A country prone to tropical cyclones should install additional observation facilities to supplement the basic meteorological network used for its normal forecasting and climatological purposes as has been done in India. The data collected should include the loss of human and cattle lives, the number of people injured, areas inundated and/or damaged, crop losses, the number of dwellings destroyed and damaged etc.

The real-time monitoring and assessment of drought requires collection of rainfall and other related drought data. It is necessary to supplement the synoptic data with information on evaporation, radiation, soil moisture, the underground water table etc. The accumulated precipitation amount is one of the most essential elements in a real-time drought surveillance service and must supplement data on temperature, humidity, cloudiness and wind. In relation to weather hazards, data are also required on the state and stage of crops.

Data including frequencies and duration of water levels and discharges exceeding certain thresholds are very important for design and planning of the observation system. Usually the regular observation network does provide information on storm rainfall distribution and on flood peak discharges of tributary streams. During severe floods, permanent stream gauge installations can be washed away and records lost. For such reasons valuable information can be obtained by a flood survey conducted in the storm/flood area following a severe occurrence. Soil moisture data at weekly/monthly intervals, presented as graphs, are useful in scheduling the application of irrigation and also in river forecasting. Data on extent, depth and water equivalent of snow cover together with the daily and accumulated number of degree days above or below a certain base and melting degree days are useful for forecasting snow-melt run-off. A particularly important factor on which to have information is frost which can be very damaging to plants.

For crops affected by pests and diseases, information is needed of the state and stage of the crop, the availability and release of spores, incidence and spread of infection, etc. Information is also required on the hatching of various insects, the build up of insect populations or their invasion from other territories.

Since there is a direct relationship between weather and fire danger, and between weather and fire behaviour, a knowledge of past, present and future weather is desirable. This should include temperature, relative humidity, wind, precipitation and thunderstorm data. Information is also required on the state of forest litter and its liability to burn.

The ability of cattle in the open air to withstand low temperatures is fairly strong. However, it is the secondary effect of weather often accompanying a cold wave which causes widespread livestock losses. Snow covers forage and drinking water supplies freeze. As a result cattle caught in a winter storm can starve rather than die directly from the cold temperatures. Cattle, pigs, poultry and other livestock are adversely affected by high temperature together with high relative humidity. Meteorological data on these aspects are very useful in forecasting extreme episodes and minimizing losses.

Without doubt, the most spectacular observational tool of the last few decades has been the meteorological satellite. Some satellites provide data on "wetness" of the vegetated surface and "surface wetness". Such data, though not being agrometeorological extreme events can provide useful information as to when a meteorological extreme event such as a tropical storm, excessive rains, drought or an attack by pests may occur and are thus highly useful.

1.4 EXTREME EVENTS AND AGRICULTURAL PRODUCTION

Agriculture depends on the mean climate of a particular region. Each plant has its own climatic requirements for growth and development and any large-scale deviation from them exerts a negative influence.

As the temperature of the atmosphere and of the soil varies, so the development rate of plants varies up to an optimum value beyond which it tends to decrease. Plant growth is most sensitive to temperatures just above a threshold value and near the maximum value where growth normally stops. Therefore, periods of extreme temperature values, which are well below the threshold value or very high above the maximum value are hazardous to plant development and growth. Periods of extreme temperature conditions such as those experienced during extreme cold spells causing cold stress and frost, or high temperatures and heat waves leading to heat stress can affect agricultural production. Snow and ice storms in late spring or early autumn are very hazardous to many temperate crops, exposing them to layers of snow and ice and causing freezing of the crop.

Similarly, extremes in moisture conditions, namely dry desiccating winds, drought episodes and low moisture availability as well as very humid atmospheric conditions including wet spells affect agriculture. High soil moisture in situations of waterlogging and flooding associated with heavy rainfall and tropical storms adversely effects plant growth and development since it influences the rate of transpiration, leaf-area expansion and, ultimately, plant productivity. Drastic changes in rainfall distribution can have a very significant impact, particularly in climatically marginal zones such as arid, semi-arid and sub-humid areas where the incidence of widespread drought is frequent.

There are, however, some advantages to dry spells or drought at certain times in the development of some crops such as sugar cane where a brief dry spell is essential during the pre-harvest stage. This helps to concentrate or increase the sucrose content of the cane. Additionally, there is often a lower incidence of pests and diseases in periods of drought.

In regimes prone to strong winds, damage to plants and reduced agricultural production occur as a result of very high evapotranspiration (ET) rates. Strong winds cause mechanical damage or breakage to herbaceous plants with weak stems such as sugar cane and banana. Windstorms and tropical storms (hurricanes and typhoons) with very high winds can destroy fields of cereals within minutes reducing the yield significantly.

Extreme climates also impact on plants through the development of pests and diseases. For example, the growth and development of locusts and grasshoppers depend heavily on the climatic conditions in the infected areas. Locusts cannot thrive under severe cold conditions or extremely wet situations.

Other hazardous climatic events include thunderstorms, tornadoes, squall lines, hailstorms and weather-related wildland fires.

1.5 SOCIO-ECONOMIC IMPACT OF EXTREME EVENTS

As populations grow, more people become vulnerable to damage from the occurrence of extreme events in nature. Social losses from avalanches, earthquakes, tropical cyclones and many other natural hazards are increasing. This is the case even though new measures for dealing with hazards proliferate. In some areas measures are curbing losses to a significant extent. Generally, sophisticated means of providing relief in times of disaster are better developed than the means of preventing disasters.

People who have experienced tropical cyclones are generally very receptive to any warnings that are issued and to follow advice given, including instructions for evacuation to safer areas. Everyone should be made aware of the dangers posed by tropical cyclones. Furthermore, since memories are apt to fade, this awareness must be kept alive and up-to-date even for those who have experienced a tropical cyclone in the past. Loss of life as a result of storm warnings being disregarded is a consequence of people's attitudes and emotions. Undoubtedly, this is a problem deserving close attention.

In many respects, the human response to the threat of danger from extreme events is the very core of disaster prevention and preparedness. Ultimately, the success or failure of the warning systems depends upon people. An accurate forecast, a well-designed disaster preparedness system and all the aids that technology can provide count for little if societal response is not in tune with the realities of the event.

The impact of extreme events on society can be positive or negative. Negative or adverse impacts include damage or loss due to droughts, tropical cyclones and floods. However, sometimes extreme events have positive effects such as increased rainfall in coastal areas from tropical cyclones, fixing of atmospheric nitrogen by thunderstorms, germination of native plant species resulting from bush fires, silt deposition, water reserves repletion and soil desalinization due to floods. Of particular note in this context are river bed changes and major landslides which may completely modify the agricultural landscape.

Extreme events can be direct or indirect in their effect. Direct impacts arise from the direct physical contact of the event with people, their animals and their property. For example, tropical cyclones directly cause the loss of farmers' standing crops and damage irrigation facilities; drought directly reduces crop yields and leads to the death of livestock and people. Indirect effects tend to appear progressively as a result of low incomes, decreases in production, environmental degradation and other factors related to the disaster. Indirect impacts include the evacuation of people in the event of cyclone landfall, disruption to households, stress induced sickness and apprehension, (Handmer and Smith, 1992; Anaman, 1996) and tidal wave-related salinization of soils. Factories and warehouses may be out of commission for a time. In agriculture there can be large losses in primary production on account of delays in the recovery of arable land that has been inundated.

Extreme events cause many losses of a personal and domestic nature. The loss of personal belongings, such as clothing, furniture and household items, can be a severe blow to families whose financial reserves are small. The breakdown in public utilities can lead to considerable losses in the domestic context. For example, an electricity failure which puts refrigerators out of action causes perishable foodstuffs to be wasted. All these losses, when aggregated, can amount to a substantial financial loss for a whole community.

The emotional shock of disaster, the death or injury of family members, the separation of families, changes in living accommodation, the burden of hardship from material losses, physical handicap resulting from injury and the loss of income or employment can all create socio-economic problems and affect the ability of an individual or family to recover. The agencies concerned must be conscious of the need to deal with such problems. Some situations require only counselling and advice but there can be many cases in which material help and constant support are needed.

1.6 PREVENTION AND PREPAREDNESS

In recent decades people throughout the world have become increasingly alarmed by natural disasters which are becoming more frequent and more destructive. The forces of nature cannot, yet, be controlled. Humans cannot prevent the formation of a tropical cyclone, an earthquake or the eruption of a volcano. However, we are able to contain rivers, stem tides and build structures that give considerable, if not total, resistance to the forces of nature. Since natural phenomena will continue to occur, the problems they present must be faced, and due priority to policies for disaster planning, preparedness and prevention must be given (ESCAP/WMO/LRCS, 1977).

Disaster prevention measures are complex because of their wide scope and their technical nature. They relate not merely to the disasters themselves but also reflect the interaction between development and the environment on the one hand and between social and economic interests on the other. Except where social considerations are an overriding priority, decisions on disaster prevention should be based on cost-benefit and associated criteria. For example, a proposal to locate an industry in a disaster-prone area should be examined in relation to the probability of damage (vulnerability) and economic factors such as access to water, energy, transport, labour, raw material, etc. The environmental impact of disaster prevention measures should also be considered. Flood control measures and flood management may yield valuable benefits by reducing risks of silting, soil erosion and landslide. When considering the social, economic and even psychological factors at national, regional and local levels, the complexities of disaster prevention and range of technical options to employ are great.

Disaster preparedness is the plan of action or emergency measures which come into force when an extreme agrometeorological event is about to occur. These measures remain in force until some time after the adverse conditions have abated, because action is required not only when an event is approaching but also when it is actually present and in its aftermath.

In an integrated disaster plan, there are two categories of measures. The first concerns those of a permanent nature, referred to as prevention measures. These include structural components – levees, dams, reservoirs, etc. – and non-structural components – land use and zoning, building codes, etc. The second category – preparedness measures – consists of emergency measures, though these must also be planned well in advance. Both categories are essential and should not be viewed as separate undertakings but as essential parts of the overall system for protecting life and property.

1.7 REHABILITATION

If, as a result of the material damage suffered in a locality a large-scale programme of rehabilitation is required, the aim might be to improve rather than merely restore existing living standards and social conditions. Morale is a key factor in rehabilitation. It is possible for people to emerge from a disaster feeling hopeless and apathetic. If this attitude is allowed to persist, people will become over-dependent on welfare services and be a permanent burden to the nation. High morale can be fostered by helping people but at the same time promoting self-reliance.

Rehabilitation should be carried out via a two-pronged programme covering both the victims of the disaster and the public services and amenities

(ESCAP/WMO/LRCS, 1977). For the victims, assistance may include the repair of homes, the provision of basic home needs such as furniture and kitchen utensils, the provision of food and clothing and resettlement. In the agricultural sector, all possible help should be directed at the recovery of land, resowing, desalination, replacement of crops and livestock, repair of irrigation facilities, etc. The costs of restoring these facilities can be very heavy and this consideration should be compared with the area's vulnerability and other factors.

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CHAPTER 2

AGROMETEOROLOGICAL ASPECTS OF DROUGHT AND DESERTIFICATION

(by H.P. Das)

2.1 DROUGHT

2.1.1 INTRODUCTION

Since the beginning of human civilization drought has had severe and sometimes catastrophic effects on vital human activities around the world. Among the various hazards of nature, drought is one of the most disastrous. Few parts of the world can boast of not having faced this calamity at some stage in history. Drought is a progressive ("creeping") phenomena. Both the onset and the end of a drought can often be difficult to identify because they lack a sharp distinction from non-drought dry spells. Drought creates innumerable problems immediately or with a time lag as the economy gradually experiences the adverse effects of this phenomenon. If the drought is widespread and prolonged, the cumulative effect is usually disastrous. A major drought not only causes serious dents in the economy but also dampens peoples' resolve. Drought impacts are felt not only on agriculture but also on urban water supplies, industrial production, pollution control, navigation and energy recreation.

The occurrence of severe droughts throughout Africa and in India, North America, China, the Soviet Union, Australia, and Western Europe in the 1980s once again underscored the vulnerability of both developed and developing societies to drought. Even in the present age of high technology and instant communication, agricultural and livestock production can be sharply reduced by drought-related stresses. No country can claim to be immune from the uncertainties of seasonal or annual rainfall. Although we have little capability (if any) to avert meteorological drought, reliable information about drought and its impacts could be used by individual farmers as well as planners and political leaders at national level to improve society's ability to minimize the scope and severity of its consequences. Societal vulnerability to drought is increasing, largely because of population growth and society's increasing demand and competition for limited water resources.

Drought has also been blamed for prompting mass migrations, environmental degradation (often referred to as desertification) and internal unrest. While drought by itself may not appear to be a major cause of societal dislocation, it can combine with underlying societal problems to initiate new changes or to accelerate the otherwise slower changes that are already underway. Often the impacts of drought lingers long after a drought has ended, thereby dissociating the drought itself from many of its impacts.

2.1.2 DROUGHT AND FAMINE

Droughts often become highly visible when they are associated with famine. The truth is that governments prefer to blame natural factors such as droughts for extreme food shortages. For the most part, droughts can occur without precipitating a famine situation; and historical records have shown that famines have frequently taken place in the absence of drought conditions. Many authors have explained why droughts need not result in famine and famines do not necessarily have their origin in drought (Sen, 1981; Watts, 1983; Torry, 1984). Often, drought, a "creeping" phenomenon, combines with other underlying societal and environmental conditions to produce famine-like conditions. The fact that drought need not be a causative agent in producing famine became clear in 1992. The reason 1992 is cited as the critical year for understanding famine comes from the situations of three distinct groups of people (Bosnians, Somalis, and Kurds) in three separate parts of the world (Europe, Africa and the Middle East, respectively). In each case one found starving people, yet in each case, weather played little or no role, while military conflict played a major one. Though governments would prefer to have blamed their inability to feed their people on weather-related problems, these three 1992 famine situations do not allow them to get away with it (Glantz, *et al.*, 1985).

2.1.3 Drought concepts, definitions and quantifications

In order to discuss drought phenomena and their impacts, the concept "drought" needs to be defined. The definition and particularly the quantification of the term "drought" (and even the concept of drought) is controversial. In the past, there has been no universally accepted definition of drought, partly perhaps because the concept is not absolute but relative to users and expectations. In very general terms, drought is a condition of moisture deficit of sufficient magnitude to have an adverse effect on vegetation, animals and people over a sizeable area (Warrick, 1975). Drought has been grouped by type as follows: meteorological, hydrological, agricultural and socio-economic (Wilhite and Glantz, 1985).

Meteorological drought can be defined as a percentage departure from the long term average rainfall in a given region. A meteorological drought is sometimes difficult to identify with any degree of reliability, because meteorological and climatological information in many countries is either not available at all or available for only short time periods or is of relatively poor quality. Definitions of meteorological drought are considered as region specific since the atmospheric conditions that result in deficiencies of precipitation are highly variable from region to region. Human perceptions of these conditions are equally variable. Hydrological drought is represented by the water shortage formed by an imbalance between surface water and underground water. It is mainly affected by hydrological factors such as surface run-off and shallow or deep drainage. Meteorological drought, if prolonged, could result in hydrological drought with a marked depletion of surface water and consequent drying up of reservoirs, lakes, streams and rivers and a fall in the water table. Hydrological drought is often out of phase with meteorological drought.

In defining agricultural drought, rainfall deficiency has to be taken into account, along with the physical and biological aspects of plants, interactions within the soil-plant-atmosphere continuum and the balance between the water demand of plants and its supply. An agricultural drought occurs when soil moisture and rainfall are inadequate during the growing season to support a healthy crop growth to maturity causing extreme crop stress and a drastic fall in yields. While meteorological droughts result from precipitation deficiencies; agricultural droughts are largely the result of soil moisture deficiencies. A plant's demand for water is dependent on the prevailing weather conditions, its genetic characteristics, its stage of growth and the physical and biological properties of the soil. An operational definition of agricultural drought should take into account the susceptibility of crops to extreme meteorological conditions at different stages of their development. For example, deficient subsoil moisture during an early growth phase will have little impact on final crop yield if topsoil moisture is sufficient to meet early growth requirements. However, if the deficiency of subsoil moisture continues, a substantial loss in yield may result.

Finally, socio-economic drought refers to drought attributed to the joint effects of natural and societal factors. This type of drought is associated with the supply and demand of some economic goods. It occurs as an interaction between agricultural activity (i.e. demand) and natural events (i.e. supply) resulting in inadequate water volume or quality for plant and/or animal needs. The supply of some economic goods (e.g. water, hay, electric power, etc.) is weather dependent. In most instances the demand for goods in general is increasing as a result of increasing population and/or per capita consumption. Therefore socio-economic drought could be defined as occurring when demand exceeds supply as a result of weather related shortfalls (Sandford, 1979). This concept of drought supports the strong symbiosis that exists between drought and human activities. This type of drought is related to factors such as the distribution of plants, animal and human populations, life style, land use, etc.

2.1.4 Data availability

Most drought monitoring systems are based largely on meteorological data. Such systems are valuable as a first stage in drought assessment. Meteorological data can be used in conjunction with other data and information to estimate the probable impact of a drought. Identification of drought of any category and its extent needs different types of data depending upon the purpose for which the drought is being defined. The most common data for all types of drought assessment is rainfall. Hydrological drought monitoring requires rainfall and evaporation data and information on the water holding capacity of the soils in the catchment areas of the water bodies. For agricultural drought assessment data on soil type, its texture, water holding capacity, the slope of the surface, soil bulk density, cultivar characteristics, irrigation and crop management are needed.

Among developing countries, India now has systematic data, covering more than a 100 years, on important weather factors such as rainfall, temperature, atmospheric pressure, winds, etc. for a number of stations. For information relating to earlier centuries, one has to fall back on cursory records and such indirect information on weather patterns as is provided by growth rings of old trees, i.e. dendrochronology. As far as agricultural drought is concerned, the water requirements of crops vary considerably between different crops and between different stages of the same crop. A detailed study of crop water requirements is presented by Doorenbos and Pruitt (1977) and Yao (1981). The impact of droughts will not be well understood unless the key phases of crop development especially susceptible to adverse weather conditions are considered. Data on crop type and developmental stage should also be collected and analyzed for calculations of crop specific evapotranspiration. Criteria and thresholds for the onset and cessation of drought conditions must be developed, integrating meteorological and crop data for specific regions. Unfortunately, such data are greatly lacking in most countries. In India, reliable data is now available from nearly 200 agrometeorological observatories and 620 observatories recording evaporation. Data on the evapotranspiration loss of crops are also available from 39 stations.

In arid zones, much of the rainfall is lost by surface run-off or evaporation. Countries such as Tunisia, Jordan and Syria have reported successful utilization of surface run-off water for irrigation. Unfortunately in most cases, there is no accurate quantification of surface run-off.

Strong emphasis must be placed on the reliability and timeliness of data. Data must be collected at an adequate spatial density to properly represent drought conditions and it must be of sufficiently high quality to allow accurate assessment. Information on the onset, severity, spatial extent and the probable impacts of the drought are not always disseminated to users in a real-time mode. Information should reach users in time to be incorporated in the decision-making process. It is imperative that the timing of critical decisions by primary users be taken into account. It is also essential that data and information delivery systems be developed in concert with user requirements and that educational programmes be made available to primary users to train them in product application. Lines of communication must be established with all primary users and they must be open at all times.

Monitoring, detection and reporting systems are generally more effective if they are built on several independent data collection networks. Three main types of data collection networks exist for this purpose:

(*a*) Networks of surface-based instruments, including both low (e.g. manual weather observation networks) and high technology (e.g. automated weather observation networks) types;

(*b*) Satellite imagery; and

(*c*) On-site inspections.

Ironically, the so-called low technology methods of communication are not a feasible option for transmitting data and information in many developing countries because of poor basic infrastructure. Automated data collection or high technology systems that can transfer many kinds of data from meteorological and agronomic sensors through surface-based or satellite linkages are becoming more affordable. No data collection system is however complete unless it includes an efficient and effective means of communication from the observation point to the processing or analyzing point. Adequate quality control, regular instrument maintenance, efficient procedures, and communication channels for transmitting advice and warnings to users are also essential. Maintaining or enhancing existing networks and/or establishing new data collection networks is generally costly, but this is essential to ensure a dependable monitoring system. An inventory may identify areas of data deficiency (quantity or quality) that must be addressed. Needless to say, meteorological data represent an important part of any drought monitoring system.

Conventional surface observation stations within National Meteorological services provide essential benchmark data and time series necessary for improved monitoring of the climate and hydrologic system. Currently, many observational networks, especially in developing countries, do not provide sufficient information for some user applications. Reporting networks also need to be upgraded by adding automated stations to provide more timely reporting of data and/or data gathering from remote locations. All these have been defined by Wilhite (1990) as the data-information continuum (Figure 2.1). Incidentally, automated networks have been operating on a routine basis in many developed and developing nations. In this connection, the use of Advanced Very High Resolution Radiometer (AVHRR) digital data from the GOES satellite, operated by NOAA (Tucker and Goward, 1987) should be considered seriously. These data are transmitted by the satellite in five discrete bands of the electromagnetic spectrum, two of which are useful for land resource investigations. These data can be used to depict changes in the photosynthetic activity of vegetation and thus are useful in the early detection of the onset and spread of drought conditions. These data are used routinely as part of the Famine Early Warning System (FEWS) in Africa and the National Agricultural Drought Surveillance System in India (Thiruvengadacheri, 1991); many other nations also use the data.

2.1.5 Causes of drought

Drought is a regional manifestation of general climatic fluctuations associated with persistent large-scale aberrations of the atmospheric circulation. Meteorologists usually explain drought in a given region in terms of the abnormal atmospheric

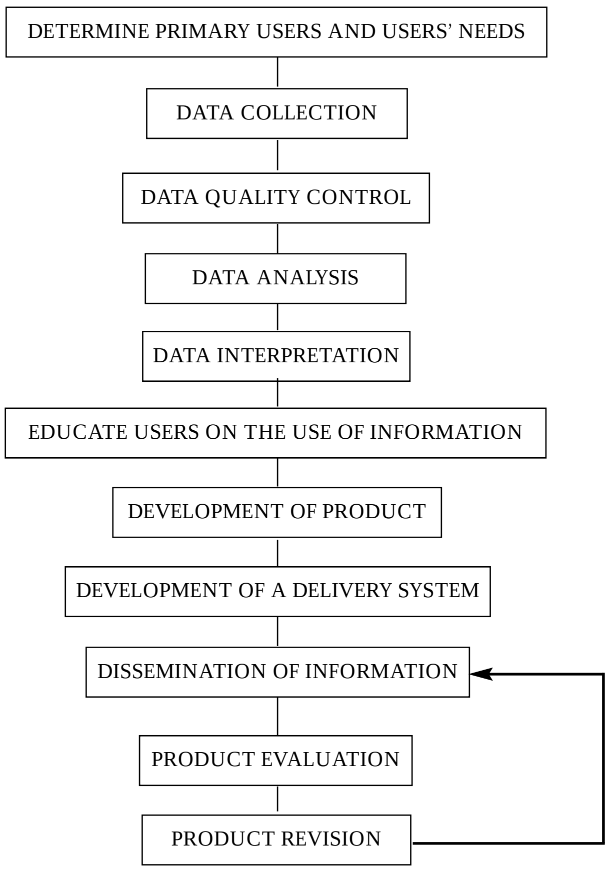

Figure 2.1
The data-information continuum for the development of weather/climate data-based products (Wilhite, 1990)

circulation patterns which favour subsidence over the region. Although ultimate causes for climatic fluctuations and variations have not been identified with certainty, factors may include changes in the composition of the atmosphere, large-scale volcanic activity and episodes in sea-surface temperature in the equatorial Pacific (called El Niño), etc. Identification of the consistent El Niño Southern Oscillation (ENSO) precipitation relationship provides the clearest indicator that seasonal meteorological drought in quite extensive areas of the globe may be predictable. The link with ENSO can be formalized by calculating precipitation probability distributions conditional on the state of ENSO (Ropelewski, 1995).

2.1.6 Spatial and temporal aspects of drought

The importance of precipitation to agriculture is obvious, being the principal source of moisture required for crops and livestock. Timing and frequency of precipitation are extremely important. Short-term episodes of dryness may be of little consequence to crops at a particular phase of their growth cycle, while a similar occurrence during a highly sensitive phase may ultimately ruin the crop and drastically reduce the yield potential. Identifying the onset of drought should consider not only the normal climatic regime but also regional agricultural zones. The commencement of drought need not coincide with the beginning of a dry spell, since as far as agricultural drought is considered, the crops may survive for some time on stored moisture. The depletion of water levels in dams and rivers, which connotes meteorological drought, is felt only after the level drops substantially. The cessation of a drought episode is also difficult to determine because brief intermittent interruptions of the drought event may be of little significance to agriculture (WMO, 1992). A heavy rainfall event following a long dry episode may produce more run-off than moisture penetration into the parched soil and hence, though useful for terminating hydrological drought, may be of little consequence to agriculture.

The onset of drought may be hastened by anomalies in high temperatures, high vapour deficits and strong winds. These should be factored into the drought analysis. Another distinguishing feature of drought is its duration. Droughts usually require a minimum of two to three months to become established and usually last for more than a season, but sometimes for several years or even decades. The magnitude of drought impacts is closely related to the timing of the onset of the drought, its intensity and the duration of the event. Droughts also differ in terms of their spatial characteristics. They can occur over areas of a few hundred square kilometres but almost invariably intensities are not uniformly severe and duration is relatively short. On the other hand, continental drought may extend over vast areas covering hundreds of thousands of square kilometres. In large countries, such as Brazil, China, India, the United States and Australia, drought rarely affects the entire country.

2.1.7 Impact of drought

Drought is a phenomenon that can be realized only after it has occurred. The importance of drought lies in its impact on agriculture and related socio-economic factors.

2.1.7.1 Drought and its agricultural impact

In agriculture, severe drought is the phenomenon where soil moisture is insufficient to meet normal plant development and growth requirements. It is a complex phenomenon affected by a number of factors namely:

(*a*) Meteorological factors, i.e. precipitation and its intensity, air and soil temperature, solar radiation and sunshine duration and wind speed;

(*b*) Agricultural factors, i.e. the type of crop, stage of plant development and method of cultivation;

(*c*) Natural environment factors, i.e. soil, hydrology and drainage of the soil, topography and land forms; and

(*d*) Irrigation and anthropogenic factors associated with land use practices, notably deforestation and over grazing which tend to modify the surface reflectivity (albedo), surface roughness and moisture convergence.

These affect the feedback on moisture recycling mechanisms leading to reduced evaporation and hence available atmospheric moisture required for cloud formation and hence precipitation (Gbeckor-Kove, 1995).

Lack of water in the soil results in less water being absorbed by the roots of plant while at the same time more is being transpired by the leaves. As a consequence, the water budget within the body of a plant becomes unbalanced leading to water deficit. Water deficiencies during the growing season often result in stunted or distorted development and reduced crop yields. When hardened plants are subjected to drought, their protoplasm shows a lower viscosity and higher permeability to water than that of similar but non-hardened plants. Higher rates of photosynthesis, lower rates of respiration and a higher root/shoot ratio characterize hardened plants contributing to large yields. The reverse is the case for non-hardened plants. When effective moisture in the soil decreases to a certain level, plant roots are hindered from absorbing moisture and the plant begins to wilt. In due course permanent wilt brings severe damage to plant.

Drought conditions also lead to:

(*a*) Shortage of food production due to crop failure;

(*b*) Shortage of fodder and drinking water for cattle, migration of livestock population and even decrease in animal population;

(*c*) Shortage of draught power for agricultural operations during the subsequent period as a result of the reduced animal population; and

(*d*) Deforestation because of increased fuelwood needs due to the non-availability of agricultural wastes and crop residues.

Droughts have an immediate effect on the recharge of soil moisture resulting in reductions of streamflow reservoir levels and irrigation potential and even the availability of drinking water from wells. In regions dependent on groundwater for irrigation, poor farmers are affected because their wells are shallow. Rich farmers have deeper wells and can afford higher pumping costs. Thus, drought increases disparities. When drought occurs consecutively for two years, hydropower generation is also adversely affected (Wilhite, 1993). Indirect effects of drought on agriculture-related activities:

Area under cultivation

In the event of a prolonged drought, farmers, either alone or with the entire family, may abandon their land in search of work and food in nearby cities. Fewer and weaker family members remain to till the land, affecting the area under cultivation (McCann, 1986). The acreage planted to food crops is also affected by land quality. Due to the uncertainty of rains during the drought, farmers sometimes make several attempts at sowing of seeds leading to a drastic reduction in seed reserves, which in due course are neither sufficient for planting nor for consumption. The farmer is then obliged to borrow, offering labour or perhaps a portion of the future harvest as payment for the loan.

Land degradation

Drought not only exposes and accelerates existing land quality problems, it also initiates new ones. The cultivation of lands subject to a high degree of rainfall variability makes them extremely susceptible to wind erosion (and desertification) during prolonged drought episodes, as the bare soil lacks the dense vegetative cover necessary to minimize the effects of aeolian processes. As the fertility of the land and crop yields decline farmers search for new land to cultivate. Farmers are sometimes forced to cultivate lands considered marginal from the viewpoint of soil quality, terrain slope and rainfall (Glantz, *et al.*, 1986). These newly cultivated lands are high risk areas in the long run for rainfed agriculture.

Decreased export potential

Governments usually give certain agricultural commodities favoured treatment for export to earn foreign exchange. Even cash crops grown in relatively fertile and better watered areas are not immune from the secondary effects of prolonged droughts and fail to attain their full potential. Generally, foreign exchange earned from cash crops is not used for agricultural development; instead it is often diverted to support non-development related programmes. Drought affects labour supply in the agricultural sector; men often leave their villages in search of income-generating work. This robs the rural areas of the much-needed labour supply for agricultural activities and leads to a fall in agricultural production (Glantz, 1987).

2.1.7.2 Socio-economic impacts

Other socio-economic implications of droughts include a rise in the prices of essential commodities, import of food grains, distress sale of cattle, rural unemployment, health hazards, depletion of farmers assets, the spread of refugees, social instability and deaths due to malnutrition and hunger. Desertification and a reduction of water resources are also indirect effects of drought. Drought impacts are long lasting, at times lingering for many years. Human and social factors aggravate the effect of drought as it takes several years for small and marginal farmers in drought areas to recoup the losses. Wilhite and Wood (1994) presented a comprehensive list of the impacts of drought classified as economic, environmental and social.

2.1.7.2 Beneficial aspects of drought

While we have focused on the negative impacts of drought, it does also have some beneficial aspects. Generally, the beneficial aspects are less emphasized and may have smaller economic and social significance than the negative aspects. Moderate drought in the post flowering maturity stage of sugar cane, for instance, helps to increase the sucrose content.

Other beneficial aspects include mosquito reduction, reduced cost for snow removal in snowfall regions and other related activities, emergency water conservation leading to the permanent and efficient establishment of water saving use patterns, etc. At the secondary level, drought may reduce population immigration to areas especially prone to droughts.

Droughts may help control overproduction in agriculture and other sectors, thus contributing to more stable prices and survival of farming communities which may be threatened by overproduction.

2.1.8 Forecasting drought

Drought is a phenomenon associated with water scarcity. The period during which the scarcity is likely to be experienced, the extent of the scarcity and also the areas/regions that are likely to be affected by drought have to be known in advance. Such information can be utilized to make an assessment of the impact of drought and identify suitable mitigation measures. This problem can be investigated by subjecting the drought data, particularly rainfall, to statistical techniques to explore the possibilities of any systematic pattern – trend, persistence or cycle. Kogan (1997) brings out the importance of the antecedent precipitation to some drought impacts as shown by satellite monitoring. However, forecasting of meteorological drought is not yet operationally possible, although some statistical and dynamical forecasts have been prepared experimentally for the Sahel, north-east Brazil, the United States and Japan (Barnett, *et al.*, 1993; Cane, *et al.*, 1994).

The information on the probable occurrence of droughts of various intensities can be used for evolving land use systems and appropriate management practices that can minimize the impact of drought, in the event of its occurrence. Certain concepts and related research results that may be useful in moderating the effect of soil moisture stress during the occurrence of drought have been described in detail by several workers (Katyal, *et al.*, 1992; Hough, *et al.*, 1996). Information on the critical dates beyond which the sowing of traditional crops/varieties is likely to adversely affect crop yields can facilitate the evolution of contingency crop plans under low rainfall conditions. Finding adequate fodder for cattle during drought years is a serious problem and mobilization of fodder from elsewhere involves enormous transportation costs. Therefore, fodder security has to be at the top of the agenda in drought prone areas. The generation of raw materials as inputs for agro-based rural industries will provide additional employment opportunities for the people living in drought prone areas.

2.1.9 Drought detection, monitoring and early warning

A drought detection, monitoring and early warning system must provide reliable and timely information to users. Through such a system, by using real-time information about the onset of drought conditions, it should be possible to reduce the adverse effects of drought.

Such information could facilitate:

(*a*) Decisions at the time of sowing about the choice of crops/varieties;

(*b*) The adoption of management practices related to soil moisture conservation, fertilizer application and thinning of plant populations during the crop growing period.

The onset of drought is gradual and its intensity develops slowly over a prolonged period. These features of drought have made monitoring drought conditions a difficult task. In general, two types of monitoring systems exist: surface observation and satellite/remote sensing networks. Using both methods, a three-dimensional monitoring system can be established, characterized by combinations of ground-based observation and space-based and mobile observation facilities. These networks are capable of monitoring all the critical elements associated with drought, including precipitation, surface water, soil moisture, crop water requirement, groundwater, irrigation and drainage. In addition, drought indices can be calculated using data collected from these networks. It is vital to transmit this information in a timely fashion via suitable telecommunications systems. A properly organized delivery system is essential for the monitoring and early warning system to be effective as a disaster mitigation tool. On the basis of the information generated through this system, emergency activities can be better coordinated. This information, used in combination with weather/drought forecasts, can provide decision-makers with the information needed for disaster management and also provide a scientific rationale for government and other sectors to make short-, medium- and long-range decisions. In drought monitoring, it is essential to establish appropriate and reliable drought indices for different user groups.

2.1.9.1 Drought indices

A drought index calculated from known values of selected parameters enables the description of drought to be expressed quantitatively. There are two primary uses for an index of drought, namely for evaluating the drought hazard over an area and in assessment of the current extent and severity of drought over a region. The majority of indices reflect the meteorological drought but not the agricultural one. These indices, as such, cannot serve the purpose of drought problems linked to crop production. The problem of agricultural drought pertains to the physical and biological characteristics of plants and their interaction with the environment. Hydrological drought differs from meteorological drought in that the streamflow rate, water reservoir supplies and groundwater levels are affected by longer durations of unseasonable dryness.

Meteorological drought indices

Most meteorological drought indices use deviation of the seasonal or monthly value of various weather elements from a central value to quantify drought severity. With a view to assessing deficiency in monsoon rainfall in India, an index termed the Monsoon Deficiency Index was developed by Mooley and Parthsarthy (1982). This index was obtained by expressing the area of the country receiving 80 per cent of the normal seasonal rainfall as a fraction of the total area of the country. Mooley and Parthsarthy (1983) proposed another criterion based on rainfall expressed as a standard deviate, Y_i given by:

$$Y_i = (X_i - \bar{X})/\sigma$$

where X_i is the rainfall of i^{th} year; $\bar{X}$ the normal rainfall; and σ the standard deviation. They consider drought to have occurred when $Y_i < -1.28$, the value 1.28 being 10 per cent value of the Gaussian distribution.

Gibbs (1964) has shown that the mean and standard deviation of the square roots can give an adequate description of the entire rainfall distribution. The percentile and decile methods are also often used. The fifth decile or the median is the amount that was exceeded on 50 per cent of occasions. The first decile range (i.e. the range of values below the first decile) implies abnormally dry conditions, while the tenth decile range (i.e. above the ninth decile) implies very wet conditions.

The most elaborate and perhaps the most satisfactory indices are the Drought Severity Index derived by Palmer (1965) for Colorado and his Crop Moisture Index (1968); the former reflects meteorological drought and the latter gives an idea of the severity of agricultural drought.

The Palmer Drought Severity Index (PDSI) relates drought severity to the accumulated weighted differences between actual precipitation and the precipitation requirements of evapotranspiration. The PDSI is based on the concept of an hydraulic accounting system and is actually used to evaluate prolonged periods of abnormally wet or abnormally dry weather. McKee, *et al.* (1993) developed the Standardized Precipitation Index (SPI) as an alternative to Palmer's index.

Historical data are used to compute the probability distribution of the monthly and seasonal observed precipitation totals and then the probabilities are normalized. This methodology also allows expression of droughts (and wet spells) in terms of precipitation deficit, percent of normal and probability of non-exceedance. WMO (1975) gave a number of drought indices based on rainfall and temperature for meteorological drought.

Agricultural drought indices

Agricultural drought indices are mainly developed from rainfall, evaporation, evapotranspiration, water status of soil at different stages of crop development, etc. and have been used to quantify the severity of agricultural drought. Agricultural drought begins when the vegetation cannot extract water from the soil rapidly enough to replace the moisture loss by respiration. It persists when there is no continued replenishment of the water in the soil. Most of the agricultural drought indices are used to express the degree to which the agricultural system has been affected by water deficit.

There are many indicators that a plant is suffering from physiological drought, which is related to agricultural drought, such as wilt, leaf colour change and loss of rigidity, leaf shedding, change in orientation, growth retardation, leaf and stem elongation etc. Considering the complex physical processes involved in the response of the agricultural systems to water deficit, it may be very difficult to quantify the effects of agricultural droughts accurately. Agricultural drough indices have therefore been derived from a variety of simple parameters to more complex functions involving a combination of soil moisture, crop parameters and many other factors. A very useful method of finding the severity of an agricultural drought – the Crop Moisture Index (CMI) – was devised by Palmer (1968) by modifying the PDSI. The CMI defines drought in terms of the magnitude of the computed abnormal evapotranspiration deficit.

Dyer and Baier (1979) developed an index to approximate the drying patterns of various soil types. This replaced an earlier approach of selecting a table of coefficients for each drying curve. This technique was used in the "Versatile Soil Moisture Budget" model (Baier and Robertson, 1966). Jackson (1982) presented a theoretical method for calculating a Crop Water Stress Index (CWSI), requiring estimates of canopy temperature, air temperature, vapour pressure deficit, net radiation and wind speed. The CWSI was found to hold promise for improving the evaluation of plant water stress. The use of canopy temperature as a plant's drought indicator and stress is used by Idso, *et al.* (1980) to calculate the Stress Degree Day (SDD) index. The cumulative value is related to final yields.

Other indices have considered the major agrometeorological factors which are severely affected by moisture deficits. Such parameters include the biological condition of plants, soil type, nutrient constraints, stages of plant development, final crop yield and several other agrometeorological factors. Many of these methods have been discussed by WMO (1971, 1975*a*, 1975*b*, 1983, etc.).

Hydrological drought indices

The frequency and severity of hydrological drought is often defined on the basis of its influence on the river basin. Hydrological droughts are often characterized by low streamflow, low precipitation, a fall in the levels of lakes, wells and reservoirs, depletion of soil moisture, lowering of groundwater tables, changes in run-off patterns, evaporation rates, etc. Changes in these parameters together with other hydrological factors have been used to quantify the severity of hydrological droughts (Chow, 1964; WMO, 1969, 1983*a*). Water balance indices can also be derived for the hydrological system. Although the PDSI is sometimes used as an indicator of hydrologic drought, other definitions have been formulated which better serve the needs of hydrologists. For example, a definition of hydrological drought was developed in Colorado in 1981.

To assess drought conditions in high elevation river basins that are dependent on snow melt as their main source of water supply (Shafer and Dezman, 1982), the Surface Water Supply Index (SWSI) was intended to be complementary to the PDSI, with the latter applying mainly to non-irrigated areas independent of mountain water supplies. The SWSI integrates historical data with current reservoir figures and precipitation at high elevation into a single streamflow.

2.1.9.2 Monitoring by satellite remote sensing

The ability to use satellite data to detect drought conditions is based on the spectral manifestations of reduced photosynthetic capacity which is associated with precipitation shortfalls. By analyzing several years of satellite data, we can make comparisons between years in terms of estimated photosynthetic capacity. Lower than average conditions provide the means to substantiate the occurrence of drought. Monitoring by remote sensing techniques is most appropriate for detecting the status of crop growth, soil moisture, evapotranspiration and precipitation. Using a surface observation station network and remote sensing techniques, development and spread of drought conditions can be monitored in a routine and cost effective manner. Since 1979, the Assessment and Information Service Centre (AISC) of the NOAA/NESDIS has been providing drought early warning alerts and climate impact assessments to national and international agencies that require such information for disaster preparedness and agricultural assessment (Sakamoto and Steyaert, 1987). The Drought Early Warning programme of AISC is an operational programme that includes assessment modelling, assessment reporting and development of technical assistance in less developed countries.

2.1.10 Adaptation and adjustments to drought

Drought does not descend all of a sudden. It results from a set of weather sequences that requires an extended period to develop. Thus it takes a long period for a drought situation to begin, expand and decay – allowing time to adopt contingency plans to reduce the adverse effects of drought. There are two distinct phases in which the application of weather and climate knowledge can reduce the impact of drought on communities. The first is long-term planning in which strategies can be devised, and precautions taken to reduce impact. The second phase is the action to be taken to reduce the adverse effects during the onset of the event.

In arid, semi-arid and marginal areas with a probability of drought incidence, it is important for those responsible for land use planning to seek expert climatological advice regarding rainfall expectations. Drought is the result of the interaction of a human pattern of land use and rainfall regimes. In these regions a detailed examination of rainfall records is essential. In this regard, the development of methods of predicting, many weeks or months in advance, the occurrence of rainfall 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 to the overall water requirements within an individual agroclimatic zone. Crops which 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, need to be monitored with 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, etc. 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 varietal manipulation. By adopting varieties that are drought-resistant at different growth stages, the effects of drought can be avoided or minimized.

If drought occurs during the middle of a growing season, corrective measures can be adopted; these can include reducing the plant population, fertilization and 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.

However, no one strategy can be adopted universally. In fact, all such strategies are location, time, crop, crop stage and (to some extent) socio-economic condition specific. Developing such strategies for each specific factor can help make agriculture sustainable.

Once drought has set in, individual farmers, in an effort to adapt and adjust, often: (i) reduce consumption; (ii) postpone social arrangements such as marriages; (iii) migrate to better areas with livestock or sell livestock; (iv) take loans; and (v) sell assets such as gold ornaments (Venkateswarlu, 1987).

Only very few farmers are able to store food grains and fodder to tide them over the crisis during the years of drought. Some strategies also believed to alleviate drought conditions include: (i) groundwater exploitation; (i) soil and water conservation and management; (iii) intercropping; (iv) introduction of alternative crops/varieties; (v) afforestation; and (vi) the creation of storage facilities for food and fodder by constructing of rural godowns.

2.1.11 Drought management: mitigation, preparedness and policy

Drought is a recurring phenomenon and its occurrence cannot be avoided. However, its impact can be minimized through the application of science and technology in developing suitable drought management plans (Das, 1995). Usually within a drought affected region, while some areas are devastated there are always others which remain unaffected. It is important to develop infrastructure for mitigating drought. Drought planning and water crisis management need to be proactive – the overall policy, legislation and specific mitigation strategies should be in place well before a drought or water crisis affects the regular supply of the country's water resources. Ad hoc crisis management is inferior and more costly than implementing a pre-planned crisis policy. Hastily prepared assessment and response procedures may lead to an ineffective, poorly coordinated and untimely response (Wilhite and Easterling, 1987; Bruins, 1993).

The analysis of drought risk can be investigated on the basis of meteorological, paleoclimatic and historical data on climatic variations (Bruins, 1994; Issar, *et al.*, 1995). The timescale in which severe droughts recur may exceed the average human lifespan. Perception of both risk and impact may therefore disappear from public memory – this can have a bearing on planning and policy by the authorities. Drought definitions need to be precise, regional and even specifically targeted at selected economic activities to be useful for government policy and proactive planning.

Assessments have to be made of the impact of drought on the various water resources, economic sectors, towns, villages and the environment. Respective vulnerability of different sections of the environment, economic activities and social groups needs to be studied at different levels – local, provincial, national and regional (Bruins and Lithwick, 1998). Drought scenarios have to be drawn up on the basis of available information, including frequency and severity, if applicable. Finally, proactive drought contingency planning needs to be developed. Wilhite (1993) outlined in considerable detail a generic process with meteorological steps that may be adopted by governments (Wilhite, 1986; Wilhite and Hayes, 1998) to develop comprehensive drought planning and management. Proactive planning needs to be executed through interactive management (Bruins and Lithwick, 1998) to ensure planning for future drought situations is as comprehensive as possible. Actual realization of the proactive plans in times of drought needs to be adjusted and updated through interactive management.

The major issues that need to be addressed in this connection are:

(*a*) Research efforts must deployed in making a reliable assessment of the likely impact of the drought;

(*b*) Availability of resources such as credit, fertilizers, pesticides and power for increasing production;

(*c*) Organization of buffer stocks of food grains and fodder to cope up with the likely or anticipated shortages;

(*d*) Coordination of the activities of various agencies in implementing drought management plans;

(*e*) Education of the population on the various mechanisms available to cope up with the drought situation;

(*f*) The enhancement of local employment opportunities to reduce the percentage of the population dependent upon agriculture in drought prone areas or their migration to the cities; and (*g*) Providing economic relief through the creation of durable assets rather than extending subsidies.

Coping strategies for responding to and preparing for drought are numerous and range from the individual or household level to the national level, as described in this chapter. Government policy responses to drought can be broadly classified into three types (Parry and Carter, 1987): pre-impact programmes for impact reduction, post-impact government interventions and contingency arrangements or preparedness plans. Pre-impact government programmes are defined as those that attempt to mitigate the future effects of drought. Specific drought-related examples include the development of an early warning system, augmentation of water supplies, demand reduction (such as water conservation programmes) and crop insurance.

Post-impact government interventions refer to those reactive programmes or tactics implemented by government in response to drought or some other extreme climatic event. This includes a wide range of reactive emergency measures such as low-interest loans, transportation subsidies for livestock and livestock feed, provision of food and water via tankers, drilling wells for irrigation and public water supplies. This reactive crisis management approach has been criticised by scientists, government officials and many relief recipients as inefficient, ineffective and untimely (Wilhite, 1993). More recently, the provision of emergency relief in times of drought has also been criticized as being a disincentive to the sustainable use of natural resources because it does not promote self-reliance (Bruwer, 1993; White, *et al.*, 1993). In fact, this approach may increase vulnerability to drought as well to other natural hazards.

Contingency arrangements refer to policies and plans that can be useful in preparing for drought. These are usually developed at national and provincial levels, with linkages to the local level. The ultimate goal of these preparedness plans is to reduce vulnerability to future episodes of drought. Until recently, nations had devoted little effort to drought preparedness, preferring instead the traditional reactive or crisis management approach.

Deficiencies of previous drought assessment and response efforts are well documented (Wilhite, 1992). They include:

(*a*) Lack of appropriate climatic indices and early warning systems, as well as a lack of triggers for initiating specific actions;
(*b*) Insufficient databases for assessing water shortages and potential impacts;
(*c*) Inadequate tools and methodologies for early estimates of impacts in various sectors;
(*d*) Insufficient information flow within and between levels of government on drought severity, impacts and appropriate policy responses;
(*e*) Inappropriate or untimely emergency assistance programmes;
(*f*) Poorly targeted emergency assistance programmes that do not reach vulnerable population groups and economic sectors;
(*g*) Meagre financial and human resources that are poorly allocated;
(*h*) Lack of emphasis on proactive mitigation programmes aimed at reducing vulnerability to drought;
(*i*) Institutional deficiencies that inhibit effective emergency response; and
(*j*) Lack of coordination of policies and programmes within (horizontal) and between (vertical) levels of government.

Institutional, political, budgetary and human resource constraints often make drought planning difficult (Wilhite and Easterling, 1987). One major constrain that exists worldwide is a lack of understanding of drought by politicians, policy makers, technical staff and the general public. The recent efforts to combat drought through policies formulated by the government agencies include: (i) crop weather watch groups at national and state levels; (ii) food security through buffer stocks; (iii) priority in the most seriously affected areas through the "food for work"/National Rural Employment Project and other programmes; (iv) high priority of food production in the most favourable/irrigated areas as compensatory programmes; (v) optimum input use; (vi) the construction of rural godowns to avoid distress sales; and (vii) crop insurance schemes.

The approaches and types of programmes in response to drought, whether long term or short term should be constantly scrutinized to find ways of improving them and each drought phenomenon must be followed by a review of the functioning of the organization and of the public response.

2.1.12 Summary and conclusion

Although in one sense drought is essentially a physical phenomenon as described above, in another sense it can be considered essentially a socio-economic phenomenon. Physical drought encompasses various hydrometeorological characteristics, while socio-economic drought evaluates the effects of the same variables on the general well-being of the society.

Drought characteristics and impacts have both long-term and short-term effects. Short-term effects are generally well known. Dryland agriculture is often the first to experience the direct effects of drought, usually in the form of reduced yields and dust blowing winds. When soil moisture levels drop during drought situations, transpiration and plant growth decrease, the latter being more pronounced than the former. Irrigated agriculture also suffers directly. When household water provision is disrupted, while economically less important, the drought is brought home to everyone and, in extreme cases, can create severe problems in health, nutrition and sanitation.

The long-term effects of drought are more subtle and difficult to assess, but it is reasonable to assert that their magnitudes could exceed short-term effects. Very few of the expected long-term drought effects have been studied in sufficient detail to assess the magnitude of economic losses and social inconvenience and maladjustment. Likewise, there is insufficient knowledge for developing and assessing cost-effective means of mitigating long-term effects.

At regional, and especially at national levels, the policy issues and corresponding drought strategies acquire different dimensions. Here the imperatives are not simply for pooling physical requirements in multipurpose, basinwide, integrated water systems, but rather for actions which facilitate provision of credit, technological expertise, research funding, etc. Other devices include the provision of drought insurance, loans, grants, etc.

The use of drought resistant crops and vegetation can be an effective way to cope with restricted or limited water availability during droughts. Agronomic research in this area requires proper identification of drought resistant plant varieties and various possible conditions as defined by such variables as rainfall distribution, soil type and growing season. This knowledge, in addition to proper quantification and evaluation of drought resistance, should accelerate development of plant hybrids resistant to droughts. Continuing research on the response of crop varieties to limited or scarce water supplies is needed. Where water is available, irrigation and conservation practices may provide effective ways of agricultural adjustment to drought. In these cases, aspects such as timing of irrigation, management of land and crop use, etc. need to be studied.

2.2 DESERTIFICATION

2.2.1 Introduction

Desertification is a worldwide phenomenon affecting all continents but it mostly affects the arid and semi-arid zones of the world. In recent years this menace seems to be accelerating most rapidly in developing countries. These countries are experiencing a phenomenal increase in population largely because of their traditional high fertility rate and a reduced mortality rate, made possible by modern healthcare facilities. This increase in turn imposes a corresponding rise in livestock or in expansion of arable farming on lands which are only marginally suited because of adverse soil or climatic factors. Desertification is the spatial extension of desert-like conditions resulting from human impact on the ecosystems of semi-arid regions. It takes place mainly in desert boundary regions and involves a complex physical geographical processes disturbing the natural ecological equilibrium. Factors which disrupt the ecological equilibrium include the sparse vegetation and the surface water balance.

Desertification results from the over-exploitation of arid and semi-arid lands. There is a widespread, but largely erroneous, belief that desert expansion is caused by drought. This belief deflects attention away from human responsibility for environmental deterioration. There have always been deserts, and there have always been droughts, but only in comparatively recent times have normal climatic fluctuations led to starvation and death on so massive a scale as we have witnessed during the Sahel droughts of 1968–73 and 1982–85 (Dregne, 1983).

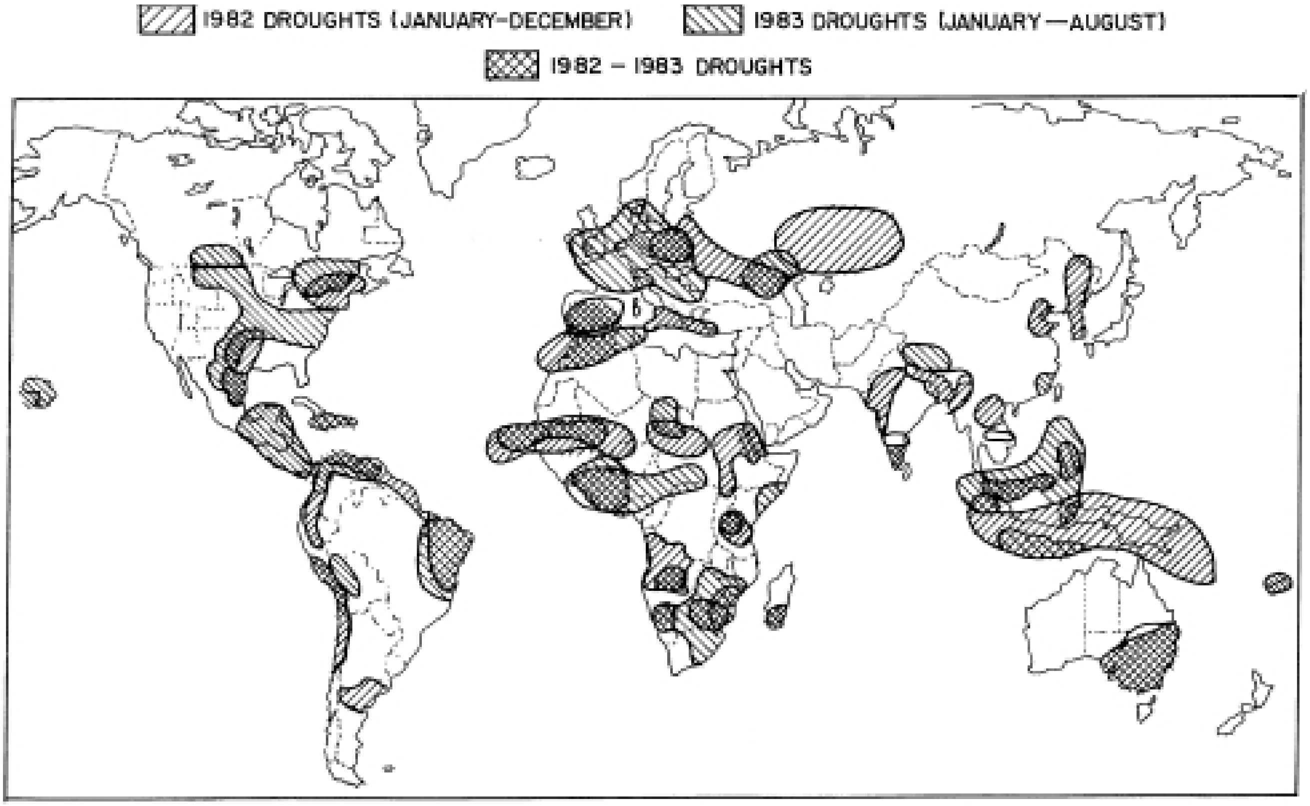

Figure 2.2
The occurrence of drought (January 1982 to August 1983)

Desertification can only be halted by encouraging multiple land use, exploiting the natural diversity of the desert biome and, at the same time, exercising restraint in the size and scale of developmental projects in the fragile arid ecosystems. For it to be effective, however, the cooperation of local inhabitants – frequently neglected in the past – is absolutely essential. Not only must they be given alternative food and employment if their flocks of sheep and goats are to be reduced, but they also need to be provided with fuel oil if they are not to cut down trees for charcoal to cook with. We cannot expect the poor of developing countries to deny themselves the sustenance of life for the benefit of mankind in general – even though desert-dwellers are renowned for their generosity and hospitality.

2.2.2 DEFINITION OF DESERTIFICATION

Desertification is a degradation of an ecosystem resulting in a desert-like environment in arid, semi-arid and some sub-humid zones. According to FAO/UNEP, desertification is a process involving all forms of degradation (natural or human-induced processes disturbing the equilibrium of soil, vegetation, air and water) of land vulnerable to severe aridity, leading to the reduction or destruction of the biological potential of the land, deterioration of living standards and intensification of desert-like conditions (WMO, 1985). It is perceived as a package of processes which brings about certain basic changes in a particular ecosystem and converts it from relatively non-desert to desert terrain. This involves an interplay of climate, edaphic and biotic factors.

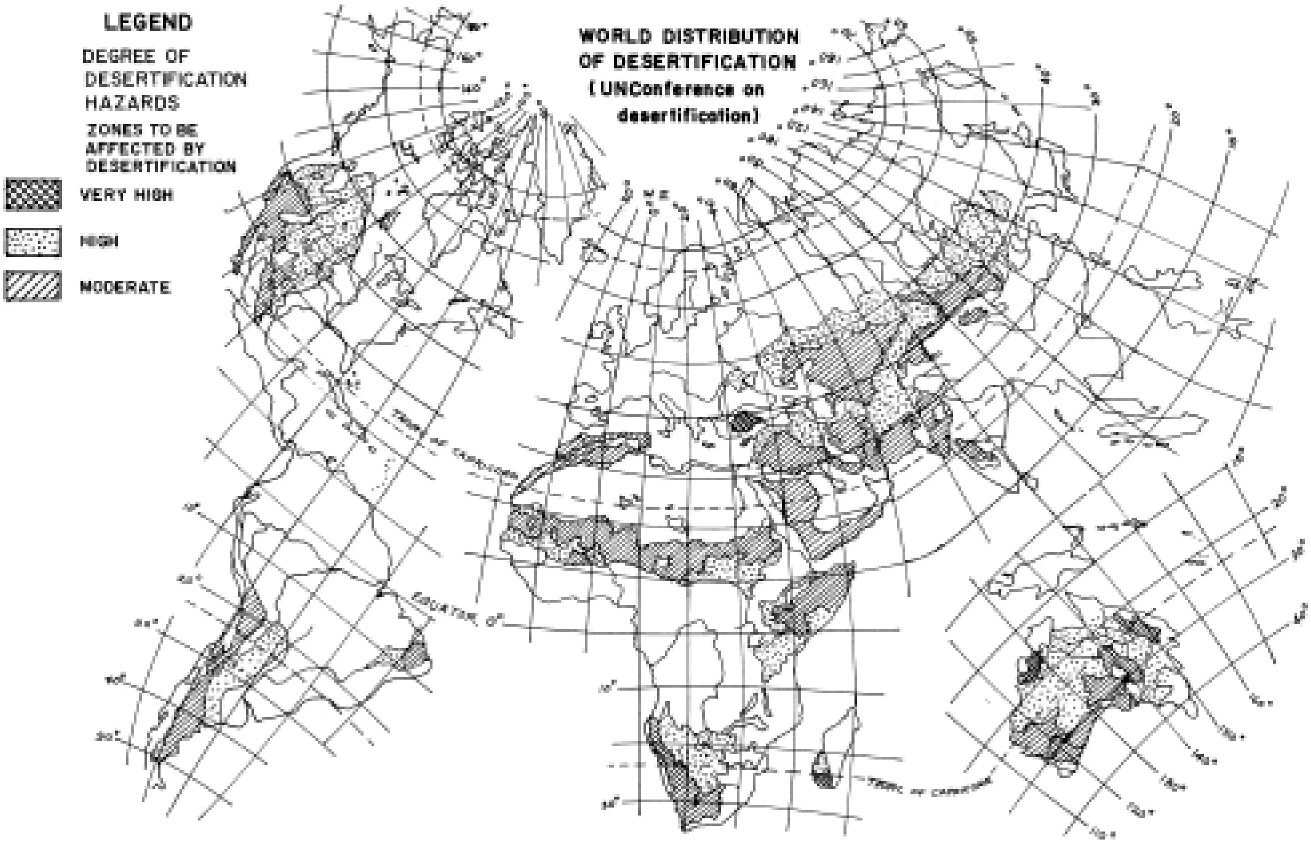

Figure 2.3
World distribution of desertification

Recently the United Nations Conference on Environment and Development (UNCED) adopted the definition of desertification as land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors including climatic variations and human activities. It is a widespread but discrete process of land degradation in space through the drylands. The process of desertification is manifested by an increase of aridity, invasion of blown sands, loss of moisture, accumulation of salt in soil, decline of soil fertility, reduction of vegetative coverage, change of species composition and enlargement of the extent of sandy areas.

2.2.3 Distribution of desertification

Desertified lands are mainly located in arid and semi-arid zones with some of them appearing even in sub-humid zones (Figure 2.3). Desertification means not only the encroachment of existing deserts but also the appearance of desert-like landscapes in originally non-desert areas. The area of land affected or threatened by desertification is about 39.4 million square kilometres which is 26.3 per cent of total land (Hopkins and Jones, 1983). The distribution of these desertified lands are as follows: 36 per cent (about 14.2 million square kilometres) in Asia; 25.4 per cent (about 10.4 million square kilometres) in Africa and 11.8 per cent (about 4.65 million square kilometres) in North and Central America. More than 100 countries and regions are confronted by this problem. There are about 50–70 million square kilometres of land likely to be desertified every year, according to one estimate. At the end of this century, one third of arable lands will probably be lost, directly threatening 14 per cent of the human population living in arid and semi-arid lands. Therefore desertification is one of the most serious environmental problems of this and next centuries. It has rightly been called the “Earth’s cancer”.

2.2.4 Desertification trends

In the Sudano-Sahelian region, desertification is likely to continue to advance under the combined pressure of growing human and livestock population, inappropriate agricultural policies and possible further political unrest. Although desertification of the rangelands remains the most widespread problem, the most severe hazard in terms of potential environmental damage, lost productivity and population affected, lies in rangelands, croplands and adjacent grazing lands near the dry limits of cultivation. The countries showing accelerating trends of desertification include Chad, Djibouti, Ethiopia, Mali, Mauritania, Niger, Senegal, Somalia and Sudan (UNEP, 1984). The regional trends of desertification within land-use categories and major natural resources are shown in Figure 2.4.

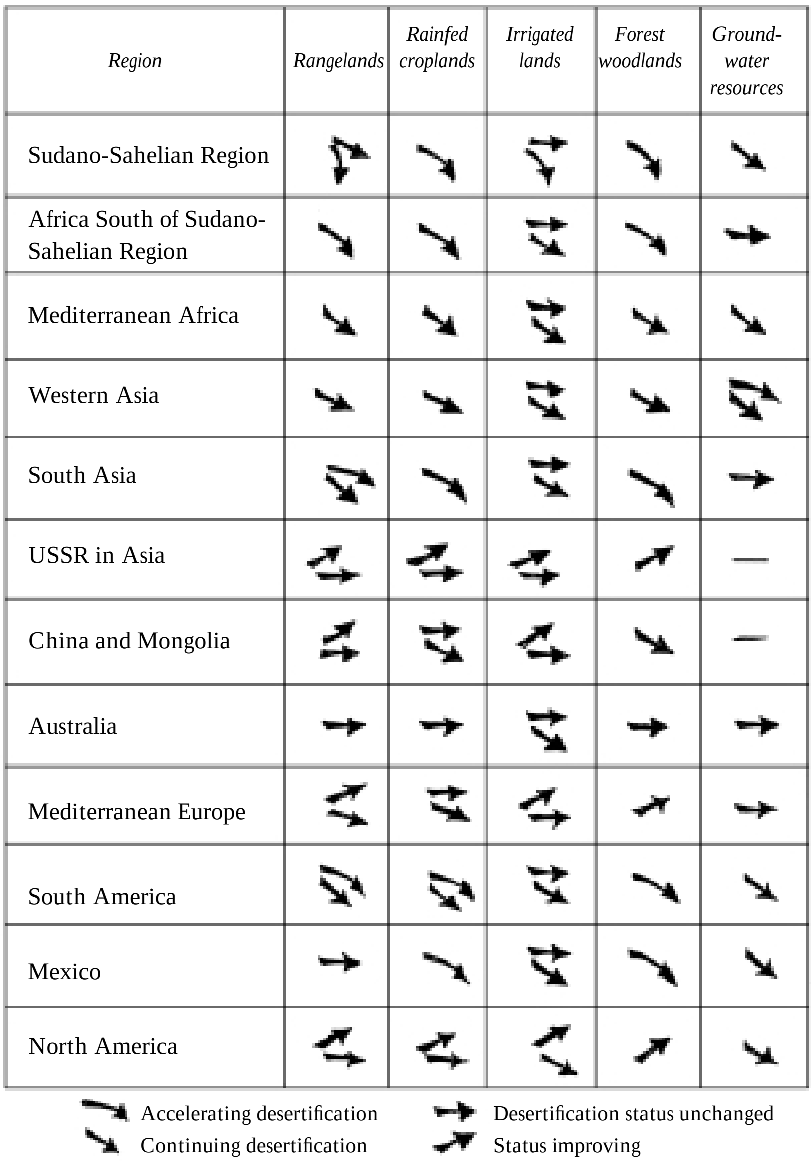

Figure 2.4
Regional trends of desertification within land use categories and major natural resources (UNEP, 1984)

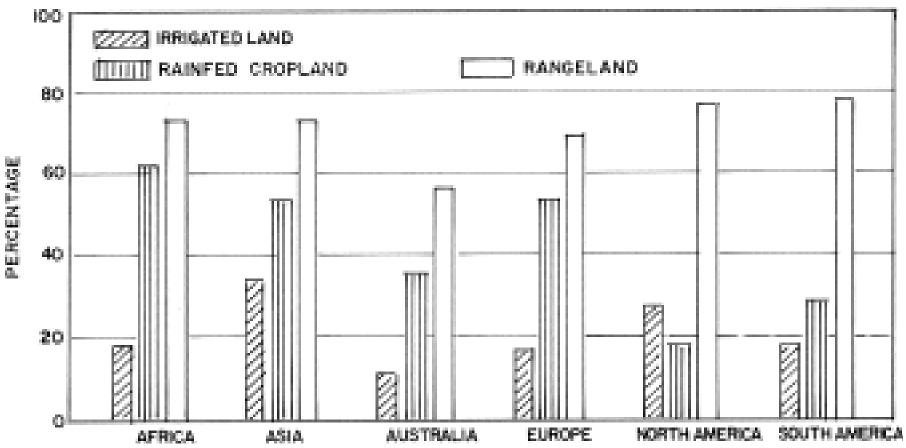

Figure 2.5
Percentage of drylands affected by desertification

In North Africa, there are records of success in afforestation and dune stabilization, particularly in Algeria and Libya. Desertification, however, has continued in rangelands and in rainfed croplands including areas of arboriculture. This is mainly due to increasing population and livestock pressures, and to the lack of appropriate conservation measures, accentuated by drought.

2.2.5 Physical processes of desertification

Desertification operates through several processes such as diminution of vegetative cover, induced instability of surface, soil erosion, encroachment by active sand dunes, the salinization of land, etc. Individual processes need not be mutually exclusive. For example, depletion of vegetative cover, deterioration of the physical condition of the soil and acceleration of wind erosion can occur together, often in a mutually sustaining mechanism. A couple of above normal rainfall years in a sequence may lead to a greatly increased vegetation cover and productivity, thus causing a large deviation from a general declining trend. Likewise, substantial spatial variation can be seen in the degree of deterioration within an area otherwise uniform in its land attributes. Lands in the immediate vicinity of settlements and watering points are often devoid of usable vegetation. Variability in intensity of use and degree of management in fact is a major factor that complicates the monitoring of the process of desertification.

2.2.5.1 Agrometeorological aspects in the desertification process

The meteorological phenomenon of drought, as has been mentioned earlier, is a combination of atmospheric and soil water stresses leading to disturbance of the water budget of plants, animals and in extreme situations, human beings. Desertification processes manifest themselves differently in different edaphic and climatic zones and land use systems. In rainfed semi-arid and arid zone agriculture, desertification is primarily evidenced by practical or total loss of vegetation cover in areas where climatic extremes and high land use pressures have reduced the growth of vegetation. In general, natural vegetation is very sparse or scanty in desertification prone areas due to insufficient precipitation. But this scanty vegetation is able to protect and to a large extent stabilize the ground surface. However, when, as a result of animal or human intervention, some of this cover gets degraded, wind erosion sets in blowing the topsoil away making permanent plant life impossible due to a lack of water reserves in the remaining shallow soil.

The impact of torrential rains over the decreased vegetative cover disperses the fine surface soil aggregates filling up and sealing the pores. The sealed surface reduces the infiltration rate, increases runoff, causing sheet and gully water erosion, especially in sloping surfaces. This results in much drier soil conditions and a marked decrease in vegetation and plant productivity. Patches of land so degraded may gradually grow resulting in desertification.

2.2.6 Causes of desertification

Two major factors are certainly involved in desertification; the periodic stress of climate and human use and abuse of the sensitive, vulnerable dryland ecosystem. Climatic fluctuations, with changes in the temporal and spatial distribution of rainfall, often result in lengthening aridity phases, higher temperatures and stronger winds. Similarly, increasing human pressure on the ecosystem may result in the extension of the cultivated area beyond the borders where the human-environment equilibrium is disturbed. Such human pressure normally includes the extension of irrigated areas, improper land use practices in semi-arid and sub-humid areas resulting in land degradation through water and wind erosion, overgrazing by livestock, deforestation for firewood and building, bush and forest fires, salinization, alkalinization and waterlogging. As the degradation of land advances, restoration may become more difficult and expensive. At certain stages, feedback mechanisms may come into play to reinforce the desertification process.

The natural causes of desertification, as well as those induced by people, are of an extremely complex character and take varying forms, duration and degree of intensity and development. Desertification is manifested through the degradation of plant and soil cover and depletion of water resources in an area, i.e. the whole basis for human well being deteriorates.

Arid and semi-arid ecosystems are extremely fragile and can be easily harmed, since historically they developed under very hard xerothermal conditions, and recover very slowly when these conditions are disturbed. In certain extreme cases, ecological imbalance results in the irreversible destruction of the biological potential of the land. Some important factors leading to desertification are mentioned below (Oladipo, 1985; Dhir, 1986; Ogallo and Gbeckor-Kove, 1989).

2.2.6.1 Natural factors

Broadly, natural factors resulting in desertification can be classified as follows:

Climatic factors

Climatic factors leading to fragility of desert ecosystems are generally associated with inherent soil moisture deficit, high intensity of solar radiation, increasing albedo of the underlying soil surface, low and erratic precipitation, shifting spatial and temporal distribution of rainfall, high air temperature and dryness, high wind speed, etc. These factors cause high climatic stress.

The Earth's major desert belt lies in sub-tropical and tropical latitudes where widespread and persistent subsidence occurs through the influence of atmospheric circulations. In these regions of mainly subsiding air, rainfall is not sufficient to permit perennial cultivation, but pastoralism and the growing of drought-resistant crops (such as sorghum and millet) are practised. Obviously, limited choice of crops, low cropping intensity and low yield potential of conventional crops are the characteristics of these regions.

The majority of the arid and semi-arid regions of the world suffer from low and erratic precipitation in addition to high inter-annual variability. This unevenly distributed rainfall in both space and time causes acute moisture shortage and makes these regions prone to recurrent and sometimes intense drought.

Though vegetation often recovers after a drought, there are occasions when the drought is so intense and persistent that the vegetation is not able to recover fully, even when the rains return. As a result, the equilibrium of the ecosystem in these areas is dramatically lost, initiating the process of desertification.

Hydrological factors

These are changes in the water regime, such as those in ephemeral surface run-off, which can accelerate or alter the erosion process and can cause permanent, seasonal or temporary sources of water to be much reduced or lost.

Geomorphological factors

These factors are related to the nature of the surface of the land and its underlying structure that can be influenced by certain climatic factors giving rise to water and wind erosion.

Pedological factors

These factors include potential weaknesses in the soil forming processes, low humus or high carbonate content, high calcareousness and salinity, susceptibility to erosion and waterlogging.

Vegetative factors

Vegetative factors are those which relate to the nature and behaviour of the plant cover. They include the periodic natural reduction of plant density, the plant growth and development cycle, low biomass productivity and an increase in xeromorphic and succulent forms.

2.2.6.2 Human use and abuse of vulnerable dryland ecosystems

Overgrazing

One of the most widespread and obvious processes of degradation is the decrease of vegetation cover through overgrazing. Persistent overgrazing brings about a dramatic change in the cover, although it varies according to natural conditions and soil type. In the early stages the most palatable species are damaged first.

When the number of animals exceeds the carrying capacity of the ecosystem, pastures do not have time to recover. The situation may be exacerbated at times of too frequent or too persistent droughts. When pastures do not have time to recover between droughts, there is even more severe overgrazing as animals graze the remaining grasses even closer and browse shrubs and trees ruthlessly and destructively. The recovery of the soil to its original condition becomes extremely difficult.It is often lost permanently.

Trampling

Hooves are far more damaging than mouths. Bare stretches around watering points are ample testimony to this. The effect can be seen in a radius of 1 to 2 km from a waterhole. Cattle movement on moist soil with sparse vegetation cover causes compaction. This not only causes a reduction in infiltration but is also a hurdle to the emergence of seedling and the proliferation of root systems.

Lopping and cutting of trees and shrubs for fuel and timber

Arid and semi-arid lands often carry a sizeable representation of trees and shrubs in the vegetation cover. The open thorn forest of the Asian sub-tropics and the savannah of Africa are good examples of these. The cutting of these woody species for fuel wood, building materials and bush fencing for enclosures and night shelters for livestock seriously depletes this cover. This large-scale cutting leads to the disturbance of soil cover, development of sand deflation and wind and water erosion.

Plant cover degradation over large areas also leads to:

(*a*) An increase in albedo leading to a lower level of absorbed solar radiation;
(*b*) An increase in soil temperature and resulting increase in stress on organisms;
(*c*) The loss of fine materials, both mineral (clay and slit) and organic, due to erosion; and
(*d*) A reduction in water storage capacity.

These four interacting processes represent local climate changes and the deterioration of surface microclimate, water budget and soil hydrothermal ultimately lead to the irreversible processes of desertification. A schematic illustration of the climatic and anthropogenic causative factors in the desertification process is given in Figure 2.4.

Wild bush fires

Fires over large areas, which are quite common in arid regions of the world, often result in considerable loss of human life, vegetation, crops, livestock and infrastructure. Consequently, fires are sometimes a cause of desertification in arid and semi-arid areas. Intensive wood fires may destroy the soil cover by burning the debris layer and organic matter in the upper horizon, resulting in the elimination of soil fauna, and subsequently in water and wind erosion. Any change in the vegetative cover due to fire may also lead to changes in the microclimatic conditions of the ecosystem, which, in turn, have an effect on the intensity of water or wind erosion which cause the greatest damage to the fertile layer.

Extension of arable farming to marginal lands

Intensification of arable farming and the opening up of new lands to farming which are either too sandy and highly erodible, or with shallow soils or are located in situations where climatic conditions permit only occasional success with cropping, have accelerated the process of soil degradation. These lands are not able to recover their original cover nor do they sustain farming. On the contrary, cultivation of these marginal climatic areas causes increased erosion of the top soil unless vegetable stubble is left on the farm to protect the soil (Olderman and Van Lynden, 1997).

Accelerated soil erosion, sand sheeting and active dune formation

More prevalent in arid zones is the incidence of wind erosion, which causes the loss of the most productive top soil layer, spreads sand sheeting and forms shifting dunes. The sub-soil may also be less fertile and of poor structure and permeability and thereby affect the productivity of the land. The problem is serious in Iraq, Afghanistan, Pakistan and India where dunes are showing increasing signs of instability. As with water erosion, the incidence of wind erosion is also the result of the interaction of the erodibility of soil and vegetation cover, besides, of course, the wind regime. Large dust storms that carry particles thousands of kilometres are originated in such areas as the Sahara, north and west China, the south-west United States, central Australia, central India and the Russian steppes.

Salinization and waterlogging

Water is the main problem in dry zones and hence the development of irrigation, despite the huge investment, has been looked upon as a major means of increasing food and fodder supply. Egypt, Iraq, Sudan and Pakistan have established large canal irrigation projects. This has permitted a manifold increase in productivity. However, poor water management and over-irrigation have created problems of waterlogging and/or salinization. Salinity influences the osmotic process and induces physiological dryness in the same way as scarcity of rainfall and high evaporation. Saline seeps resulting from the replacement of perennial deep rooted vegetation by shallow-rooted annual crops have also contributed to desertification, especially on land with a hard sub-soil base material. The problem is then aggravated by fallowing after harvest.

Generally, salinization and waterlogging go together since the latter is also caused by irrigation. These two factors act together to reduce yield, limit choice of crops to cultivate and ultimately lead to the complete loss of irrigated lands. Salinization is also caused by fertilization.

Other agricultural practices, such as the use of tractors, tillage implements, watering of livestock, etc., can cause soil compaction and crusting. These reduce infiltration and soil permeability, increase water run-off (and hence erosion) and ultimately prevent plant growth. In due course the land becomes barren and desertified.

Over-exploitation of groundwater

Whereas river basin irrigated areas are showing a rise in the water table, in areas which are groundwater irrigated aquifer depletion is occurring. The Indian arid zone in Gujarat and Rajasthan and pocket irrigation development in the sub-Saharan region and southern Africa are cases in point. The process is also accompanied in many cases by a deterioration in water quality.

2.2.7 Desertification and feedback mechanism

For spreading desertification, several processes may operate simultaneously, feeding back into the system, intensifying the degradation of the quality of the resource base and the decline of biological productivity.

The speculation that drought may indeed feed on drought to promote long-term desiccation has led to the postulation of some feedback mechanisms (Hare, 1983, 1984; Sabadell, 1982). Among the proposed mechanisms is the albedo feedback hypothesis (Charney, 1975) which postulates that the increased albedo of damaged surfaces intensifies atmospheric subsidence and leads to the suppression of convection and the maintenance of a desert-type climate, with reduced soil moisture tending to diminish the contribution of latent heat to the atmospheric energy budget (Walker and Rowntree, 1977). The increase in albedo, coupled with oxidation or deflatation of organic litter during prolonged drought, may lead to positive feedback effects in the microclimate with the result that “desert may be feeding on desert”.

Other proposed mechanisms include a reduction of the biogenic supply of freezing nuclei produced as vegetation decays, and a reduction in the surface radiative heating, convection and precipitation by increased wind blown dust over a degraded region.

Some of these cause-effect feedback mechanisms, especially the albedo feedback hypothesis, have been extensively tested by general circulation model (GCM) experiments and have been found to provide some evidence that the concept of positive feedback between the surface and the atmosphere in reinforcing drought and desert-like conditions is correct.

Another example of the feedback mechanism is related to the irrigation of agricultural land in arid and semi-arid regions. Poorly-designed irrigation schemes with poor drainage may result in waterlogging and in soil salinization. This is very detrimental to most plant species and may result in vegetation cover disappearance, increased albedo and wind blown dust, which in turn influences the surface microclimate and causes changes in the rainfall regime and ecology. To be able to control and reverse desertification, therefore, a better understanding is needed of the interdependency between resources-uses-changes and the postulated positive feedback mechanisms.

The main point here is to emphasize that climatic vagaries, manifested in terms of drought, and human activities may combine to fuel the process of desertification. Desertification occurs first in drought years in patches of specific soil and vegetation types where a fragile equilibrium is initially, even if temporarily, disturbed. Thus drought administers a shock to the ecological system.

2.2.8 Desertification and development

Desertification is occurring everywhere in the world and even the most highly industrialized nations are not exempt from it. The United States, for example, has had to face the degradation of its irrigated lands and increasing problems connected with its groundwater reserves. Russia faces similar problems on its irrigated lands. In Mediterranean Europe, forests and woodlands have been brought into better condition. In Australia, the advance of desertification has been halted.

It is in the developing world that desertification is accelerating most rapidly. It has been established that there is a negative correlation between desertification and development. The lack of success in arresting desertification in developing countries is due to destructive land use practices and neglect of coherent planning. Unrestrained population growth and a corresponding rise in livestock numbers impose increasing pressure on a fragile environment. Chronic shortages of food and the desperate compulsion of these countries to export their crops against adverse terms of trade are continually destroying the fundamental resource base of these countries. The irony is that many of the urban problems of developing countries have their origins in the countryside. Loss of land productivity has forced villagers into the towns.

Paradoxically, people living in areas strongly affected by desertification display the highest birth rates in the world. Desertification produces poverty. The declining productivity of dry zone croplands and rangelands has its most serious impacts on scores of millions of the world's most wretchedly poor. Depending quite directly on the soils and forests around them, people in the zones see their prospects for a better life dry up along with the natural resource base. Poverty in turn produces desertification and the fight against mismanagement of the land can succeed only as part of a more general attack on underdevelopment. Desertification is not a detached technological problem; in most cases the term describes the ecological dimensions of a development process gone bad, a process which fails to provide people with a reasonable standard of life.

Various developing countries have since accorded high priority in their development plans to (i) self-sufficiency in food production; (ii) improved living conditions for the people; and (iii) the restoration of ecological balance (Dhir, 1986). Though countries like India have made major strides, particularly on the food front, the overall picture in developing countries still appears dismal. Despite national concern and some action plans to combat desertification, the struggle against land degradation is getting harder and harder.

2.2.9 Monitoring and assessment of desertification

Because desertification is a phenomenon dynamic in time, space and intensity, its monitoring is an absolute necessity. The principal objectives of monitoring are to:

(*a*) Enlarge our knowledge and understanding of the processes, their causes and evolution;

(*b*) Allow early detection of areas recently subject to accelerated desertification as a result of climatic vagaries and the development of planning programmes.

A number of biophysical and social indicators have been identified to quantify desertification and monitor changes over time. For all of these indicators, we are required to know: (i) how widely occurring the particular process is spatially; (ii) the rate at which it is occurring. First of all, the rate of change in a particular component is far from uniform, with many of them being highly episodic in character. For example, major advancement of sand sheeting and shifting sand dunes can occur during a few years of an extraordinarily strong wind regime. Likewise, major deterioration of natural vegetation may occur during periods of extended droughts with substantial recoveries in between. Therefore, in many of these processes, short-term observations may lead to conclusions which are far off the mean, if not misleading. Long-term studies are needed to discern a distinct trend in the face of such large amplitudes in annual deviation. Secondly, the causative factor, i.e. human and livestock pressure, is never uniformly distributed spatially. A large variation exists in the manifestation of the process even in situations where all other land attributes remain the same. The establishment of the magnitude of a particular process therefore calls for observation at a number of sites (Gbeckor-Kove, 1988).

Analysis of rainfall and preparation of isohytal maps for a region, every 10 years for example, will allow the displacement of isohytes towards the drier zone to be followed, indicating progressive desiccation, and hence measures to avoid extending rainfed operational agricultural activities into that region can be taken.

Global surveillance of the climate, the status of dryland ecosystems and of land use can be achieved most economically through the remote sensing capability of orbiting weather satellites or earth resources satellites. In addition to sampling for ground truth (e.g. vegetation changes) and aerial photography, satellite coverage can also be used in conjunction with airborne remote sensing consisting of thermal infrared cameras, multispectral visible and near infrared scanners and microwave radars. Conventional air photography produces a finer resolution than satellite imagery and is therefore useful for providing more detailed information about land use in areas undergoing desertification. These methods can be used for mapping desertification status.

2.2.10 Recovery and control of desertification

The problems of desertification are multidimensional and require integration of various areas of activity, such as settlement, development of natural resources of soil, water and vegetation, extension and training, research, etc. It is obvious that a lack of financial resources hampers integration and hence the tackling of the problem effectively in developing countries.

As the degree of interaction of desertification processes varies from place to place, counter-measures differ in importance from one affected country/region to another. The reclamation of deteriorated lands requires cultural practices in order to recover the ecological equilibrium. These practices include the rational use of natural resources in arid and semi-arid areas, land use according to ecological requirements and taking into consideration land potential and environmental changes. Methods of control aimed primarily at improvements in land use would also improve the microclimate on which the natural vegetation and crops depend (Polevoy, 1992). Given the importance of economic development in developing countries, afforestation and animal raising should be emphasized along with the creation of a diversified economy. Obviously desertification can only be halted by encouraging multiple land use, exploiting the natural diversity of the biome and, at the same time, exercising restraint in the size and scale of development projects in a fragile ecosystem. Le Houerou (1987) discussed some myths and realities regarding the prevention of desertification.

In view of the magnitude and complexity of the problem, it is important to have a comprehensive time-phased plan of development with a clear idea of relative priorities and the interdependence of various programmes. For instance, in dairy development or sheep husbandry, it is necessary to produce sufficient fodder. This will necessitate controlled grazing, the production of green fodder and the planting of leguminous shrubs wherever possible.

The action programme to combat desertification is a major task which covers activities in many disciplines and consequently encompasses several institutions, both in the spheres of investigation and implementation. It is also clear that the solution to the complex problem of desertification must be executed simultaneously with other projects which have relevance to the desertification problem. Measures to contain desertification (Polevoy, 1992; Zhu, 1990) should include integrating the measures listed below:

(*a*) The natural resources of soil, water, forests and pastures should be judiciously utilized and conserved;

(*b*) Efforts should be made in the reclamation and distribution of new farms and to train farmers in modern agricultural methods to increase production and enhance income.

(*c*) There should be increased support for action-oriented research related to desertification and the improvement of affected lands;

(*d*) Greater regional and international cooperation in scientific, technical and social sectors concerning desertification should be encouraged;

(*e*) Population growth should be controlled in order to reduce pressure on the land;

(*f*) Energy efficiency in desertified areas should be improved to put an end to the undue collection of fuel wood and the destruction of vegetation;

(*g*) The livestock grazing pressure on pastures should be lowered and specialized fodder growing farms created. In rangeland areas, proper rotational grazing should be practised;

(*h*) A preference for forestry to livestock breeding in the agricultural sector;

(*i*) The protection of natural vegetation cover and the fencing off of deteriorated land should be encouraged to allow better recovery conditions for grasses and other vegetation;

(*j*) The creation of protective forest belts to stabilize sand dune surfaces is an important element in the rational use of tree stands for sand arrest. The introduction of forest belts on lower sites and sand-binding species on sand dunes provides an effective measure against desertification. The choice of suitable local species well adapted to the desert conditions is essential;

(*k*) The creation of a system of protective forest belts to fight wind and sand erosion near oases may be practised. Such belts adequately protect field crops, arrest sand movement and give food and shelter to wildlife; and

(*l*) Arid horticulture, including pomegranate trees, date palms and jujube, should be encouraged. Pasture improvement by introducing leguminous crops is yet another effective technique.

2.2.11 Summary and conclusion

Desertification has four main causes; over-cultivation, overgrazing, deforestation and poor irrigation practices. These are human causes, the result of bad management of resources. Human and livestock population pressure often plays a major role in desertification when the population exceeds the sustainable level in fragile arid, semi-arid and sub-humid ecosystems. These are often exacerbated by other factors such as social and political systems which lead to unequal and inequitable access to resources, which force populations in developing countries to overexploit the land for mere survival.

Natural causes of desertification, as well as those induced by people, are of an extremely complex nature and have varying forms, scales, duration and degrees of intensity. Desertification is manifested through the degradation of plant and soil cover and depletion of water resources of the area.

Misconceptions are sometimes encountered concerning desertification and its relationship to drought. It is commonly felt that desertification spreads from a desert core. Secondly, there is a belief that droughts are responsible for desertification, particularly in the semi-arid and sub-humid zones most frequently affected by severe droughts. The truth is that desertification can, and frequently does, occur far from the climatic Sahara, Kalahari and other deserts. The classic example of this is desertification starting as a patch around a watering point from where it spreads out to nearby overgrazed rangelands. Furthermore, droughts do not cause desertification but they aggravate the harmful effects of improper land management so that desertification is intensified.

The problem of desertification is urgent because it results not only in the loss of a nation's productive resource base but also in the loss of valuable genetic resources, an increase in atmospheric dust with consequent changes in the radiation balance of the Earth and disruption of water resources.

The appropriate practical approach to combat desertification is one in which the peculiar characteristics of sensitive arid and semi-arid lands are taken into proper account. This calls for the capability to measure changes and adequate support that can adapt easily to unexpected calamities such as a protracted drought (Sabadell, 1982). In addition, development and management of resources should take into consideration the local human and natural resources, their diversity and their socio-economic needs. Such a comprehensive systematic approach would make the measurement and assessment of cause-effect relationships, cumulative stresses and detection of progressive land degradation possible.

2.2.12 Suggestions and recommendations

There are a number of practical suggestions and recommendations that can be made to combat desertification around the world.

(*a*) Drought monitoring centres should be strengthened so as to have the capacity and capability to issue warnings and long-term drought predictions. This calls for adequate data banks and computing power, trained personnel and a good telecommunication system;

(*b*) Efforts should be made to automate weather data collection by having a telemetered network of mini weather stations receiving on-line data from different regions of the country;

(*c*) Action programmes to be set up to overcome drought situations based on the understanding of the causes and overall destructive effects of drought on the people and the area. Organizational capabilities and availability of resources should be taken into consideration while planning and initiating the programmes. The involvement of local people and their organizations should form the key to the approach;

(*d*) People must be taught that drought is a recurring phenomenon and hence they should prepare themselves to minimize its impact. This may include the cultivation of drought-resistant and durable varieties of crops;

(*e*) Appropriate contingency measures should be undertaken in the agricultural sector to minimize crop losses. Measures should be taken to provide adequate fodder and nutrients for cattle;

(*f*) Water budgets should be prepared to optimize the utilization of water in reservoirs and groundwater resources;

(*g*) Steps should be taken to streamline the machinery for providing effective and timely relief to drought-affected populations through the efficient implementation of relief measures;

(*h*) Action may be initiated for public health measures and for providing supplementary nutrition for young and needy children and expectant mothers in drought affected areas;

(*i*) Community assets should be created during the drought period which may include afforestation and the planting of trees, social forestry, land reclamation, construction and repair of wells, tanks, reservoirs and ponds, the deepening of existing wells and water tanks to increase water reservoirs capacity, the creation of minor irrigation facilities, small earthen and check dams for soil conservation, etc.; and

(*j*) Specific programmes should be initiated for combating desertification which may include: (i) awareness of the dangers of indiscriminate felling of trees and over-grazing; (ii) forestry and agroforestry projects; (iii) pasture grass farming projects; (iv) poultry and fish farming projects; (v) dryland crop farming projects; (vi) small-scale irrigation and horticultural projects; and (vii) land conservation programmes.

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CHAPTER 3

INCIDENCE, PREDICTION, MONITORING AND MITIGATION MEASURES OF TROPICAL CYCLONES AND STORM SURGES

(by H.P. Das)

3.1 INTRODUCTION

Tropical cyclones are the off-spring of ocean-atmosphere interaction, powered by heat from the sea, driven by the easterly trades and temperate westerlies, the high planetary winds and their own fierce energy. A tropical cyclone constitutes one of the most destructive natural disasters to affect many countries around the globe, causing tremendous loss of life, property, agriculture, etc. The impact of tropical cyclones is greatest over coastal areas which bear the brunt of the strong surface winds and flooding from rainfall at the time of landfall. Besides the winds which blow with lethal ferocity and heavy rainfall, cyclones are also associated with a devastating storm surge which inundates vast areas of coastline.

These intense low pressure systems develop over the oceans. Tropical cyclones, hurricanes and typhoons are regional names for what is essentially the same phenomenon. Depressions in the tropics which develop into storms are called tropical cyclones in the south-west Indian Ocean, the Bay of Bengal and the Arabian Sea, parts of the south Pacific and along the northern coasts of Australia; these storms are called typhoons in the north-west Pacific and are known as hurricanes in the Caribbean, south-east United States and Central America. In the Philippines they are called bagious.

Compared with the extra-tropical cyclones, tropical cyclones are moderate in size. Still, their broad spiral base may dominate weather over thousands of square kilometres, from the earth's surface to the top of the tropical tropopause. The associated winds often exceed 200 km per hour, rainfall exceeds 50–100 cm in 24 hours and, worst of all, very high storm tides (storm surge combined with astronomical tides) often exceed 6 metres, bringing the worst devastation over the coastal areas where they strike. Today records are available for wind speeds of 317 km per hour, gusting to 360 km per hour, rainfall of 117 cm in 24 hours and a storm surge of almost 14 metres in association with tropical cyclones. The lowest pressure of 870 mb ever recorded was in association with a tropical cyclone (Typhoon 'TIP') in the Pacific which formed in 1979. Combined with duration, which is often several days, size and violence, the tropical cyclone is the most destructive atmospheric disturbance (Smith, 1993). On a positive, though less dramatic side, tropical cyclones provide essential rainfall over much of the land they cross.

3.2 GEOGRAPHICAL DISTRIBUTION OF TROPICAL CYCLONES

A thorough knowledge of the climatology of tropical cyclones is essential for cyclone forecasting, risk assessment and for planning long-term mitigation measures for cyclone disaster management.

Almost all tropical cyclones form over the warm tropical waters (SST ≥ 27°C) of the tropical oceans except over the south Atlantic and south Pacific, east of 140°W. Tropical cyclones are most commonly observed in the northern hemisphere from May to November and in southern hemisphere from December to June. The frequency of tropical cyclones, however, varies from ocean to ocean. The annual average frequency ranges from 5.6 (the least) in the north Indian Ocean to about 30 (the highest) in the north-east Pacific. About 70 per cent of tropical disturbances which later develop into tropical storms form in the northern hemisphere.

Approximately 80 tropical cyclones attain maximum sustained winds of 20–25 metres per second (m/s) over the globe per year. About half to two-thirds of these disturbances develop into the severe stage with a core of hurricane winds (wind speed 64 kts or more) (Gray, 1975). Figure 3.1 shows the annual frequency of tropical cyclones with surface wind speeds of 20–25 m/s over the globe.

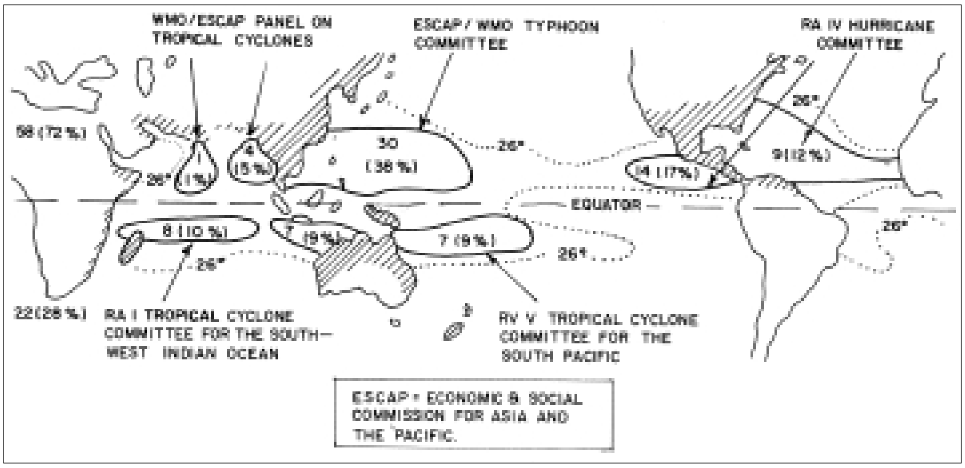

Figure 3.1
The global occurrence of tropical cyclones over the globe (after W.M. Gray, 1975). The names of tropical cyclone bodies and the tropical cyclones basins covered by their programmes are also indicated. The area enclosed by the dotted lines is the area where the sea surface temperature is greater than 26°C.

The long-term average of tropical cyclones in the north Indian Ocean (the Bay of Bengal and the Arabian Sea) is 5.6 annually. This is about 6 per cent of the global total. The frequency of tropical cyclones in the north Indian Ocean is the lowest in the world. On average, 2–3 out of 6 tropical cyclones intensify to severe cyclones. The frequency of tropical cyclones is more in the Bay of Bengal than in the Arabian Sea.

(a) (b)

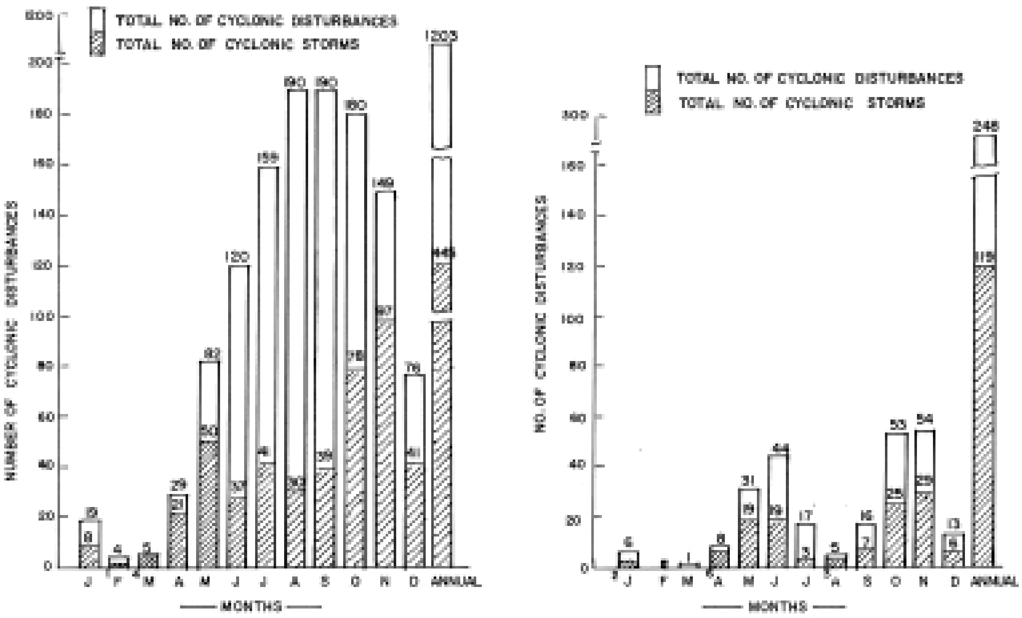

Figure 3.2
Monthly distribution of cyclonic disturbances and cyclonic storms for the period 1891–1989
(a) Bay of Bengal and
(b) Arabian sea

The average life period of tropical cyclones in the north Indian Ocean is about 2.5 days as against the world average of six days which means, compared with other oceanic areas, tropical cyclones in the north Indian Ocean are short lived.

The radial dimensions of tropical storms vary from a 50–100 km radius to a 2 000 km radius. Over the Indian seas about 17 per cent of the storms have diameters between 3 and 5 degrees and 65 per cent between 5 and 10 degrees, indicating that the majority of storms have diameters within 1 000 km and are moderate in size (WMO, 1993; Pisharoty, 1993).

3.3 REGIONAL CATEGORIZATION OF TROPICAL CYCLONES AND THEIR INTENSITY

Tropical cyclones are low pressure systems or depressions around which the air circulates in an anti-clockwise direction in the northern hemisphere and in a clockwise direction in the southern hemisphere. In the context of disaster prevention and preparedness, interest is mainly concentrated on those tropical depressions around which the wind blows with speeds exceeding 17 m/s (61 km per hour) near the surface. Meteorologists distinguish between tropical cyclones in which the wind strength is in the range 17–32 m/s (61–115 km per hour) and those in which the wind speeds are greater than 32 m/s.

Tropical cyclones, as pointed out earlier, are known by different terms according to the regions in which they occur. These descriptive terms in relation to wind speed are given in Table 3.1 (ESCAP/WMO/LRCS, 1977).

Table 3.1
Areas of occurrence and regional description

Region	*Range of maximum wind speeds (metres per second)* 17–32	32–85
Western North Pacific Ocean	Tropical cyclone	Typhoon
Bay of Bengal and Arabian Sea	Cyclone	Severe cyclone
South Indian Ocean	Tropical depression	Tropical cyclone
South Pacific Ocean	Tropical depression	Cyclone
North Atlantic Ocean and eastern North Pacific Ocean	Tropical storm	Hurricane

It is important to be aware of the different regional names given so that, for example, it will be appreciated that what is described as a severe cyclone in the Bay of Bengal is essentially the same phenomenon as that which is called a hurricane when it occurs in the North Atlantic.

3.4 CHARACTERISTICS OF A TROPICAL CYCLONE

The tropical cyclone is a severe type of weather system, having distinct characteristics (Gray, 1968; Frank, 1982):

(*a*) They are neither associated with moving anticyclones nor with fronts;
(*b*) They form only in certain regions of the tropics;
(*c*) No regularity exists in their formation or movement;
(*d*) They form in the ocean where the surface temperature is above 27°C;
(*e*) Pressure distribution and other properties are fairly symmetrically distributed around the centre with a nearly circular isobar;
(*f*) Though they derive their energy from the latent heat of condensation for their generation as well as for their sustenance, the precipitation amount varies from storm to storm;
(*g*) They occasionally have a central sea level pressure of 900 hPa or lower and surface winds exceeding 100 kts;
(*h*) They exist only over oceans and weaken rapidly on crossing the land; and
(*i*) The intense system often has a core of calm or very light winds. This region is known as the “eye” of the storm which has on an average a diameter of 20 kms and is free of any weather.

3.5 CONDITIONS NECESSARY FOR TROPICAL CYCLONE FORMATION

Based on observational evidence of a large number of storms in the Pacific and Atlantic oceans, the following environmental factors favourable to cyclones were identified (Gray, 1968; Anthes, 1982):

(*a*) Large values of low level relative vorticity;

(*b*) Weak vertical wind shear of horizontal winds;
(*c*) Large value of Coriolis parameter;
(*d*) Sea surface temperature exceeding 27°C and a depth of warm water;
(*e*) Degree of convective instability; and
(*f*) Large values of relative humidity in the lower and middle troposphere.

3.6 STORM SURGE

A storm surge is the abnormal rise of the sea level caused by the movement of the cyclonic storm over a continental shelf. It is caused by the pressure drop near the storm centre and the surface drag due to the strong winds accompanying the storm. Storm surge is the most devastating feature associated with a tropical cyclone. Most loss of human life and cattle is due to storm surges (Das, *et al.*, 1974; Pisharoty, 1993).

The storm surge depends on the following factors:
(*a*) Intensity of the system;
(*b*) Landfall point and time;
(*c*) Offshore bathymetry near landfall and its latitude;
(*d*) Radius of the maximum wind;
(*e*) Speed of the storm; and
(*f*) Angle of the track relative to the coastline.

The effect is most pronounced where the sea is shallow. The actual tide is the sum of the astronomical tide and the storm surge and as such it is highest at the time of high tide. This occurs only at the coast near the landfall point – highest to the right and lowest to the left of the point of crossing. Usually the rise is 2–3 metres, but can be as much as 5 metres in the case of a severe cyclone. A surge may also invade inland along a major river as a tidal wave and can cause flooding even 10 or 15 kilometres upstream. This causes saline inundation of croplands 10–15 km inside the landfall, inflicting irreparable loss to the coastal economy.

The storm surge occurs some distance away from the centre of the tropical cyclone, to the right of centre in the northern hemisphere and to the left in the southern hemisphere. One of the main forecasting problems, therefore, is to estimate where and when the centre of the storm will make its landfall. This estimate is a preliminary step to predicting the probable height of the storm surge at various places along the coast. Ghosh (1977) developed a dynamic method to estimate storm surge along the entire east coast of India where most of the severe cyclones from the Bay of Bengal cross the coast.

3.6.1 Protection from the storm surge

Coastal embankments susceptible to storm surges should be designed specifically to withstand the expected storm surge water heights and forces, the combined action of wind and waves and overtopping from the storm surge water. Furthermore, coastal embankment projects in deltaic areas should be planned in conjunction with other development projects, such as highways and harbour and reclamation projects, in order to avoid duplication of investment costs (Basu, 1999).

An advanced and carefully planned system of storm surge protection has been developed in Osaka, Japan, in one of the most densely populated areas of Asia. The present storm surge prevention project consists of embankments, locks, pumping stations and raised bridges lowered by land subsistence. The large locks that now protect Osaka from a storm surge caused by typhoons were constructed as an alternative to raising the height of the existing embankment for reasons of cost and time and to minimize the disruptive effect on traffic.

3.7 HEAVY RAINS ASSOCIATED WITH A HURRICANE/TYPHOON

The first manifestation of an approaching tropical cyclone is torrential rain. This may occur far from the centre of a hurricane and often starts around 12 hours before landfall. Three rainfall bands are normally formed in a hurricane:
(*a*) the eyewall region;

(*b*) the spiral rain bands; and
(*c*) the outer heavy rain region.

The eyewall region is normally within an annular region of strong ascending motion and strong precipitation about 15–50 km from the hurricane centre. The spiral rain band is usually located in the right semi-circle of a tropical cyclone in the northern hemisphere (the left semi-circle in the southern hemisphere). These can produce torrential rain. The outer heavy rain region is normally located to the north of the cyclone centre (in the northern hemisphere) where an inverted trough is formed (Raghavan, 1997; Krishna Rao, 1997).

Heavy rainfall is normally influenced by the following factors:

(*a*) Sustenance of the hurricane vortex after landfall;
(*b*) Stagnation of the hurricane;
(*c*) Sustained supply of water vapour;
(*d*) Interaction between middle and lower latitude circulation;
(*e*) Topographical effects; and
(*f*) Small and mesoscale circulation systems in the hurricane.

Rainfall over land commences when the centre of the cyclone is about 500 km away from the coast. The rainfall continues along and near the track of the cyclone even after it crosses the coast and moves over the land as a weak system and finally dissipates (Pisharoty, 1993).

During this period an average rainfall of 5 cm occurs over a land area about 2 000 km long and about 500 km broad. The amount of water thus precipitated is 50 000 million cubic metres (1 cubic metre = 1 000 litres).

In several cases, rainfall of 40 cm in one day can occur over an area of about 50 km radius around the centre of the cyclone. It can be 20 cm a day even at distances of 200 km from the centre. Usually the rainfall distribution around the centre is not symmetric; more rainfall occurs to the left of the track than to the right. Less, but still heavy, rainfall occurs even at distances 400 km away from the centre. Beyond that some rainfall occurs, although it is of the order of 1 or 2 cm a day. The weakened cyclone moves across the country for two or three days, giving copious rainfall.

The intensity of rainfall is quite high particularly within the core of hurricane winds. It can reach 10–12 cm per hour. Outside the core heavy intensities of 4–6 cm also occur, but they are over smaller areas, 1 00 square kilometres or so in size, and for a shorter duration of an hour or so. As the centre of the cyclone strikes the coastline, the strong winds and the heavy rain inflict havoc on the land through soil erosion, even over those areas not subjected to the storm surge. A cyclonic storm after crossing the coast may get a fresh supply of moisture and continue to cause heavy rainfall. In India similar situations often occur due to a fresh supply of moisture from the Arabian Sea.

3.8 SURFACE WIND IN A TROPICAL CYCLONE

Strong winds associated with tropical cyclones are mainly responsible for the huge loss of human life, cattle and property. Most deaths occur due to houses collapsing and the uprooting of trees. The strength of the wind depends upon cyclone intensity, structure of the vortex and the environmental pressure distribution.

The band of maximum winds associated with a typical tropical cyclone is 20–50 km away from the storm centre. However, this band may vary from between 10–150 km away. The distribution of maximum winds is also highly asymmetrical with respect to the storm centre. This may result from environmental forcing, inner core restructuring or the interaction between the moving tropical cyclone and the underlying surface. In India, the following modified Fletcher's formula, suggested by Mishra and Gupta (1976), is used for estimating maximum wind speed:

$$V_{max} = 14.2\ P_n - P_0$$

where $P_n - P_0$ is the pressure depth.

Dvorak's (1975) relationship between a satellite-derived T-number and MSLP is also very useful in estimating the V_{max}. This has been widely used in cases of non-availability of ships' observations. With an increase in the severity of a tropical cyclone, its damage potential also increases.

3.9 AVAILABILITY OF DATA FOR MONITORING AND FORECASTING TROPICAL CYCLONES

The monitoring and forecasting of tropical cyclones are dependent upon data covering a wide area, on telecommunication facilities to allow the data to be collected from the numerous observing stations and on the data being broadcast for interpretation by all the services requiring it (ESCAP/WMO/LRCS, 1977).

Observational data

In order to provide a forecast for an area the size of a country or continent, the forecaster needs data giving conditions at the surface and in the upper atmosphere over a large area. Because atmospheric processes are taking place all the time, the data must be constantly renewed, some reports being required at hourly intervals, others every 3, 6 or 12 hours, so that the state of the atmosphere and of the sea surface can be monitored continually. Some observing facilities, e.g. weather radar, permit continuous surveillance of rain and cloud within range of the equipment. Information made instantly available in this way is highly valuable.

A country susceptible to tropical cyclones should install additional observation facilities to supplement the basic meteorological network required for its normal forecasting and climatological requirements for aviation, industry, agriculture, shipping, the general public, etc. The additional facilities required by a country vulnerable to tropical cyclones should be developed on the following lines:

(*a*) Weather radars
The unique and virtually indispensable advantages of a weather radar are that, within its range, it provides a continuous watch on a tropical cyclone and enables the meteorological service to provide reliable, accurate information as the storm comes closer and closer to the coast.

(*b*) Auxiliary reporting stations
These stations should be equipped to measure pressure, wind and rainfall. They should be deployed along coastal areas and at important locations inland.

(*c*) In-flight reports from aircraft
Reports from commercial or other aircraft are always of great value in providing data from areas remote from the standard observing network, e.g. over the ocean. When it is known that a tropical cyclone has formed, requests for the transmission of in-flight weather reports should be made to any air crew expected to fly in the vicinity of the storm.

(*d*) Aircraft reconnaissance reports
US reconnaissance aircraft penetrate hurricanes in the North Atlantic and typhoons in the Pacific. These flights provide valuable meteorological information including the position of the centre, reports on cloud structure and on the distribution of temperature, wind and pressure.

Telecommunications facilities

A national meteorological service requires an elaborate telecommunications system to collect and retransmit data obtained from the national network. As and when the cyclone is formed and moves, the national meteorological telecommunications system, which includes land line and radio between countries in the vicinity of the cyclone, should, in addition to exchanges of plain language and numerical coded data, provide for the reception and transmission of weather charts by facsimile and for receiving pictures from the meteorological satellites.

3.10 DESTRUCTION CAUSED BY TROPICAL STORMS

3.10.1 Damage to agriculture

The tropical cyclone causes irreparable damage to the agriculture, ranches and forests. The loss to an agriculture system can be categorized as follows:

(*a*) Destruction of vegetation, crops, orchards and livestock;

(*b*) Damage to irrigation facilities such as canals, wells and tanks; and

(*c*) Long-term loss of soil fertility from saline deposits over land flooded by sea water.

The loss caused by a single storm may run into millions of dollars (Holland and Elsberry, 1993). This is particularly so in the case of developing countries. Coastal areas in developing countries suffer great loss of life, especially the Indo-Bangladesh coast where the shallow bathymetry of the north Bay of Bengal is prone to the highest storm surges in the world. These areas are also densely populated and are centres of brisk marine activity. Most of the population dwell in temporary thatched houses and the farmers have small land holdings. The lack of cyclone shelters and proper escape routes, the slow mode of transportation and the low elevation of the estuarine area all contribute to the regular catastrophes which occur here.

3.10.2 Salt deposition in coastal areas

The effects of strong winds in coastal areas are seen in stunted and often very sculpted trees providing unmistakable evidence of the direction of the strong winds. In addition to the battering effects of winds, there is the additional damage caused by airborne sea salt which occurs within a few hundred metres of the coast. Winds which blow from coastal seas spray a lot of salt on coastal areas, making it impossible to grow crops sensitive to excessive salt. Tamate (1956) details the results of work in Japan on reducing the salt content of the air (by filtering) by shelter belts. Immediately to the lee of shelter belts, salt concentration can be lowered to 12 per cent of that to the windward side.

Moreover, a rise in the ecstatic sea level results in the territorial extension of coastal salinity under the direct or indirect influences of sea water. Fields inundated by the storm surge suffer a loss of fertility due to salt deposition, even after the sea water has receded. The affected land takes a few years to regain its original fertility. The period of high water can last from 6 hours to several days, if the drainage is poor, and may leave the soil saline and unfit for crops. Saline soils are predominantly observed in the coastal areas of India. A rise in the sea level would adversely affect the 7 000-km coastal belt of India, comprising 20 million ha of coastal ecosystem, increasing coastal salinity and reducing crop productivity.

3.10.3 Agrometeorological loss associated with some devastating cyclones

For most developing countries, agricultural production losses represent a significant part of the damage caused by cyclonic disasters. The amount of damage caused to agriculture (and forests) by the high winds depends on the velocity of the winds and their duration. The higher the wind speed and the longer the duration of the strong winds, the greater the damage. Typhoons have been known to inflict severe damage on agriculture: for example, in south Hainan on 2 October 1989, some 25 million timber and rubber trees were blown down (Salinger, WMO, 1994) and in Mauritius on 6 February 1995 the main agricultural product, sugar cane, was reduced by 30 per cent. A typhoon which struck Thailand on 4 November 1989 wiped out some 150 000 ha of rubber, coconut and oil palm plantations and other crops (WMO, 1997).

In Mozambique, it was reported that more than 100 people died while 30 000 others were affected by the cyclone which struck the country in January 1984. The total cost of damage to agricultural crops was estimated at US$ 75 million. The crops which suffer most in Thailand are rice, upland crops and fruit; total area losses comprise nearly 160 000 ha of these commodities annually. At the same time, the logging industry suffers financial losses of US$ 30–450 million and areal losses of 4 800–7 6000 ha annually. In the USA, annual crop losses are approximately US$ 50 million. In the Philippines, livestock losses of about $4 million (for 1991) and crop losses of about US$ 5 million (for 1992) were reported. In Vanuatu, crops affected annually are coconuts (US$ 165 000–826 000 losses) with a damaged area of 50 000–100 000 ha; cocoa (US$ 41 000–226 000) with a damaged area of 10 000–20 000 ha and garden crops (US$ 816 000–4 110 000) with a damaged area of 500–1 000 ha (Bedson, 1997).

Traditional, small-scale fisheries are also hit by cyclones. In monetary terms, the losses incurred by livestock raising, forestry and fisheries mostly remain below those suffered by crops. In Madagascar, following several cyclone occurrences in 1983–84, the FAO Office for Special Relief Operations (OSRO) estimated that crop losses represented 85 per cent of the total damage to the agricultural sector, whereas the damage to infrastructure and equipment (drainage and irrigation channels, fishing gear, etc.) barely reached 15 per cent. Livestock losses were negligible (OSRO, 1984). A rather different impact pattern occurs in small islands like Antigua and Barbuda where fisheries constitute the backbone of the economy. After hurricane Hugo in 1989, 47 per cent of the losses occurred in fisheries, but crop losses still represented almost 40 per cent of the total damage (OSRO, 1989).

It is worth mentioning the losses affecting cash crops which are a major source of export earnings for a number of developing countries. In Nicaragua, it is reported that direct loss of export crops due to hurricane Juana (Joan) in late 1988 amounted to 21 per cent of total losses in the agricultural sector (MIDINRA, 1988). Coffee and bananas suffered a direct loss of their fruits and mechanical damage to plants. Nonetheless, food crop losses were estimated to be higher (35 per cent), while the livestock sector was less affected (8 per cent), of which one fifth was poultry.

Two broad categories of effects on the agricultural sector can be identified: direct and indirect effects. Direct effects to a farmer could be, for example, the loss of his current crop and damage to his irrigation facilities. Indirect effects appear progressively, as a result of low income, decrease in production and other factors related to the cyclone disaster. The farmer may well have to pay high prices for seeds because of increased demand and disruption of the transportation system. He might also lose a portion of his future harvest because of storm surge-related salinization of soil or the destruction of perennial plantation crops which sometimes take 5–10 years to re-establish. Indirect effects are thus difficult to quantify and therefore are often termed “invisible” effects. Conditions conducive to the development of pests and diseases are to be regarded as indirect effects. Tropical examples are desert locust outbreaks or increased disease incidence in sugar cane after hurricanes. Plants weakened by adverse weather are much more susceptible to cryptogamic diseases or pest attacks, such as the explosion of coconut black beetle on wind-damaged coconut trees. For example, it is taking 30 years for certain timber varieties to re-establish after hurricane Allen hit Jamaica in August 1980 (FAO, 1982). It is frequently from 6–12 months for banana and 4–5 years for coffee and sugar cane. Even for crops that regenerate easily after partial damage, harvesting is usually made difficult by the “abnormal” morphology, thus further reducing yield.

In November 1970, one of the worst cyclones in history struck Bangladesh. This coincided with the start of the Aman rice harvest, of which a sizeable proportion could not be harvested. This led to a drop in production of 1 million tons as compared with the previous year. Moreover, November is also the planting period for the Boro rice crop. Following the cyclone and ensuing floods (including a tidal wave), there was great disruption to economic activity, destruction of infrastructure and the area cultivated with Boro rice was reduced and planting or transplanting was delayed. This accounted for the sharp decrease in Boro production the following year (Gommes, 1997).

Between 14 and 16 November 1991, tropical storm 4B pounded southern India for two days; sea water inundated the coastline resulting in extensive property and crop damage. Several irrigation tanks were breached and crops on 2.36 lakh ha were damaged in Tamil Nadu State and 7 253 head of cattle and 4 500 poultry birds perished in Andhra Pradesh State, apart from damage to crops worth crores of rupees. In mid-November 1992 cyclone 10B brought in its wake extensive damage to life, property and agricultural production in the coastal districts of Tamil Nadu and Kerala in India and in Sri Lanka. Hundreds of thousands of hectares of agricultural land were submerged and thousands of cattle perished in Tamil Nadu and Kerala states. In March 1992 cyclone Fran hit the Queensland coast causing flooding and damaging sugar cane crops. In central Vietnam, tropical storm Angela (1992), accompanied by gusty winds and heavy rains, caused considerable damage to rice and vegetable crops (WMO/UNEP, 1993).

On 7–8 August 1993, tropical storm Bret (FAO, 1994) affected Venezuela causing agricultural losses, according to official sources, of 14 000 ha of maize (22 per cent of the area under cultivation), 1 500 ha of rice, 750 ha of cassava, 150 ha of bananas, 150 ha of horticulture/fruit trees, as well as 2 000 head of cattle, and large numbers of pigs, poultry and other animals.

Another example of a natural disaster was that of cyclone Nadya which affected 13 of the 22 districts in Nampula, Mozambique, in early April 1994, about two weeks before the harvest. Food crops such as maize, cashew, maxdeira, mapira and cassava were badly affected. In the worst affected districts, 80 per cent of these crops were lost and about 870 000 people were considered to be affected. In addition to its affect on agriculture, the cyclone caused outbreaks of diarrhoea and cholera associated with unsanitary conditions (DHA, 1994).

During May 1986 tropical cyclone Namu caused 100 deaths and nearly one-third of the population to leave their homes in the Solomon Islands in the south Pacific. Agricultural losses, especially timber, cocoa, coconuts and palm oil, were particularly heavy. It was estimated that 10–15 per cent of oil palm, 15–20 per cent of copra and 10–25 per cent of cocoa production would be lost over the subsequent three years (Britten, 1987).

3.10.4 Other destructive effects of cyclones

Tropical cyclones are also responsible for a large number of casualties and considerable damage to property. Destruction is confined to the coastal districts, the maximum destruction being within 100–150 km of the centre of the cyclone and to the right of the storm track where wind direction is from ocean to land. The principal causes of destruction by cyclones are: (i) fierce winds; (ii) torrential rain and associated flooding; and (iii) high storm tides (the combined effect of storm surge and astronomical tides) leading to coastal saline inundation.

Most casualties are caused by coastal inundation by storm tides; penetration varies from 10–20 km inland from the coast. Heavy rainfall and floods come next in order of devastation. Death and destruction purely due to winds are relatively small. The collapse of buildings, the falling of trees, flying debris, electrocution and disease from contaminated food and water in the post-cyclone period contribute substantially to loss of life and destruction of property. Available statistics the world over show that the tropical cyclone is far ahead of any other disaster as a killer, accounting for about 64 per cent of total lives lost. The 80–100 tropical cyclones that occur each year caused an annual average of 20 000 deaths between 1964 and 1978. The average economic loss per cycle per year was about US$ 60 million. When a cyclone hits the US coast, for example around the Gulf of Mexico, the loss can be as high as US$ 2 000 million (ESCAP/WMO, 1991).

Apart from the serious calamity of loss of human life and injuries, the impacts of a severe cyclone on a coastal district are:

(*a*) Damage to fishing and other facilities;
(*b*) Damage to off-shore and on-shore installations;
(*c*) Damage to roads, railway tracks and other public utilities;
(*d*) Damage to electricity supply systems; and
(*e*) Damage to telecommunication systems.

3.10.5 Some economic and social consequences

The factors discussed above – damage from wind, rain, flood, storm surge and sea waves – may be regarded as representing the direct impact of tropical cyclones. Loss and damage attributable to these factors can be assessed in terms of deaths and injuries to the population, buildings and installations destroyed or damaged, destruction of crops and livestock, etc. However, there are additional, perhaps indirect, consequences which cause losses to individuals, industry, the community and the nation. The magnitude of these effects can be very large and they cannot be ignored. Some brief discussion of these aspects follows.

Losses in productivity

A tropical cyclone can lead to disruption of the workforce and to other activities resulting in a substantial loss in productivity. Factories and warehouses may be out of commission for a time and many working hours may be lost because of breakdowns in land, sea and air traffic, impeding the movement of people and supplies, and because of a diversion of labour to assist with disaster relief and restoration. In agriculture, there can be large losses in primary production on account of delays in the recovery of arable land that has been inundated.

Personal and domestic losses

A tropical cyclone can cause many losses of a personal and domestic nature. The loss of personal belongings, such as clothing and furniture, can be an especially severe blow to families whose financial reserves are small. In the domestic area, breakdowns in public utilities can lead to significant losses. All these losses may be great in some homes and small in others but represent a substantial financial loss to the community as a whole.

3.11 BENEFICIAL IMPACT OF CYCLONIC STORMS

The effects of cyclonic storms are not wholly bad; benefits centre principally on the precipitation associated with them which may have considerable value to agriculture. The heavy rain associated with cyclonic storms guarantees a longer period of water availability and provides possibilities for off-site extra storage in rivers, lakes and artificial reservoirs (on farms or at the sub-catchment level) giving an improved rural water supply and expanded or more intensive irrigated agriculture and inland fisheries. The extra precipitation due to cyclonic storms on land helps to increase plant growth improving the protection of the land surface and increasing rainfed agricultural production. Ryan (1993) mentioned some important benefits of tropical cyclones in Australia. Increased water availability in water-critical regions makes agricultural production less susceptible to the dry period. Sugg (1968) estimates that nine major hurricanes in the United States since 1932 terminated dry conditions over an area about 622 000 square kilometres (240 000 square miles). Hartman, *et al.* (1969) estimated the change in total crop value brought about by these storms occurring in different months. The losses in crops for two of the storms were $54 million and $1 million; for the third storm there was an increase in total crop value of $8 million.

3.12 CYCLONE WARNING SYSTEM

One of the short-term mitigation measures against tropical cyclone disaster is an efficient cyclone warning system. The requirements for an efficient cyclone warning system are:

(*a*) Advance, accurate and detailed forecasts of dangerous conditions;
(*b*) A rapid and dependable distribution system for the forecasts, advisories and warnings to all interested parties; and
(c) Prompt and effective utilization of warnings by the government and the public.

To have a fairly accurate forecast, it is necessary to have: (i) maximum high-quality data; (ii) forecasters with sufficient ability, training, experience and time for data preparation; and (iii) foolproof techniques for preparing accurate forecasts of the storm's movement, changes in intensity and storm tides. The US Weather Research Program for Hurricane Landfall (OFCM, 1996; Elsberry and Marks, 1999) promises improved forecasts of track, intensity, surface wind and rainfall, as well as research on decision-making and the technology transfer necessary to convert advances in science and technology into products useful to society. The communication system for the distribution of advisories and warnings should be one that can dependably deliver the advisory information to all concerned in the shortest possible time, even in cyclonic conditions of strong wind, heavy rain, floods, etc.

An essential element of a warning service is that there should be certainty that the warnings will reach the intended recipients promptly. The supporting communications system, including back-up facilities, should therefore be planned and implemented in full detail.

It is also essential that the responsible authorities and individuals who receive tropical cyclone warnings should be clear as to the actions that follow as soon as the warning messages have been received at their end. The warning itself might be the signal for prearranged action to be taken. This would, of course, be the first of a series of executive measures that responsible authorities would set in motion (WMO, 1983). The meteorological warning, besides giving precise information about the tropical cyclone itself and the winds and rainfall to be expected, might also serve as a preliminary warning of a flood or storm surge. Such preliminary warnings should be confirmed or amended in due course by the forecast centre, in conjunction with hydrographers in the case of a storm surge warning. There has been considerable analysis of the key components of warning systems, for example, in the context of the WMO Tropical Cyclone Programme and the International Decade for Natural Disaster Reduction (WMO, 1990).

3.12.1 Dissemination of cyclone warning

For warnings indicating likely places of landfall, the associated maximum wind, rainfall and storm surge heights are essential for making preparations to save life and property, and it is absolutely essential to maintain an efficient telecommunications system for the dissemination of warnings.

Cyclone warnings to the main users in India are issued in two stages. In the first stage a “cyclone alert” is issued normally 48 hours before the commencement of adverse weather along the coast. In the second stage a “cyclone warning” is issued around 24 hours before the cyclone strikes the coast. Port and fisheries warnings start much earlier. These warnings are disseminated through (i) landline telegrams of special high priority; (ii) repeated broadcasts through All India Radio in different languages; (iii) bulletins to the press; (iv) the Posts and Telegraph Department’s coastal radio stations (broadcast in code for the benefit of ships on the high seas); (v) telephone, telex and teleprinters wherever available; and (vi) the wireless network of the police.

3.13 DISASTER MANAGEMENT AND MITIGATION MEASURES

Accurate warnings of a tropical cyclone will have no impact unless protective measures are taken by the government and the affected people. Recently government awareness has increased greatly and proper action is being taken regarding tropical cyclone warnings. Disaster management refers to all activities connected with prevention, preparedness and relief (Mandal, 1993). Disaster prevention may be defined as measures designed to prevent natural phenomena from causing or resulting in disasters. A disastrous event does not pose much of the threat and ceases to be a disaster if suitable and adequate mitigation measures are adopted well in advance. Prevention of the formation of tropical cyclones is not in the realm of possibility, but much of their disastrous potential can be reduced, restricting thereby the loss of human life and loss of property, by adopting appropriate strategies and taking timely precautions on the receipt of weather warnings. Climatological data helps in the advance preparation of long-range policies and programmes for disaster prevention. Disaster preparedness, on the other hand, is the action needed to minimize the loss of life and damage to property by organizing timely and effective rescue, relief and rehabilitation operations when an area is struck by a disaster. Thus, disaster prevention is essentially based on climatology, and preparedness on weather warnings. Though different in nature, both require advance and complementary planning. Some important aspects of disaster management have been mentioned in ADB (1992).

3.13.1 Prevention

Four ingredients are required to implement disaster prevention planning: (i) a technical evaluation of the climatological risk of cyclones and cyclonic effects in the coastal areas; (ii) an assessment of the relative vulnerability of population, within the selected boundaries; (iii) the establishment of structural design codes, regulatory controls and minimum safety standards designed to encourage public adherence; and (iv) an educational programme to gain community acceptance of the cost of cyclone disaster prevention. It is evident that long-range tropical cyclone mitigation planning or prevention measures are highly interdisciplinary because they involve liaison between meteorologists, hydrologists, environmental planners, engineers, agricultural specialists, marine scientists and administrators. The objectives of tropical cyclone disaster prevention in national planning have been comprehensively described in guidelines in ESCAP/WMO/LRCS, 1977.

3.13.2 Preparedness

Disaster preparedness for impending cyclones, as we know, refers to the plan of action needed to minimize loss to human lives, damage to property and agriculture. The effectiveness of disaster preparedness ultimately depends on the effectiveness of planning and response at the district or local government level (Oakley, 1993).

"Preparedness" in an agriculture system can include early harvesting of crops, if matured, safe storage of the harvest, etc. Irrigation canals and embankments of rivers in the risk zone should be repaired to avoid breaching. Beyond this, as the storm approaches the area, nothing more can be done.

Examples of major non-agricultural-related decisions under "preparedness" include the evacuation of ships from ports, the progressive closure of sea, road, rail, air, and inland river transportation systems and power supplies, the closure schools and suspension of commercial activities, requests to the military for assistance with evacuation, emergency food, clothing and medical supplies, etc. Each of these activities requires a special meteorological briefing to explain the contents of official or broadcast warnings. The cyclone warning centres need to liaise with the relevant radio stations for broadcasting the latest cyclone bulletins. The public and officials are advised to monitor these weather bulletins. Fishermen in the concerned coastal belt must be specifically warned not to go to sea. Irrigation and waterways authorities should inspect the embankments of rivers in the risk zones to avoid breaching. This stage helps to avoid the danger of over-warning.

Twenty four hours before the likely onset of adverse weather, a specific warning about the position of the storm, its intensity and likely place of landfall and associated weather, including tidal waves, should be issued and given wide media (visual and audio) coverage.

The following are the important steps to be taken for "disaster preparedness due" for cyclones:

(*a*) Adequate storm warnings for mariners on the high seas;
(*b*) Port warnings for the safety of ships leaving port (distant signals);
(*c*) Port warnings for the safety of the port, ships and craft plying coastal areas and ships moored in the port;
(*d*) A warning for the safety of fishermen; and
(*e*) A cyclone warning to the state government authorities and non-government agencies for safety of the coastal population.

3.13.3 Evacuation

In many coastal areas it may be prudent to evacuate the population in advance of a storm. Evacuation can be horizontal or vertical. The former makes use of routes to move people to higher ground inland, the latter moves people to highrise, storm-proofed buildings. Both types of evacuation require careful contingency planning, identifying routes and possible hazards (ESCAP/WMO/LRCS, 1977). There are many problems specific to horizontal evacuation. For example, routes inland may become blocked by pre-storm flooding, fallen trees and power lines or by traffic jams. To overcome the latter problems, the volume of traffic on evacuation routes should be strictly controlled and, in some cases, limited to public transport only. Island communities relying on causeway or ferry links are particularly vulnerable. In extreme cases even 24 hours' warning may not be sufficient to effect a complete horizontal evacuation, due to either low traffic capacity or distance. It would, for example, be difficult to effect a total evacuation, even with an adequate storm warning, in cases where islands are linked to the mainland by long tortuous, low-lying causeways.

Vertical evacuation entails the movement of people into secure storm-proofed highrise buildings. Such an operation is obviously less cumbersome than horizontal evacuation, but it still requires careful planning. Such planning may be tackled in two ways; first by designating routes or havens of sufficient capacity to absorb the at-risk population. This may entail road widening, removing or relocating toppling hazards and strengthening building foundations and super structures. Secondly, at-risk communities may impose ceilings on the size of population or development inside the known area.

3.13.4 Mitigation

For any effective cyclone mitigation measure public awareness plays the most important role. People in coastal areas must understand the physical nature of the threat and its disastrous potential (Rakshit, 1987). They should understand the language of the cyclone warnings so that they can respond effectively. To that end, the warnings should be worded in simple language, easily understood by all. Extensive educational programmes should be conducted. Lectures, film shows, seminars, etc. may be arranged in schools and in public theatres. Non-governmental organizations (clubs, scientific organizations, etc.) play a very effective role in mass education. Wide publicity through different media such as radio, TV and newspapers during the pre-cyclone season can remind people to become alert to the potential calamity. The fishing community is the most vulnerable as they go to sea and remain there for a considerable period. They must carry at least transistor sets to keep them aware of the latest weather situation. It should be stressed that once they are caught in an offshore wind associated with a cyclone, they are likely to be drawn away from the shore and may not be able to escape the cyclone. Many fishermen may also suffer from a false sense of security as they might claim to have weathered a number of cyclones in their long careers, but there is no guarantee that they will be lucky every time.

The mitigation of cyclone disaster requires progress in four areas:

(*a*) Accuracy of warnings;
(*b*) Expeditious dissemination of warnings;
(*c*) Community understanding of the cyclone; and
(*d*) Effective utilization of the warnings by the community.

Typical pamphlets such as “Know your tropical cyclone warning system”, “What do you do when a cyclone strikes?”, “Beware, cyclone are killers”, etc. can be prepared and distributed free of charge. Placards can be displayed in public places and at roadsides. A list of cyclone shelters and maps showing evacuation routes should be prominently displayed. Frequent broadcasts/telecasts direct from cyclone warning centres can convey the correct assessment of a cyclone threat with an authority and authenticity which can have a far reaching impact on viewers and listeners.

Persons entrusted with cyclone distress mitigation work should have a higher level of cyclone awareness and education. It is therefore essential to have training facilities for these officials and volunteer group leaders at appropriate levels (UNDRO, 1991). In India, for instance, cyclone familiarization meetings/seminars are held on a routine basis twice a year where state and central government officials directly associated with cyclone distress mitigation activities participate and exchange knowledge and experience.

To alleviate the distress of the people affected by cyclones the following steps should be taken in order of urgency:

(*a*) Medical aid;
(*b*) The prompt disposal of dead bodies and carcasses;
(*c*) Preventive measures against epidemics such as cholera and other waterborne diseases;
(*d*) Arrangement for the supply of safe drinking water and food;
(*e*) The carrying out of repairs to tanks and other water stores;
(*f*) The mobilization of building materials and their distribution for repair work; and
(*g*) The supply of cattle feed and fodder.

Cyclone disaster management needs to be a long-term, multi-sector responsibility which interacts with, and contributes significantly to, national development. It should be intimately concerned with the root causes of community vulnerability to hazards. To be successful, vulnerability reduction programmes need high level coordination and the support of the entire community (Stenchion, 1997).

3.14 OTHER MEASURES

Cyclone-prone areas should be subject to land reform. The harvests should be so phased that they coincide with the safe period or periods of low risk. Better communications are also needed, both to improve the speed of information and to aid evacuation. Protective forests (mangrove) should be encouraged, both to reduce the frequency of inundation and to initiate reclamation, although it is not easy to divert limited resources for such measures.

Risk zone mapping and analysis of land use pattern should be undertaken to guide growth and development away from cyclone-prone areas. Land use legislation and building regulations should be established and strictly enforced in cyclone-prone areas. Architects and planners have a great responsibility in the field of disaster mitigation. They must discourage the development of primary social functions, vulnerable production facilities and human settlements in cyclone-prone areas.

All existing public or community buildings such as schools, hospitals, etc. should be made totally safe against cyclones. Easy exits and access to structures should also be ensured. Raised platforms for livestock, emergency food grain storage facilities, drinking water storage and wells with covers to avoid pollution and silting during inundation should be built in cyclone-risk areas and properly maintained (Shanmugasundaram, *et al.*, 1993). Action plans for health care after a disaster should be prepared in advance in cyclone-prone areas and implemented if necessary. Such plans should be published, volunteers trained and health kits distributed. Training for survival during a cyclone should form part of such action plans (Madhava Rao, 1990).

A syllabus on topics connected with cyclones and floods may be included in school and college curricula in disaster-prone areas. The general public and industry may be educated about insurance schemes against natural disasters and be encouraged to be insured.

3.15 SUMMARY AND CONCLUSION

When a tropical cyclone approaches a country, the threats are threefold – winds, river floods and storm surges. Although strong and violent winds are a fundamental characteristic of tropical cyclones, it is often the rain-induced river floods and the storm surges which cause the heaviest loss of life and do the greatest agricultural and other damage. In any planning of disaster prevention and mitigation, the hazards likely to arise from winds, river floods and storm surge should be analyzed separately and also collectively, particularly in coastal areas.

A tropical cyclone as a single event is a test of the effectiveness of a country's ability in disaster prevention and preparedness. By the time a tropical cyclone has formed over the ocean and been detected, there will not usually be much time to do more than implement the emergency measures that already exist. The meteorological service no doubt will make every effort to predict the movement of the cyclone and, as it approaches the country, issue warnings to responsible officials and the general public, but the protection of the country and its people largely depends on measures that have been taken over several or more years in the recent past and on the efficiency and zealousness with which they are applied during an emergency.

Cyclones cannot be prevented but an increase in public awareness and effective pre-cyclone, on-cyclone and post-cyclone measures can definitely reduce their potential disaster to a very large extent. It is common knowledge that proper attention is never given before the occurrence of calamity; we often forget that prevention is better than cure. The cooperation of the public during a calamity is best guaranteed by ensuring that full information and advice is readily made available to all. For this purpose the mass media – radio, television and the press – are extremely important.

3.16 RECOMMENDATIONS

(*a*) Steps should be taken to encourage the building of capabilities in the areas of cyclone forecasting and the quick transmission of information to the area likely to be affected, as well as long-term measures to build up a physical infrastructure that facilitates the organization of rescue and relief operations in a systematic manner in order to minimize loss of life.

(*b*) Efforts should be made for the setting up of a number of wind observatories, the installation of high power storm detection centres, the upgrading of radio stations to communicate weather warnings and the streamlining of the administrative system for effective utilization during rescue and relief operations.

(*c*) Long-term measures such as (i) construction of cyclone shelters and identification of existing buildings to serve as cyclone shelters; (ii) afforestation along the coast to reduce wind velocities in order to minimize damage; and (iii) the linking up of coastal villages by a reliable road network to facilitate the quicker disbursal of relief.

(*d*) Cyclone stores should be established in various cyclone-prone districts consisting of essential drugs, large cooking vessels for use in relief camps, equipment for cleaning debris and road clogs, pumps, generators, etc.

(*e*) The coastal villages which are frequently affected by cyclones should be provided with cyclone shelters which not only withstand high velocity winds but which are also located at elevated places to provide shelters even during storm surges. Where the construction of shelters is not possible because of physical or financial constraints, existing public and private buildings may be identified for providing shelter.

(*f*) The construction of permanent houses, reconstruction of damaged infrastructure, especially irrigation, drainage and communication systems, inputs to agriculturists, especially for horticultural crops, the removal of sand from fields and the desalination of affected fields, the supply of boats and fishing yarn, repairs to inland fisheries, etc are to be undertaken.

(*g*) Historical data about cyclones should be compiled, documented and archived and the existing database widened. Models for pre-disaster and post-disaster management may be developed by research institutions on a priority basis. Research may also be undertaken into promoting studies/pilot projects for determining the useful effects of afforestation and plantations in cyclone-prone areas.

(*h*) Training and disaster awareness programmes should be made so that disaster-prone communities have a more realistic understanding of the risks to their community and take more practical measures to save life and property.

(*i*) Efforts should be made to record storm surge and tide data on different sections of coastline for the analysis of surge heights along different sections of the vulnerable coastline required for designing harbour installations, coastal planning and coastal engineering works.

(*j*) After the cyclone has passed, the public should be informed about what has happened and what the government is doing to meet the emergency needs of the people. The public should also be kept informed of the facilities that are being made available and should, at the same time, be advised on the action they should take as families or as individuals.

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CHAPTER 4

ASSESSING THE ECONOMIC AND SOCIAL IMPACTS OF EXTREME EVENTS ON AGRICULTURE AND THE USE OF METEOROLOGICAL INFORMATION TO REDUCE ADVERSE IMPACTS

(by K.A. Anaman)

4.1 SOCIAL AND ECONOMIC IMPACTS OF EXTREME EVENTS AFFECTING AGRICULTURE

4.1.1 Classification of extreme events affecting agriculture and rural society

An extreme event generally refers to a relatively rare natural phenomenon which could be geophysical, biological or atmospheric and which affects human society in terms of human suffering, damage to infrastructure and loss of life that substantially exceeds normal expectations. Chapman (1994) classifies natural hazards into three main groups:

(*a*) Those hazards originating primarily from the atmosphere and hydrosphere such as tropical cyclones, tornados, thunderstorms, floods, droughts, storm surges and possibly dust storms;

(*b*) Those originating primarily from the lithosphere such as earthquakes, volcanic explosions, dust storms, mass earth movements including mudslides, landslides and avalanches; and

(*c*) Those originating primarily from the biosphere such as wildfires, bacteria, viruses, disease-causing agents and other flora and fauna directly affecting human welfare.

Extreme events affecting agriculture considered under the terms of reference of the working group include regional droughts, extreme hot and dry weather, frost, flooding, excessive rainfall, tropical cyclones, storm surges, high winds, hailstorms, heat stress and cold injury, forest fires, locust invasions and volcanic aerosols and belong to all three groups of natural hazards. They are predominantly from the first group of natural hazards noted above, i.e. hazards originating from the atmosphere. However, hazards from the second group, such as volcanic explosions, are significantly important, tend to have considerable regional impact and receive great mass media attention. An example is the 19 September 1994 volcanic explosions in Rabaul, East New Britain Province of Papua New Guinea, which not only destroyed the town of Rabaul but significantly affected cocoa production and other agricultural activities of the province. The volcanic explosions also led to other natural hazards such as mudflows, mudfills and flash floods (Blong and McKee, 1994). Natural hazards originating primarily from the biosphere also receive mass media attention such as the Ebola virus outbreak in 1995 in Zaire. Such hazards directly affect agriculture through the displacement and evacuation of farm workers and animals from infested areas.

4.1.2 Assessment of economic and social impacts of extreme events

4.1.2.1 Types of impacts from extreme events

Impacts from extreme events on agriculture can be positive or negative. While it is easier to contemplate negative impacts of extreme events such as droughts, tropical cyclones and floods on agriculture, there are several positive impacts or benefits of extreme events on agriculture. These positive impacts 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 the fertility of flood-plain soils due to flooding (Blong, 1992). Chang (1983, 1984) showed that while Hurricane Frederic caused about US$ 1.6 billion of property damage and other direct losses in the State of Alabama, it also led to an influx of about US$ 670 million in government and private sector recovery funds resulting in a US$ 2.5 million increase in the municipal funds for the city of Mobile within 12 months. The overall long-term impact of the hurricane was negative to the State of Alabama.

However, certain sectors of the state economy actually benefited. While positive impacts can be shown to occur for some extreme events, it is the negative or adverse impacts of extreme events which are more pronounced and do affect human society significantly (Joy, 1991; Mitchell and Griffiths, 1993; Sofield, 1993). These negative impacts are often referred to as damages or losses.

Impacts of extreme events can also be classified as either direct or indirect. Direct impacts from extreme events arise from the physical or direct contact of the events with people, their property and equipment and animals. For example, when bush fires come into contact with crops and farm buildings or when drought conditions directly reduce yields of crops and lead to the death of livestock and people. Indirect impacts of extreme events are those induced by the events. Indirect impacts often occur away from the scene of the extreme event or after its occurrence. Indirect impacts include evacuation from houses or even permanent displacement from an area, disruption to household and leisure activities, loss of utilities and basic community services, stress-induced sickness and worry and anxiety about future extreme events, for example, floods or bush fires (Handmer and Smith, 1992).

Important indirect impact is normally termed secondary economic impact, in economic jargon. The secondary economic impact of an extreme event is derived from the impact on the local or regional economy due to an extreme event originating or initially affecting one or a number of sectors of the economy. A chain reaction impacts over a period of time, say one year, on different sectors of the economy. These impacts can be quantified and measured. For example, prolonged droughts may lead to direct losses such as death of farm animals but may also lead to various indirect effects on the incomes of suppliers of inputs to farmers as a result of the downturn in the agricultural sector. Secondary economic impact is estimated using input-output analysis or variations of this technique such as computable general equilibrium analysis (Jensen and West, 1986; West, 1993).

In addition to impacts of extreme events being classified as positive or negative, direct or indirect, they can also be classified as tangible or intangible. Tangible impacts are those which can be easily measured in monetary terms. Tangible benefits or positive impacts include, for example, the increased rainfall from severe weather events, the amount of which can be measured by meteorologists. Tangible losses or adverse impacts are easily quantifiable losses such as damage to farm buildings from bushfires or floods. Here losses can sometimes be recouped if properties are insured. Intangible impacts are often difficult to measure in monetary terms because they are not purchased or sold in well-defined markets and hence direct market values do not exist. Intangible losses or adverse impacts are sometimes referred to as non-economic or "social costs" in some of the literature (for example, Togola, 1994). Intangible losses include anxiety and fear of future severe events (Oliver, 1988), inconvenience and disruption to farm work and stress-induced ill health and human fatalities. Intangible benefits or positive impacts of severe events include improved preparedness by the population for future severe events. Finally, impacts of extreme events can be expressed as short term or long term, depending on the duration of the after-effects of the events.

4.1.2.2 Valuation of impacts of extreme events

The classification of effects of natural hazards as tangible or intangible is a first step towards evaluating the impacts of these hazards on agriculture. The estimation of economic losses and impact from natural hazards is often imprecise, with double counting common if concepts are not clearly defined and applied consistently. Impact assessment from natural hazards should be based on sound economic principles. The evaluation of adverse impacts of extreme events on agriculture and rural society requires delineating the impacts on society in general from those on individuals, households or businesses. The distinction is necessary to determine financial losses applicable to individuals and societal economic losses attributed to society as a whole. A single economic unit such as a farm is dealt with via analysis in changes in net income when financial losses are considered. Market prices are often used to approximate changes in income imposed by extreme events on individuals. For societal economic analysis, the analysis is done for all members of a defined society affected by the extreme events. The society can be a town, a region or a nation. Market values are sometimes adjusted to reflect economic scarcity of resources and inherent market imperfections. Regardless of whether an individual economic unit or the whole society is being considered, impacts are always measured as the difference between the occurrence and non-occurrence of an extreme event.

Valuing tangible losses at the level of the farm/firm/household

There are several ways of evaluating losses of assets at the farm/firm/household level which are caused by extreme events. The method depends on whether the asset has been completely destroyed or rendered unusable and whether the asset can be adequately repaired or restored to its former state. In the latter case, the relevant costs are those required to restore the damaged asset to its former state (before the occurrence of the extreme event). In the case where the asset has been completely destroyed, there are several alternative methods for valuing losses. These include: (i) the cost or market price of the asset before it was damaged which ever is lower; (ii) the net selling price of the asset before it was damaged defined as the market price minus selling cost; (iii) the cost of the asset minus accumulated depreciation; (iv) current replacement cost of the asset before it was damaged; (v) the income capitalization method. The income capitalization method involves deriving the net income of the asset (before it was damaged) in each year over its remaining lifespan and discounting the future net incomes to the present value by the market interest rate less the inflation rate. The composite sum of the yearly present values of the net income represents the value of the asset. Under ideal competitive market conditions, all these methods should yield identical market values of the asset. However because of market imperfections, an ideal valuation outcome may not always be possible. Certain methods are appropriate for certain types of asset and these are described below.

Current assets defined as those that are expected to be realized within one accounting period or one year, such as cash, are valued by their face value. Thus US$ 500 cash lost during the burning of a farmhouse by a bush fire is simply valued as a US$ 500 loss. Farm commodities, such as rice stored at a farm to be sold in the future, are valued at their current market prices less the expected costs of selling the produce.

Machinery and working assets are those which are considered to have expected working lives of between one and five years. Losses of machinery and working assets destroyed by severe events are valued based on the condition of the assets before the occurrence of the extreme event. If the machinery and working assets are partially destroyed then the costs to restore them to their previous states are the relevant losses. However, if these assets have been completely destroyed then there are a number of methods to value the losses. One method normally used for machinery is the cost of the asset if the destroyed asset was new. For old machinery and farm animals, the loss is the equivalent current market value.

Another option is to value the loss of the destroyed asset as its cost minus accumulated depreciation up to the time of its destruction. For growing field crops which are not yet ready for harvest but have been destroyed by an extreme event, losses are valued as the sum of all costs incurred in producing and maintaining the crops till the time of their destruction. This value should be compared with the market value of the growing crops if available and the lower of the two assessments used to establish the value of the losses. The income capitalization method is commonly used to value buildings which are destroyed by severe events. This method is sometimes used for valuing losses due to destroyed farm animals based on expected income over their remaining lifespan (Anaman and McMeniman, 1990).

Valuing aggregate tangible losses

Aggregate values of losses are often derived by multiplying the average individual farm losses by the number of farms affected or by simply estimating the losses for each farm or firm or household and adding up all the losses of affected businesses or households. Sometimes insurance payouts to households and businesses are used to derive approximate total losses from severe events for a particular region. Joy (1991) estimated that insurance payouts represented about 25 per cent of total losses from severe weather events in Australia. Total losses were then derived by multiplying the insurance payouts by a factor of four.

Valuing intangible impacts

Intangible impacts of extreme events are usually difficult to value in economic terms because they cannot be easily measured in monetary terms. They are likely to be expressed in non-monetary values, for example, through the use of social indicators such as the number of human deaths and the number of people affected by stress induced by the extreme event. For example, a summary of fatalities from some natural hazards in Australia since European settlement has been compiled by the Natural Hazards Centre of Macquarie University, Sydney (Coates, 1996). These natural hazards included heatwaves, tropical cyclones, floods, bushfires, lightning strikes and landslides. The number of human fatalities from bushfires over the period 1827–1991 was estimated as 678, deaths from floods as 2 207 for the period 1803–1996, fatalities from lightning strikes as 650 for the period 1803–1992 and deaths from tropical cyclones totalled between 1 863 and 2 312 for the 1827–1989 period (Coates, 1996). The qualitative listing of general intangible impacts affecting people caused by an extreme event without listing the specific number of people affected is also common. Briefly, intangible impacts include: (i) human deaths or fatalities; (ii) loss and destruction of personal and cultural memorabilia and artifacts; (iii) anxiety, stress and induced ill-health; and (iv) inconvenience and disruption of personal and family daily non-business activities.

Loss of human life is difficult to value in monetary terms and is often avoided by professional impact assessors. However, there is growing literature developed by economists to attempt to put a monetary value on human life (Field, 1994; Dwyer, 1986). These methods include the contingent valuation method based on individuals' willingness to pay to take measures to reduce the possibility (probability) of death from extreme events. Briefly, a contingent valuation study involves identifying and describing the environmental improvement being evaluated such as the supply of advance warning meteorological information to reduce the possibility of death from the extreme event (e.g. tropical cyclones and severe floods), identifying and selecting respondents, especially from the target group at risk of the extreme events, using scientific sampling procedures, designing and applying a survey questionnaire through personal, phone or mail interviews, analyzing the results statistically and aggregating individual responses to represent an aggregate value for the group (Mitchell and Carson, 1989; Bateman, 1994; Field, 1994; Drake, 1995). The other popular method of valuing human life is the extension of the income capitalization method described earlier to value life based on the expected yearly earnings throughout the rest of the expected lifespan of the deceased person.

Destruction of cultural artifacts and sites is not possible to value in monetary terms because they are generally considered as irreplaceable. It is also difficult to establish future incomes from these assets when these assets are not sold or bought in well-defined markets. Anxiety and stress-related sickness are also difficult to value. However, increases in health-related costs induced by the extreme event may provide a proxy for a value of its intangible impact.

4.2 ECONOMIC USE OF METEOROLOGICAL INFORMATION AND SERVICES TO REDUCE ADVERSE IMPACTS OF EXTREME EVENTS ON AGRICULTURE

4.2.1 DATA, INFORMATION AND SERVICES AS ECONOMIC RESOURCES

Data are facts or figures often derived from direct observations. Data tend to be raw pieces of facts and figures. When data are processed or transformed into forms useful to people they become information. Information is also sometimes defined as knowledge communicated or received concerning some circumstance or event implying that information involves both the transformation and communication of data from one source to another. Economists define information as data which have been processed into forms that are relevant and useful to recipients (Davis and Olson, 1985). The supply of meteorological information and data in forms demanded by customers is the provision of a service. Historical daily rainfall figures of a particular location are data. When these data are transformed into monthly and yearly totals to describe the type of crops that can be grown in a particular location they become information to a prospective farmer. The provision of rainfall data and related information as to the suitability of crops grown by farmers is a service. Scientists use data as inputs into models to generate outputs which become information since those outputs provide utility to the scientists or their sponsors in explaining or better predicting natural or human-induced events.

The services of national meteorological services are often used as important inputs in the decision making of many businesses of the national economies and also sometimes by other countries, for example, the sharing of atmospheric data for airline travel. Meteorological services such as public weather forecasts and warnings are also used by households as consumption goods since the public weather services provide personal convenience to individuals for their day-to-day living. National meteorological services are often responsible for the collection, storage and archiving of weather and climate data such as rainfall and temperature data for use by future generations. They also have important roles to play in the free international exchange of meteorological information and other services administered by the World Meteorological Organization.

In the context of the production and use of agrometeorological data, processed data, information and services, it is essentially a feedback process as is illustrated in Figure 4.1. A national meteorological service produces agrometeorological data and information (including agricultural statistics), sometimes in conjunction with other national and international institutes. The agrometeorological processed data and information are sent to farmers through a distribution network which involves verbal contacts, post, phone and facsimile services. In many countries, the key link between the national meteorological service and farmers is the local agricultural extension office or possibly research office. Officers in the local agricultural extension or research office work closely with meteorological officers to further process meteorological information in forms that can be understood by farmers, especially small-scale farmers. Meteorological information has to be tailored to suit the production of certain crops and the role of extension officers is important to encourage the effective dissemination of information. Extension officers also provide a source for feedback reaction and information from farmers to the national meteorological service, thus allowing it to continually upgrade the quality of its information products.

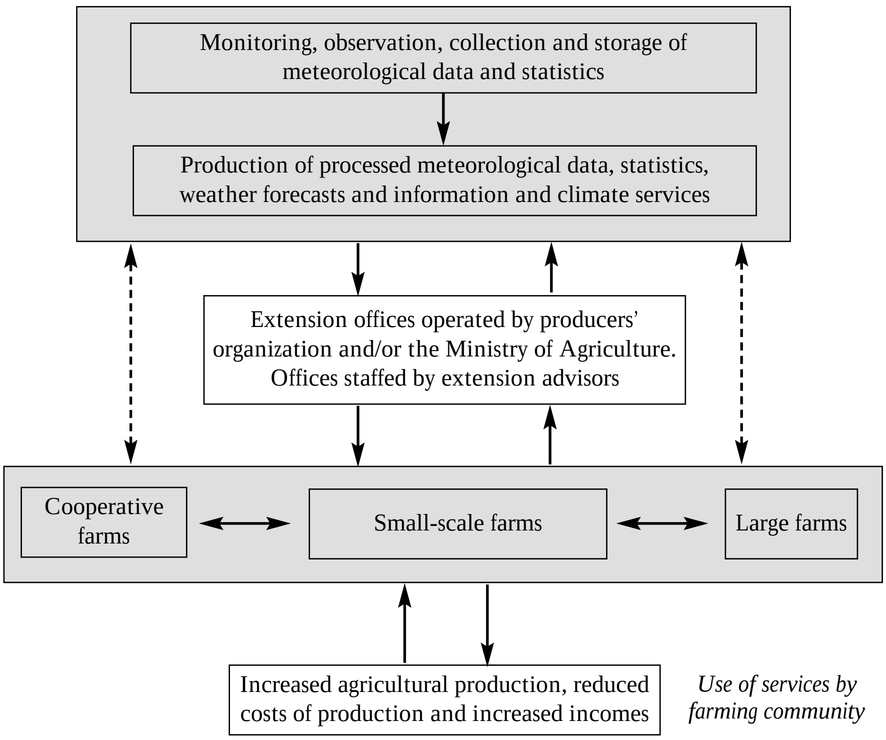


Figure 4.1
Diagrammatic representation of supply, demand and distribution of agrometeorological information and services to farmers by a national meteorological Service

Under some conditions, the national meteorological service can reach some large farmers in developed countries directly without the need to pass the information through extension offices. This can be done through direct phone or postal contacts or indirectly through the use of facsimile machines to retrieve weather information produced from designated centres.

Agrometeorological data and information are also useful for other decision makers in addition to farmers. Government officials in the Ministry of Agriculture and related bodies such as Ministry of Economic Planning may require information about the severity of droughts or the predicted amounts of rainfall for a given season in order to plan the importation of food to meet any shortfalls in production. For example, the Division of Agrometeorology of the National Institute of Meteorology and Hydrology of Romania regularly produces and sends agrometeorological information for use by the President of the Republic, the Senate, the Ministry of Water, Forestry and Environmental Protection, the Ministry of Agriculture and Nourishment, the Academy of Agricultural Sciences and Forestry, the Romanian Water Authority and the mass media such as radio, television and newspapers (Baier and Anaman, 1996).

The economic classification of environmental resources such as agrometeorological data, information and resources is best done using the concepts of indivisibility and non-exclusiveness (Randall, 1981). A good service is indivisible (or non-rival) if its consumption by an individual does not reduce its availability in terms of quantity or quality to others. A good service is non-exclusive (or excludable) if individuals cannot be excluded or if it is difficult to exclude individuals from using it. Exclusiveness is achieved through the charging of fees, the setting up of direct barriers and/or very high entry hurdles and the non-provision of information about availability of the service so that some individuals cannot access it because of ignorance of its existence. Based on the concepts of indivisibility and non-exclusiveness, services produced by national meteorological services can be classified into four main groups:

Indivisible (non-rival) and non-excludable goods such as basic public weather services and tropical cyclone warning services which are freely accessible to all individuals through the mass media. This group also includes weather and climate data collection and archival services which allow climate data to be made available to both current and future generations and international public goods such as freely-exchanged meteorological data among member countries of the WMO. Indivisible and non-exclusive goods are often called “public or collective goods” and are usually financed by governments (Field, 1994).

Indivisible (non-rival) and excludable goods such as specialized exclusive services for certain farmers such as the Cottonfields Weather Service and Weather-by-Fax Services in Australia (Anaman and Lellyett, 1996a). These services require users to pay some fees but the use of the services by one individual or firm does not reduce the quality and quantity of the service to others, at least up to a certain point of congestion.

Divisible (rival) and non-excludable goods such as services dealing with the recording of certain extreme meteorological events where the number of weather stations recording these events may be declining over time. This means that future generations will not have access to certain types of data available to past generations. In addition, the automation of weather recording using satellites and other technological advances sometimes leads to the non-recording of certain events (phenomena) which are more easily observed and recorded by humans. It is believed in some quarters that satellites might in the future replace human observers for recording many meteorological events (Myers, 1994). But this might be achieved at a cost of non-recording of several associated weather phenomena which are more easily recorded by humans. Automation of the recording of weather events through technological advances appears to contribute in some way to the divisibility of certain meteorological services as would be perceived by future generations of individuals and businesses.

Divisible (rival) and excludable goods such as specialist services supplied for exclusive use by selected companies which pay commercial market-based rates for those services. These services are of such a nature that potential users who are not prepared to pay fees for their use can be easily excluded. These services are called private or market goods and are usually produced by private firms. Where government-financed firms produce these services, consumers often pay the full cost of production, including a competitive-based profit margin.

4.2.2 Desirable attributes of meteorological information and services

Because of the importance of weather and climate to the production of crops and livestock, the availability of accurate meteorological information is an important input to producers, especially for their weather and climate-sensitive activities. Meteorological information may contribute to the reduction of direct tangible losses from extreme events by giving producers signals to act to reduce damage to their property including crops, livestock and farmhouses, to reschedule weather-sensitive production and leisure activities and also to assure the safety of their families. For example, in the context of droughts, meteorological information may be used for both operational (tactical) and strategic planning and the management of agricultural activities to minimize the impacts of droughts. With the operational use of weather information, small farmers in Mali increased their crop yields by 20–30 per cent based on a pilot project (World Meteorological Organization, 1997; Togola, 1988). In a strategic sense, weather and climate information may also be used in drought adaptation strategies such as changes in the seasonal cropping calendar and the use of drought resistant crop varieties.

Information such as weather information is communicated as a signal from the source of origin (e.g. national weather service) to another point (e.g. homes or farms) where it is used by producers to plan and manage their business operations. Information is transmitted through a medium such as radio or television. The transmission of information signals can be affected by engineering problems which may make these signals difficult to understand, especially if the equipment carrying the signals is outmoded. The transmission may also be affected by problems related to whether users are able to understand the messages contained in the information and make the best use of it.

Meteorologists define the quality of meteorological information in terms of technical attributes such as skill, reliability, resolution, sharpness, uncertainty and accuracy (Murphy, 1991; Lynagh, 1990). From an economic perspective, the quality of meteorological information is directly related to the degree of usefulness of the information to improve decision making by consumers. The economic quality of meteorological information may therefore subsume technical measures of quality. Economic quality is often measured by a number of characteristics or attributes. These attributes may be expressed in one or more dimensions, for example, physical structure or aesthetic appeal. Some important economic quality attributes of meteorological information to users include: (i) relevance (i.e. the extent of usefulness of the information for a given purpose); (ii) ease of understanding; (iii) aggregation (i.e. the level of detail contained in the signal or message); (iv) accuracy; (v) impartiality; (vi) convenience; and (vii) timeliness (Mitchell and Volking, 1994). These attributes determine the economic value of the information. Since information is interpreted differently by users, quality of information will be perceived differently by users. Key quality attributes are discussed below.

4.2.2.1 Relevance

Meteorological information that is relevant meets the needs of users. Users will only acquire information that is relevant. Relevancy of meteorological information is its most important attribute. Because of the many uses of meteorological information, national weather services have to produce different types of information for different groups of agricultural producers, distributors and consumers.

4.2.2.2 Ease of understanding

Meteorological information must be provided in a form that can be understood by end users such as farmers. Such information is often provided in the language of local producers and in a format that can be understood and interpreted by users. Meteorological information that is not easily understood will likely be regarded as irrelevant. However, not all information that is easily understood by farmers would be regarded as relevant.

4.2.2.3 Desired level of aggregation or detail

The level of desired aggregation or detail of useful data contained in an information signal required by users varies from individual to individual and the purposes the information will be used for. For example, some farmers may sometimes only require forecasts about whether it will rain or not for harvesting decisions. However, others may at times require information on the expected intensity of rainfall for activities such as irrigation. Decision makers may also incur costs to enhance the quality of weather information contained in a message through more detailed provision of information about expected weather events.

4.2.2.4 Impartiality

Perceptions of impartiality of information relate to the degree of trust between the weather information provider and its users regarding whether the information being supplied has the level of quality based on verbal and/or written agreements between the producer and users. Users who trust their information providers therefore assume that the information being received, while not necessarily perfectly accurate, is the best available given the technology, resource constraints and mutual agreements. Asymmetric market information may exist because agrometeorological information providers (sellers) of weather and climate information tend to know the quality of their products better than the buyers (users). Hence a high degree of trust between sellers and buyers of weather and climate information is necessary for the efficient use of such information.

4.2.2.5 Convenience

Convenience is an important attribute of information desired by users. The convenience of information to users involves the ease of access to the information and also the ease with which the acquired information can be used. Information which users can acquire inexpensively for their decision making processes can be classified as relatively convenient.

4.2.2.6 Timeliness

The attribute of timeliness implies that the information is supplied at the time required by users. This attribute is indeed very important since information supplied at the wrong time may be worthless. Because the quality of meteorological information can degrade quickly over time due to rapid changes in conditions of the atmosphere, timeliness of such information to agricultural producers often implies having access to the latest available information, for example, rainfall forecasts for the next day, to decide whether to irrigate or not.

4.2.2.7 Accuracy

Accuracy is a perennial problem in weather forecasting and the provision of meteorological information and services. Accurate information is desired by producers because it reduces the chances of errors in decision making. However, despite all the technological developments of the modern era, weather and climate forecasting is an inexact science and it might never be possible to produce perfectly accurate forecasts due to the inherent uncertainty of the natural world. Decision makers who use meteorological information are aware of this situation and often require a reasonable operational level of accuracy from weather information providers rather than perfect accuracy. Users of weather and climate information attach some degree of subjective probability of the occurrence of the forecasted natural event. Sometimes the probability of the event occurring is supplied by the weather information producers. Weather and climate information may have high levels of attributes such as ease of understanding and convenience and can be readily used to plan weather information-sensitive activities. However, its overall usefulness and consequently its economic value may still be low for many decision makers if it is consistently inaccurate. Decision makers could suffer losses if the accuracy of the information supplied to them deteriorates and they continue to use that information.

4.2.2.8 Empirical illustration of attributes of weather information services

Table 4.1 illustrates the economic quality attributes of two meteorological services produced by the Australian Bureau of Meteorology: (i) a specialist weather information service for cotton farmers in the State of New South Wales called the Cottonfields Weather Service; and (ii) the basic public weather service (forecasts and warnings) for the Sydney metropolitan area, also in the State of New South

Wales (Anaman, *et al.*, 1998). The Cottonfields Weather Service is an enhanced form of the basic public weather service provided to the cotton growing areas of New South Wales. The service provides, at some cost, the latest weather information and forecasts for a particular district which are much more detailed than the basic public weather service provided freely through the mass media. This service is available to producers through facsimile machines. Charges are imposed per minute for retrieving weather information from the service. The basic public weather service, on the other hand, is available free of charge to householders through the mass media in the Sydney metropolitan area. This is used mainly by urban householders but also by hobby farmers, gardeners and farmers within close proximity of the metropolitan area and professionals in agricultural marketing and processing.

Ease of understanding the information was ranked as the highest valued attribute for both services. Not surprisingly, the benefit/cost ratios of the services were high, partly because users understood the messages contained in the information. For all the common quality attributes (i.e. ease of understanding, overall usefulness, relevance and accuracy), the Cottonfields Weather Service was considered by users to be higher than the basic public weather service for the Sydney metropolitan area. This specialist weather service for the cotton industry was regarded as the better quality product because of the enhancement of the basic public weather service for explicit needs and use by cotton growers. The lowest ranked attribute for the two services was accuracy. However, accuracy of both services was generally considered to be satisfactory with an average ranking above 3.0.

Table 4.1
Users' quantitative assessment of the quality of two meteorological services produced by the Australian Bureau of Meteorology in terms of the average ranking of various economic quality attributes of information and benefit/cost ratio of services

Quality attribute of information	*Cottonfields Weather Service for cotton growers in New South Wales**	*Basic public weather service for use by householders in the Sydney metropolitan area*
Ease of understanding	4.3 (0.12)	4.2 (0.17)
Overall usefulness	4.2 (0.14)	3.8 (0.20)
Relevance	4.1 (0.15)	4.0 (0.24)
Adequate level of details	4.1 (0.15)	–
Timeliness (provision of information with sufficient time to modify decisions)	3.9 (0.13)	–
Accuracy	3.6 (0.14)	3.2 (0.25)
Frequency (time of day)	3.5 (0.23)	–
Benefit/cost ratio of service	12:1	4:1

* 5 was used to denote that the information was considered excellent in terms of the specific attribute while 1 meant that information provided was regarded as very poor in terms of the attribute. The scores 4, 3, 2 indicated good, satisfactory and unsatisfactory assessments respectively. The coefficients of variation of the scores (defined as the standard deviations divided by the means) are in brackets.

4.2.3 Introduction to the economic theory of markers

Economic theory attempts to explain the actions of individuals using simplified models that capture the essentials without all the details observed in the real world. Economic analyses are driven by economic theory and are underpinned by three main components: human beings, products and resources (McInerney, 1987). Human beings are at the centre of the science of economics. Human beings have desires for things. These desires generate the driving force for economic activities and are satisfied when people get the goods and services they want. These goods and services are produced using resources or inputs (Dijkhuizen, *et al.*, 1994). They are then distributed to people who want them through private and institutional marketing systems.

Actions by individuals involve costs and personal sacrifices. These actions often create value. Costs are incurred in producing goods because the resources needed to produce the goods have to be purchased or supplied by the producer. The relevant cost from an economic perspective is the opportunity cost. The opportunity cost of a resource is the return that could be realized if the resource is used in its best alternative use instead of in the production of goods as mentioned earlier. Under ideal competitive conditions, the market price of the resource reflects its true cost or its opportunity cost. The value side of human actions rests on the assumption that people have preferences for goods and services and can express their preference for one over another or one package over another. The economic market value of a service is what an individual is willing and able to pay for it.

A market is defined as a process by which sellers and buyers determine what goods and services they are willing to sell and buy and the terms of the contracts involved in the transactions. This process takes place in a geographical location such as a farmers' market or may not involve a specific geographical location, as occurs with foreign exchange transactions across several continents (Heyne, 1991). A competitive market involves many buyers and sellers interacting with each other. When the quantity of goods or services sought by buyers equals the quantity offered for sale by sellers the market is said to be in equilibrium. An equilibrium is a situation where there is stability. The price of the goods at this point is the equilibrium market price. The actual price of goods is what is observed in the real world and tends to approximate the equilibrium price because of the continuous interplay of factors influencing demand and supply to correct imbalances. The two components of the market process are supply and demand and are discussed below.

4.2.3.1 Demand

Economists define demand as the relationship between the price of the goods and the quantity consumers are willing and able to purchase in a given period assuming all other things are constant. This relationship is often an inverse one, with the quantity sold increasing when the price decreases as illustrated by the line P_hDemand in Figure 4.2. A given quantity of goods bought by consumers at a particular price is referred to as the quantity demanded. Although price is an important determinant of the demand, there are other important determinants such as taste and preference, the price of other goods and services, the income of consumers and sometimes the weather. For example, the demand for ice cream increases in periods of hot weather. A change in any of these determinants causes an increase or decrease in demand. Based on the graphical presentation, an increase in demand is an increase in the quantity demanded of the goods at each and every price and is therefore represented by a shift to the right of the demand curve. Likewise, a decrease in demand leads to a shift of the demand curve to the left.

4.2.3.2 Supply

The other component of the market is supply. Economists define supply as the relationship between the quantity of goods that producers are willing to offer for sale and the price of the goods in a given period of time, assuming everything else holds constant. This relationship is called the supply curve. Because additional (marginal) costs of production tend to rise with the increasing level of production, the supply curve is generally positively-sloped as shown in Figure 4.2 with DS_0 as

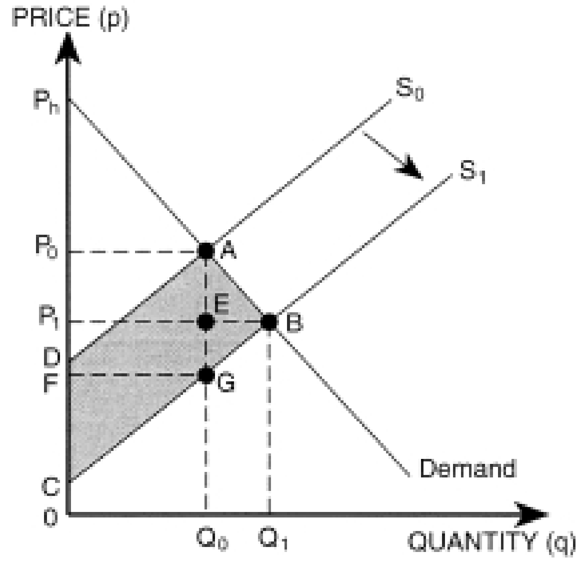


Figure 4.2
Change in consumer and producer benefits with a parallel shift in the supply curve due to the use of improved meteorological information derived from a specialist enhanced weather service produced by a national weather bureau

the supply curve of the commodity with the use of unimproved information about the natural world. A given quantity of goods offered for sale at a particular price is referred to as the quantity supplied. Similar to the concept of demand, there are determinants of supply other than the price of the commodity. These other factors include the technology of production, costs of inputs or productive resources used in the production process, the length of the time period under discussion, weather and quality of weather information service used by managers of businesses. A change in one of these determinants will cause an increase or decrease in supply. An increase in supply is an increase in the quantity offered for sale at each and every price and is represented by a downwards shift of the supply curve as shown in Figures 4.2 and 4.3 with curve DS_0 shifting downwards to become curve CS_1 based on the use of meteorological information. A supply curve is relevant to a particular period of time and its shape and position tend to depend on the length of the period.

4.2.3.3 Elasticities of demand and supply

The shape of the market demand of goods varies according to the type of goods and market. The sensitivity of the quantity demanded as a result of changes in price also varies from one product to another and by market. For some products, a small change in price leads to a large change in the quantity demanded while the opposite holds true for other goods. The sensitivity or responsiveness of the quantity demanded of a product to changes in its price is measured by the price elasticity of demand. The price elasticity of demand is the percentage increase in the quantity demanded as a result of a 1 per cent change in its price. Hence if the price elasticity of the demand of tomatoes is –0.5 for a country, it means that a 100 per cent increase in the price of tomatoes leads to only a 50 per cent decrease in the quantity of tomatoes demanded. Goods with elasticities that have absolute values of between zero but less than unity are classified as price demand inelastic. Goods with elasticities having absolute values greater than unity are classified as price demand elastic. Many food commodities tend to be price demand inelastic because they tend to be basic necessities of life and hence increases in their prices do not dampen their consumption by as much as the percentage increase in prices.

Similarly to the price elasticity of demand, the price elasticity of supply is defined as the percentage change in the quantity of a product supplied as a result of a 1 per cent change in the price of the product. Thus if a 1 per cent increase in the price of tomatoes results in a 0.5 per cent increase in the quantity of tomatoes supplied in the medium-term period, then the medium-term supply elasticity of tomatoes is 0.5. The medium-term period is a reasonable period of say one season or one year that allows farmers to adjust to the increasing price of the product by increasing the supply to the market. The supply curve and price elasticity of supply of a product are directly dependent on the time period under discussion (Mansfield, 1994).

For very short time periods, farmers cannot respond quickly to changes in price unless they have large quantities of the product in store. Hence the price elasticity of

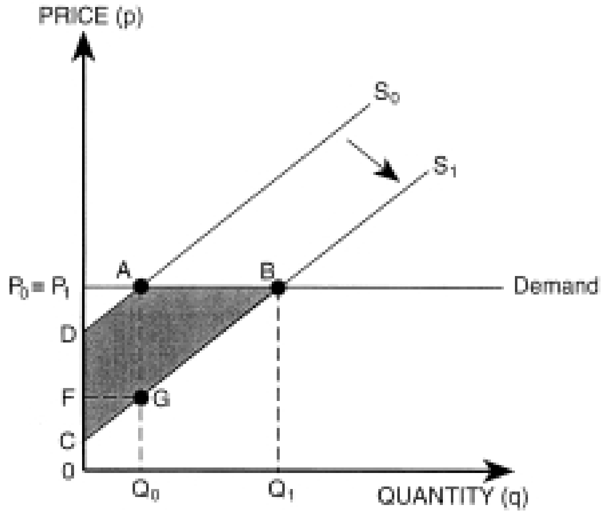


Figure 4.3
Change in producer benefits based on constant price resulting from perfectly elastic demand and the use of improved meteorological information from a specialist enhanced weather service produced by a national weather bureau

supply in the very short term tends to be close to zero. However, in the medium term, farmers can respond to an increasing price of goods by cultivating larger areas of the goods. The price elasticities of supply and demand are therefore important parameters required to understand the benefits accruing to producers and consumers of goods when technological or managerial advances lead to the efficiency of production.

4.2.4 Valuation of meteorological information and services based on benefits accruing to producers and consumers of commodities that utilize meteorological information as inputs in their production processes

The use of improved meteorological information by producers leads to increased efficiency if more output of a product is produced with the same amount of existing resources and given technology. In economic terms, improved information leads to a downwards shift of the supply curve of the commodity. This shift results in changes in economic benefits for producers and consumers. The changes in benefits are referred to in common economic jargon as producer and consumer surplus. Consumer surplus is the excess of what consumers would be willing to pay for a product (rather than go without it) over the amount they actually pay based on its market price. Consumer surplus increases with improved meteorological information that results in larger quantities of a product being produced, leading to lower market prices. Thus the benefit to consumers of improved meteorological information is that the product becomes cheaper, allowing more people to purchase larger quantities of the product. Vice versa, consumer surplus decreases in the presence of supply shocks such as extreme climatic events, for example, drought. Producer surplus or benefits reflect the amounts by which the market price exceeds the costs of production (net returns). Changes in both producer and consumer surplus allow for assessment of the economic value to the whole society of improved meteorological information rather than its value to one producer.

4.2.4.1 Domestic economy considerations only

The changes in consumer surplus and producer surplus as a result of the use of improved meteorological information by producers of a commodity are illustrated in Figure 4.2, based on using a parallel shift in the supply curve of the product and linear supply and demand curves and an initial assumption that we are dealing with only the local economy. Foreign trade considerations will be introduced in a later section. With the use of traditional knowledge of climate and weather, the equilibrium market price of the product is P_o with an amount Q_o of the product bought by consumers. The consumer surplus is therefore denoted by the triangular area P_hAP_o. The producer surplus is denoted by the triangular area P_oAD. With the use of improved meteorological information, provided by say an institutional provider such as a national meteorological service, the increase in production of the commodity leads to a new equilibrium price denoted as P_1.

Consumer surplus increases in size to the area P_hBP_1 due to the supply shift caused by the use of the improved information. The increase in the consumer surplus is therefore made up of rectangle P_oAEP_1 and triangle AEB (that is area P_hBP_1 minus area P_hAP_o). The producer surplus with the use of improved information is equivalent to the area P_1BC. Hence the change in producer surplus is denoted by area $P1_1BC$ minus the area P_oAD. Since the vertical difference between the two curves is constant, area FGC is equal to area P_oAD. Hence producer surplus measured as area P_1BC minus area P_oAD can also be measured as area P_1BC minus area FGC. This gives rise to area P_1BGF as the measure of producer surplus (which is made up of two components, the rectangle P_1EGF plus the triangle EBG. The change in producer surplus is therefore equal to the producer surplus added as the increment from Q_o (old production level) to Q_1 (new production level) and could be estimated from either of the two supply curves. The net total economic gain from the use of improved information by producers is the sum of the changes in both consumer surplus and producer surplus denoted by the shaded area ABCD.

The use of the improved information about the natural world by producers may sometimes have negligible effect on the market price of the commodity, even though production may have increased. This is represented by the infinitely-elastic demand curve in Figure 4.3. This implies that there is no change in the consumer surplus because the market price of the commodity with the unimproved information service is the same as the market price with the improved information service

(Anaman *et al.*, 1995). The change in producer surplus is therefore the shaded area shown in Figure 4.3 (area ABCD derived from area P_1BC minus area P_1AD). The producer surplus can be estimated by incremental net returns of producers using the improved information service through producer surveys. While the change in consumer surplus from the use of improved weather information is likely to be positive, the extent of the change is not predetermined and depends on the nature of the supply and demand curves of the commodity measured by the elasticities of supply and demand. The mathematical formulae used to derive producer surplus and consumer surplus based on the elasticities of supply and demand are found in several papers such as Rose (1980); Alston (1991); Ott, *et al.* (1995); Alston, *et al.* (1995) and Anaman and Lellyett (1996*b*).

Assuming that the supply shift caused by the use of improved meteorological information is parallel so that the vertical difference between the two curves in Figure 4.2 is constant and equivalent to the unit cost reduction resulting from the use of the information, the producer and consumer surpluses can be expressed based on the elasticities of demand and supply and the old price and production levels, P_o and Q_o. Let us denote E_d, E_s and C as the medium term elasticity of demand, medium term elasticity of supply and the actual unit cost reduction from the use of improved information respectively. Expressing the unit cost reduction as a percentage of the initial price (K), K = C/P_0, the percentage reduction in the price of the crop due to the supply shift from the use of the improved information (R) is equal to R = (K*E_s)/(E_s – E_d). The producer surplus, consumer surplus and the total economic surplus can be expressed as follows:

CHANGE IN CONSUMER SURPLUS = P_o*Q_o*R(1 + 0.5*R*E_d)
CHANGE IN PRODUCER SURPLUS = P_o*Q_o*(K-R)(1 + 0.5*R*E_d)
CHANGE IN TOTAL ECONOMIC SURPLUS = CHANGE IN CONSUMER SURPLUS + CHANGE IN PRODUCER SURPLUS = P_o*Q_o*K(1 + 0.5*R*E_d)

Working example for deriving the economic surplus: assume that the use of improved meteorological information supplied to farmers by a national meteorological service reduces the cost of growing cotton by US$ 10 per tonne. Without the use of improved information, the price is US$ 1 000 per tonne of raw cotton and the quantity supplied to the market is 300 000 tonnes. Medium-term elasticities of demand and supply (for a period of one year) are –0.4 and 0.1 respectively. The change in producer surplus, consumer surplus and the total economic surplus are calculated as follows:

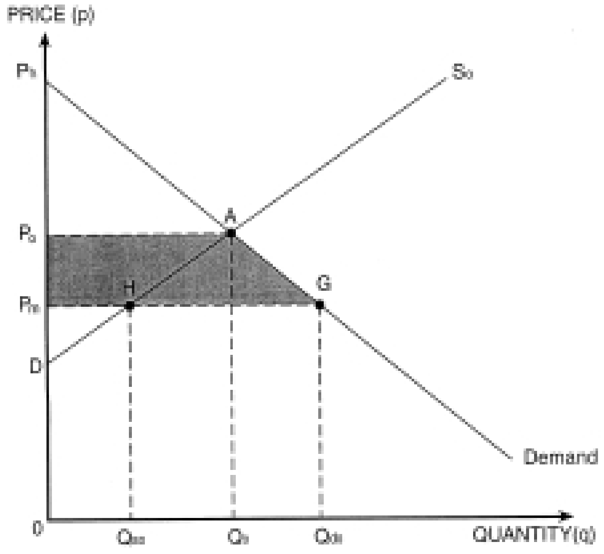
K = (10/1000) = 0.01; R = (0.01*0.1)/(0.1 + 0.4) = 0.001/0.5 = 0.002
CHANGE IN ANNUAL CONSUMER SURPLUS = (1 000*300 000*0.002)*
(1 + 0.5*0.002*0.4) = US$ 600 240
CHANGE IN ANNUAL PRODUCER SURPLUS = (1 000*300 000)*(0.01–0.002)*
(1 + 0.5*0.002*0.4) = US$ 2 400 960
CHANGE IN TOTAL ANNUAL ECONOMIC SURPLUS =
(1 000*300 000)*(0.01)*
(1 + 0.5*0.002*0.4) = US$ 3 001 200.

4.2.4.2 Incorporation of international trade into economic analysis

The intersection of supply and demand curves in Figure 4.2 denotes the equilibrium or market clearing prices of the goods in the absence of international trade for the goods. With international trade, the equilibrium price will be above price P_0 if the country is an exporter of the product and below price P_0 if the country is an importer, as is shown in Figure 4.4, in the case of an importing country. In this case, using rice as an example, at the equilibrium price the domestic quantity supplied is Q_{s0} and the quantity demanded is Q_{d0}. The difference between Q_{d0} and Q_{s0} is the level of imports of the product.

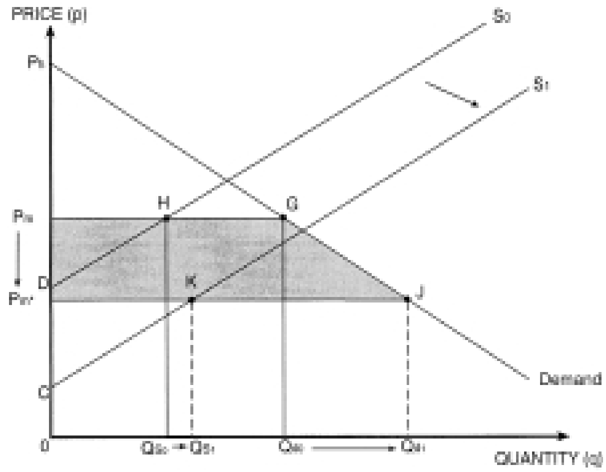
Let us assume that the country imports small enough quantities of the product that it does not significantly affect the world price of that product. This is likely to be the situation of a typical small developing country. We also assume that the use of improved meteorological information reduces farmers' unit costs of the production of rice enabling rice producers to supply a greater quantity at a given price, represented by a rightwards shift of the supply curve as shown in Figure 4.5. This leads to a lower level of equilibrium price with price falling from P_0 to P_m^*. There

Figure 4.4
Consumer and producer benefits based on farmers' use of traditional knowledge of weather and climate to produce a good in the case where the country imports some quantities of the good



$Q_m = Q_{d0} - Q_{s0}$ = import of good

Figure 4.5
Changes in consumer and producer benefits due to the use of improved meteorological information derived from specialist enhanced weather service in the case where the country imports some quantities of the good



$Q_m{}^* = Q_{d1} - Q_{s1}$ = new level of imports

are increased benefits to local consumers since they can buy a greater quantity of rice at a lower price. Local rice producers are able to sell a larger quantity of the goods (Q_{s1}) but at a reduced price ($P_m{}^*$). Hence producers as a whole would benefit only if the reduced production costs plus the revenue generated from the larger quantity sold offset the reduction in revenues due to the lower price. This can be determined based on local supply and demand elasticities and the import elasticities of rice.

Figure 4.6 presents the case of a country which exports a crop for which its production is too small to significantly affect the world price of the crop. The country is a price taker. The use of improved meteorological information results in reduced unit costs of production, thereby shifting the supply curve to the right. Production increases from Q_1 to Q_2 with the extra production (Q_2–Q_1) exported. This extra export has no effect on the world price of the crop which remains at P_w. The use of improved meteorological information results in increased benefits for producers measured by the increase in producer surplus of the size ABDE. However, this result does not hold good if many producers in major producing countries also use similar improved meteorological information at the same time. Under this scenario, the world price of the crop could be reduced through overproduction. Producers may then actually lose if the price reduction resulting from the overproduction is substantial.

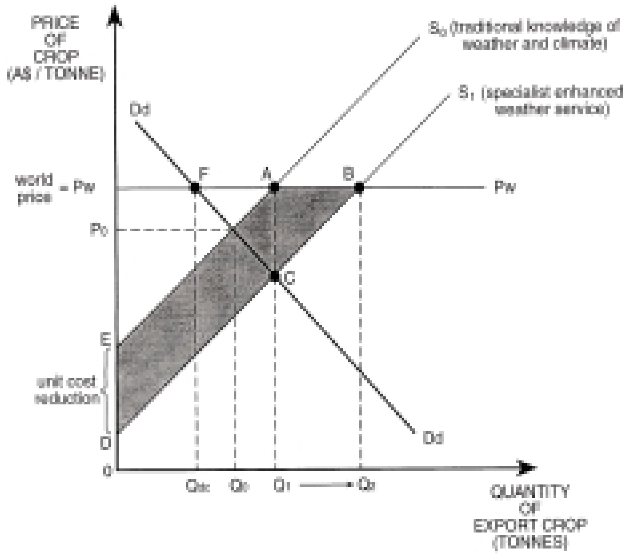


Figure 4.6
Measurement of the change in local producers' benefits as a result of the use of an enhanced weather service for the production of an export crop

4.2.5 Economic valuation of meteorological data as environmental resources

4.2.5.1 Introduction to economic valuation of environmental resources

People place values on their preferences and the use of environmental resources and amenities. Based on the axiom that every individual valuation of a resource counts, the societal economic value of a resource is derived from the valuations made by all individuals. However, a distinction is made between values derived from direct, indirect and potential human uses (use values) enjoyed by the individual valuing the resource in question and values based simply on the existence (non-use) of the resource which is independent of human use. The following values are reported in the literature: direct use value, indirect ecological function use value, option or potential use value, bequest value and existence value.

Direct use value is derived when people use or consume environmental resources, for example, an individual visiting a national park or using timber from a tropical forest. Such values are often measured using market values or surrogate/indirect market values such as the travel cost method. Indirect ecological function use value is based on benefits or use derived by humans from an environmental resource producing or contributing to an ecological stability desired by humans, for example, the benefits of flood protection derived from a forest (Bateman, 1994) or the benefits derived from oceans acting as sinks for carbon dioxide produced by humans. Option use value is linked with the potential use by an individual (possibly in the future) of an environmental resource rather than the current use of that resource. These three values, direct use value, indirect ecological function use value and option use value, are considered use values.

Bequest value refers to the value individuals attach to the preservation of the quality or quantity of a resource such as aspects of the global atmosphere or environment for use by future generations. The bequest value is considered a non-use value to the valuing individual. Existence value on the other hand is the value held by an individual independent of any actual or potential use of an environmental resource by himself/herself or any other human beings, living now or in the future. Existence value arises because some people may put a value on the preservation of certain species of animals and plants simply because they care for other non-human living things. This concept of existence value was first used in economic literature by Krutilla (1967).

Indirect ecological function use, option, bequest and existence values are often estimated by the contingent valuation method whereby individuals are asked during surveys to indicate the maximum amounts of money they are willing to pay (WTP) for an improved quality of a resource or the minimum amounts of money that they are willing to accept (WTA) for a reduced quality of the resource. The use of the contingent valuation method is due to the lack of actual markets for certain environmental resources. Therefore researchers attempt to create artificial or hypothetical markets for these resources through surveys to establish their economic values (Mitchell and Carson, 1986; Perkins, 1994). The theoretical basis of the contingent valuation of resources is based on welfare economics principles expounded by Hicks (1937). Welfare economics considers the value of an improvement to a non-priced environmental product to an individual as the income adjustment made by the individual for the improvement to the extent that his/her utility or satisfaction remains the same as before the improvement.

4.2.5.2 Valuing meteorological data by the contingent valuation method

Meteorological data such as historical rainfall and temperature figures are collected, stored and archived by national meteorological services. Such climatological data become information only when they are processed into forms useful to recipients such as was done by Ussher (1984) who used historical rainfall data, analyzed them and presented them as drought indicators – information useful for farmers and government policy makers. Information derived from these data has economic value if it allows decision makers such as businessmen to improve their decision making. In short, data are inputs required to produce an economic product called information. Without data no information can be produced and an information service cannot be provided.

Government meteorological agencies collect and store large amounts of data of which only a tiny fraction is processed into information that is currently useful to individuals, research organizations and businesses. For example, considerable amounts of climate data stored in government archives have great potential for use by current and future generations, for instance in the planning of future economic development projects and for research projects in many fields such as climate change impact assessment. The economic value of meteorological data therefore includes direct or current use value and also option use and bequest values. However, because meteorological data are not living things, indirect ecological function use value and existence value do not exist. The three components of the economic value of meteorological data are summarized as follows (Anaman, 1996):

Economic Value of meteorological data =
Direct Use Value + Option Use Value + Bequest Value

Government policy in many countries often ensures that meteorological data are made available to users free of charge or at a minimal price based on search and retrieval costs (excluding collection and storage costs). Hence the market price of such data does not reflect the economic value of the data or even the direct use value of the data. As with many underpriced environmental goods, indirect pricing methods such as the contingent valuation technique can be used to establish the total economic value involving the three component values described above. The direct or current use value of meteorological data can be determined based on the amount of money individuals and organizations in aggregate are currently willing to pay to acquire the data for their current uses. The option use value of meteorological data can be determined by the amount of money the current generation of individuals is prepared to pay to collect and store meteorological data for the possibility of use later within their lifetime. The bequest value of meteorological data may be determined by the amount of money the current generation is prepared to pay to collect and store data which will be used by future generations of individuals and organizations.

Hence, in a contingent valuation study, the researcher needs to elicit separate responses to all three component economic values. Expenditure incurred by society at large on the collection and storage of meteorological data reflects the aggregate economic value for these data. These expenditures may be less than optimal levels necessary to store and maintain large datasets of meteorological data for future generations because of the inadequate recognition of the option use and bequest values of these data, possibly due to the relatively short planning horizons of governments.

A contingent valuation survey to elicit the value of meteorological data should include both householders and businesses since businesses (such as mining firms) often use meteorological data and may have some interest in the preservation of the meteorological data system for the long-term efficient operation of their firms. Ideally, the contingent valuation survey should be made up of two components. These are: a survey of adult householders and a survey of managers of businesses.

A suggested set of open-ended questions to elicit the value of meteorological data is listed below with an introductory section to explain the questions to respondents followed by the specific questions. The introduction is as follows.

With this question our economic researchers would like to assess the economic value of meteorological data continuously gathered, processed and archived or stored by the national meteorological service since the advent of record-keeping of such data several centuries ago. A consistent way of finding the economic value of goods and services such as meteorological data is to establish what most people would be willing to pay for them in comparison to what they pay for other things they use. This question about the economic value of meteorological data is hypothetical in nature, designed to allow our research economists to measure the benefits of meteorological data to society. It does not imply any change to current government policy with regard to financing and access to climate data and other types of meteorological data.

Meteorological data such as figures for rainfall, temperature, wind speeds and occurrences of severe events are continuously collected, processed and archived by the national meteorological and hydrological service so that they can be accessed by the current generation of users and also by future generations of users (including your children and grandchildren). Meteorological data are used by a wide range of individuals, businesses and government agencies for many purposes such as the design of dams, buildings and structures, the determination of the suitability of land for the production of commodities in primary industries such as crop and livestock production and mining. With this introduction could you please answer the following questions:

1. Assume that you are in a situation whereby the only way you can access meteorological data from the National Meteorological and Hydrological Service is to pay a monthly fee.
   a. In that situation, what is the maximum amount of money that you would be willing to pay now per month for access to meteorological data for your current uses?
      ______________________dollars per month (measures direct use value)
   b. In that situation, what is the maximum amount of money that you would be willing to pay now per month in order to preserve the meteorological data system so as to allow you to have future access to such data for your own future purposes within your lifetime?
      ______________________dollars per month (measures option use value)
2. Further, assume that the only way to preserve the collection, processing and archiving of meteorological data in this country for use by future generations is to request each adult individual in this country (currently living) to voluntarily pay a monthly fee to the National Meteorological and Hydrological Service to achieve this objective. In that situation, what is the maximum amount of money that you would be willing to pay per month now in order to allow meteorological data to be collected and stored for use by future generations?
      ________________________dollars per month (measures bequest value)

The use of open-ended questions in eliciting the WTP of environmental services has been criticized as providing biased results (Arrow, *et. al.*, 1993). However, other authors such as Bateman, *et al.* (1994) and Anaman and Lellyett (1996*b*, 1996*c*, 1997) have established that the open-ended approach offers valid answers in terms of the link between the WTP and factors such as income and quality of service consistent with the economic theory of demand so long as users of the services are reasonably conversant with them. In order to avoid possible problems related to open-ended questions, a referendum approach is sometimes used. This involves asking respondents a valuation question such as “Are you willing to pay US$ 1 per month for access to and use of certain types of meteorological data?”. This is supposed to reflect the real market situation where the consumer is confronted with a specific price of a product and he/she can decide to purchase it or not at that price. However, because of the possibility of price bargaining, alternatives to the referendum format and open-ended questions have also been developed for eliciting the WTP of meteorological services. One such approach is the use of payment scales. The payment scales method involves giving respondents a selection of values or prices for an environmental product or service and asking them to indicate which price they would be prepared to pay (Donaldson *et al*., 1997). The range of prices from the payment scales approach may be based on previous WTP surveys of users in closely-similar situations or based on the current costs and prices to derive realistic price ranges.

Payment scale question format:

1. Assume that you are in a situation whereby the only way you can access meteorological data from the National Meteorological and Hydrological Service was to pay a monthly fee.
   a. In that situation, what is the maximum amount of money that you would be willing to pay per month now for access to meteorological data for your current uses?

Put a circle next	US$ 0	US$ 5	Other amount
to the amount that	US$ 1	US$ 6	(please indicate)
you are sure you	US$ 2	US$ 7	_____________
would pay	US$ 3	US$ 8	
	US$ 4	US$ 9	

   b. In that situation, what is the maximum amount of money that you would be willing to pay per month now in order to preserve the meteorological data system so as to allow you to have future access to such data for your own purposes within your life time?

Put a circle next	US$ 0	US$ 5	Other amount
to the amount that	US$ 1	US$ 6	(please indicate)
you are sure you	US$ 2	US$ 7	_____________
would pay	US$ 3	US$ 8	
	US$ 4	US$ 9	

2. Further, assume that the only way to preserve the collection, processing and archiving of meteorological data in this country for use by future generations is to request each adult in this country (currently living) to voluntarily pay a monthly fee to the National Meteorological and Hydrological Service to achieve this objective. In that situation, what is the maximum amount of money that you would be willing to pay per month now in order to allow meteorological data to be collected and stored for use by future generations?

Put a circle next	US$ 0	US$ 5	Other amount
to the amount that	US$ 1	US$ 6	(please indicate)
you are sure you	US$ 2	US$ 7	_____________
would pay	US$ 3	US$ 8	
	US$ 4	US$ 9	

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CHAPTER 5

ASSESSING THE IMPACT OF EXTREME WEATHER AND CLIMATE EVENTS ON AGRICULTURE, WITH PARTICULAR REFERENCE TO FLOODING AND HEAVY RAINFALL

(by G. Johnson)

This report is divided into two major sections, each focused on agrometeorological conditions and impacts associated with flooding and heavy rainfall. The first section is a synopsis of responses to a survey completed by 57 countries, investigating their assessments of extreme agrometeorological event impacts in their countries. The second section describes, from general to specific, the impacts of flooding and heavy rainfall on agriculture. An appendix is included at the end, presenting the complete tabular results of the survey of countries.

5.1 SURVEY OF COUNTRIES' ASSESSMENTS OF EXTREME WEATHER AND CLIMATE IMPACTS, FOCUSING ON FLOODING AND HEAVY RAINFALL

5.1.1 Overview of survey and analyses

The WMO CAgM Working Group on Agrometeorology of Extreme Events, under the leadership of Chairman Dr H.P. Das of India, developed a survey of countries regarding extreme weather and climate events and their agricultural impacts. The survey identified a number of extreme events including drought, desertification, cold/frost, floods and heavy rainfall, high winds and severe storms, tropical storms, forest and range fires and volcanic eruptions.

The survey and the analyzed results provide a significant source of information relative to the first two goals of the four terms of reference of the Working Group, which were identified at their meeting in Geneva in April 1997:

(*a*) Survey and summarize the existing knowledge base regarding the nature and impacts of extreme weather and climate events on agriculture;

(*b*) Provide examples of the use of such information from various countries;

(*c*) Help design and establish a database of extreme weather and climate events which have agricultural impacts, and document these impacts; and

(*d*) Study the requirements for instrumentation that will ensure continuous and appropriate observations of extreme events.

This chapter presents an analysis of the survey and is broadly focused on the general aspects of extreme event impacts in various countries. There is a specific focus on flooding and heavy precipitation events, including their impact on agricultural production, their relationship to other extreme events and mitigation strategies adopted or proposed by various nations in dealing with flooding and/or heavy rainfall.

5.1.1.1 Overall survey results for all major extreme agrometeorological events

The survey questions with the yes/no (or missing) responses from each of the 57 countries is contained in the appendix as Table A.1. Each of the questions are shown and are numbered on the left side of the spreadsheet. Results are summarized by question on the last page of the analysis. In addition, and for further analysis, countries were classified into two general and two specific categories: continent and main climate divisions and sub-continent and specific climate divisions. The Köppen climate classification scheme (Table 5.2) was adopted for this purpose. Several nations had multiple climate divisions; the major climate division of the most significant agricultural production region of each country was chosen.

A total of 57 countries responded to the survey. In response to the overall question, "Does agriculture and/or livestock in your country get affected by one or more of the following extreme events?", those events which were reported in the most countries included drought (91 per cent), local severe storms (83 per cent), floods (79 per cent), frost (74 per cent) and high winds (72 per cent). Those events

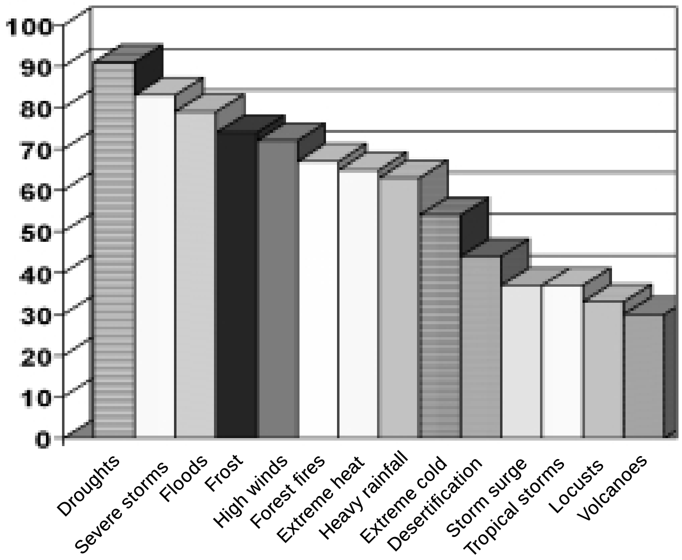

Figure 5.1
Percentage of countries reporting agricultural impacts from extreme agrometeorological events

having agricultural impacts which were reported by the fewest number of countries included volcanic eruptions and earthquakes (30 per cent), locust and grasshopper invasions (33 per cent), tropical storms (37 per cent), storm surges (37 per cent) and excessive water pollution (39 per cent). Figure 5.1 provides a graphical representation of these results.

More than 56 per cent of the responding nations had methods of predicting extreme events and nearly 85 per cent had formal warning services. About 68 per cent had methods for monitoring extremes as well as routine observations. Only 53 per cent of the countries used remote sensing technology for monitoring or prediction. Mitigation strategies were utilized in two-thirds of the countries. Slightly over one-third of the responding countries (39 per cent) felt they had adequate instrumentation to fully record and document extreme events, while 21 per cent felt their instrumentation was inadequate. Very few countries (25 per cent) had a system to assess the socio-economic impact and benefit of extreme events on agriculture, while a large percentage (70 per cent) felt that public awareness training focusing on extremes was important.

5.1.1.2 Analysis of survey results concerning flooding and heavy rainfall

A more thorough analysis was then conducted of those 45 countries which reported agriculturally-related flood problems and the 36 which reported problems associated with heavy rainfall. The distinction between flooding problems and heavy rainfall problems is somewhat diffuse, although their impacts are sometimes quite distinct (for instance, the lodging of mature crops, which can occur with improperly timed and/or intense rainfall, but in the absence of flooding). Of the 45 countries responding "yes" to the flood question (No. 1.6), 33 of these also reported problems associated with heavy rainfall (73 per cent). Thus, there were 12 countries which reported flood problems but no problems with heavy rainfall. These included: Chile, the Czech Republic, Ecuador, Egypt, France, Hungary, Ireland, Morocco, the Netherlands, Slovakia, Sudan. Whether it was simply an oversight by the survey-takers in these countries to respond in this way, or whether it truly reflects the conditions in their countries is unclear. In some cases, it is likely that floods occur not as a direct result of heavy rainfall, or at least not at the site of agricultural production, but rather by transport of water from supply regions. This could certainly be the case in Chile, where there can be significant run-off due to melting snow, and in Egypt, where water is transported down the Nile from areas of heavy precipitation in central Africa.

Table 5.1
Survey results

Question	*% "Yes" Q.1.6 (Flooding)*	*% "Yes" Q.1.7 (Heavy rainfall)*
1.10	68%	56%
1.11	33	37
4.1	46	39
4.2	56	46
4.2.2	46	40
4.3	70	58
5	51	42
6	46	39
6.3	32	25
7	25	19
8.4	60	53

An examination of the relationship between flooding and heavy rainfall, and responses to inquiries regarding certain other extreme events and mitigation/monitoring strategies, was conducted using the survey template results. Specifically, the relationships between responses to questions 1.6 and 1.7 (flooding and heavy rainfall, respectively) on the survey and responses to questions 1.10, 1.11, 4.1, 4,2,

Abbreviation	*Continent (CC)*	*Abbreviation*	*Main Climate Division (MCD)*
NA	North America	A	Moist tropical
SA	South America	B	Dry climates
E	Europe	C	Moist climates with mild winters
AS	Asia	D	Moist climates with severe winters
AF	Africa	E	Polar climates*
AU	Australia, South-west Pacific	H	Highland climates*
	Sub-continents (SC)		*Specific Climate Division (SCD)*
NNA	Northern North America	AF	Tropical rain forest
CA	Central America	AM	Tropical monsoon
NSA	Northern South America	AW	Tropical wet and dry
SSA	Southern South America	BW	Arid desert
NE	Northern Europe	BS	Semi-arid or steppe
SE	Southern Europe	CFA	Humid subtropical*
ME	Middle East	CFB or CFC	Marine*
NAF	Northern Africa	CS	Mediterranean
SAF	Southern Africa	CW	Dry winter
EE	Eastern Europe	DFA or DFB	Humid continental*
SWA	South-west Asia	DFC or DFD	Subpolar*
SEA	South-east Asia	DW	Dry winter*
EA	Eastern Asia	ET	Polar tundra*
AU	Australia, South-west Pacific	EF	Polar ice cap*
		H	Highland*

Table 5.2
Abbreviations for continent and Köppen climate classifications

4.2.2, 4.3, 5, 6, 6.3, 7 and 8.4 were investigated. Table 5.1 summarizes the responses of those countries which answered "yes" to either 1.6 or 1.7 and each of the other questions. The numbers shown in the table are percentages of the 57 countries which responded to the questionnaire.

In nearly all cases, the joint "yes" responses to each of the questions is similar for both flooding and heavy rainfall, with approximately 5–10 per cent fewer countries reporting heavy rainfall problems than flooding problems. The exception is with question 1.11, which is tropical storm activity. In that case, there were 4 per cent more countries reporting heavy rainfall and tropical storm damage to agriculture than there were countries reporting both flood and tropical storm damage.

For those countries that reported flood problems, a much higher percentage also reported problems with local severe storms (68 per cent) than those reporting damage from tropical storms (33 per cent). Similarly, only 20 countries reported agricultural impacts from storm surges (question 1.8, not shown). Thus, of the 45 countries reporting flood damage, a majority of them (25) apparently had no flooding as a result of storm surges; flooding is therefore the result of heavy rain, snowmelt and other factors.

Countries reporting flood problems were more likely to have warning services (question 4.3 – 70 per cent) than they were to have methods of routinely monitoring extreme events (question 4.2 – 56 per cent) or have prediction capabilities (question 4.1 – 46 per cent). It is unclear from the survey how 24 per cent of these countries could have warning capabilities without having forecast/prediction services, but more than likely they either purchase or obtain forecast services from other nations.

A relatively high number of counties (60 per cent) felt it was important to conduct public awareness programmes and training on how to cope with and prepare for flooding and heavy rainfall. However, of those countries which indicated that flooding or heavy rainfall were detrimental to agriculture, a fairly low percentage (25 per cent and 19 per cent, respectively) had any system for assessing the socio-economic impact of extreme events.

Mitigation strategies aimed at reducing the impact of extreme events on agricultural or livestock production were adopted and used in only about half of those countries reporting flood problems (51 per cent), and in even fewer countries reporting damage from heavy rainfall (42 per cent).

5.1.1.3 Analysis of countries reporting flood and heavy rainfall problems with respect to four classification criteria

Four classification criteria were used to categorize the various countries responding to the survey, along with their abbreviations or key codes. These four criteria and their respective components are shown in Table 5.2. In total, six continents, 14 sub-continents, six main climate divisions and 15 specific climate divisions were used for classification purposes (there were eight specific climate divisions into which none of the 57 responding nations fell – these are asterisked).

Table 5.3 provides a list of countries and basic statistics regarding the relationship between these country classifications and reported flood-related and heavy rainfall-related agricultural damage. In general, there were few, and most likely statistically insignificant, differences noted in any of the four major classifications. This analysis suffered to some degree because of the small number of countries that fell into some categories, rendering the reported numbers somewhat suspicious, at best. Nevertheless, flooding appears to have significant agricultural implications in most countries, regardless of geographic or climatic characteristics. Two exceptions would perhaps be northern Europe (code NE) and the Middle East (ME) in the sub-continent categorization. Only 60 per cent of the countries in both of these regions reported flooding as a significant agricultural problem. Also, only 60 per cent of the five countries in the arid desert (BW) category reported flood problems and in each case it is likely that the flooding occurs either by the transporting of water into these countries from other regions, or it occurs in a portion of the country that falls into another specific climate classification.

Relative differences between the various classifications were more strongly noted in the analysis of countries reporting agricultural damage due to heavy rainfall. For example, only 50 per cent of the countries in Africa and South America and only 41 per cent of the countries in Europe listed heavy rainfall as a significant agricultural problem. Meanwhile, 83 per cent of the 18 countries reporting from Asia (a more statistically significant number) reported heavy rainfall impacts. Sub-continent categorization focused this further, with only 20 per cent of the 10 countries in northern Europe reporting heavy rainfall problems, only 33 per cent from southern South America and just 40 per cent of the countries in the Middle East and northern Africa. In contrast, 100 per cent of all countries responding from Australia and the south Pacific, Central America, East Asia, northern North

Table 5.3a
Continent and floods

Country	*1.6*	*CC*
Egypt	y	AF
Morocco	y	AF
Nigeria	y	AF
Sudan	y	AF
Swaziland	y	AF
Chad	y	AF
No. of countries	6	
Per cent of the 8	75%	

Country	*1.6*	*CC*
Argentina	y	SA
Chile	y	SA
Colombia	y	SA
Ecuador	y	SA
Peru	y	SA
No. of countries	5	
Per cent of the 6	83%	

Country	*1.6*	*CC*
Austria	y	E
Czech Republic	y	E
France	y	E
Hungary	y	E
Ireland	y	E
Italy	y	E
Moldova	y	E
Netherlands	y	E
Portugal	y	E
Romania	y	E
Slovakia	y	E
Ukraine	y	E
United Kingdom	y	E
No. of countries	13	
Per cent of the 17	76%	

Country	*1.6*	*CC*
Armenia	y	AS
Azerbaijan	y	AS
Bangladesh	y	AS
India	y	AS
Iran	y	AS
Japan	y	AS
Kazakstan	y	AS
Malaysia	y	AS
Myanmar	y	AS
Philippines	y	AS
Republic of Korea	y	AS
Sri Lanka	y	AS
Thailand	y	AS
Turkey	y	AS
No. of countries	14	
Per cent of the 18	78%	

Country	*1.6*	*CC*
Australia	y	AU
Fiji	y	AU
Solomon Islands	y	AU
No. of countries	3	
Per cent of the 3	100%	

Country	*1.6*	*CC*
Belize	y	NA
Canada	y	NA
United States	y	NA
No. of countries	3	
Per cent of the 4	75%	

Table 5.3a
Sub-continent and floods

Country	*1.6*	*SC*
Japan	y	EA
Republic of Korea	y	EA
No. of countries	2	
Per cent of the 3	67%	

Country	*1.6*	*SC*
Canada	y	NNA
United States	y	NNA
No. of countries	2	
Per cent of the 2	100%	

Country	*1.6*	*SC*
Moldova	y	EE
Romania	y	EE
Slovakia	y	EE
Ukraine	y	EE
No. of countries	4	
Per cent of the 4	100%	

Country	*1.6*	*SC*
Colombia	y	NSA
Ecuador	y	NSA
Peru	y	NSA
No. of countries	3	
Per cent of the 3	100%	

Country	*1.6*	*SC*
Australia	y	AU
Fiji	y	AU
Solomon Islands	y	AU
No. of countries	3	
Per cent of the 3	100%	

Country	*1.6*	*SC*
Belize	y	CA
No. of countries	1	
Per cent of the 2	50%	

Country	*1.6*	*SC*
Swaziland	y	SAF
No. of countries	1	
Per cent of the 2	50%	

Country	*1.6*	*SC*
France	y	SE
Italy	y	SE
Portugal	y	SE
No. of countries	3	
Per cent of the 3	100%	

Country	*1.6*	*SC*
Morocco	y	NAF
Nigeria	y	NAF
Sudan	y	NAF
Chad	y	NAF
No. of countries	4	
Per cent of the 5	80%	

Country	*1.6*	*SC*
Malaysia	y	SEA
Myanmar	y	SEA
Philippines	y	SEA
Thailand	y	SEA
No. of countries	4	
Per cent of the 4	100%	

Country	*1.6*	*SC*
Egypt	y	ME
Iran	y	ME
Turkey	y	ME
No. of countries	3	
Per cent of the 5	60%	

Country	*1.6*	*SC*
Argentina	y	SSA
Chile	y	SSA
No. of countries	2	
Per cent of the 3	67%	

Country	*1.6*	*SC*
Austria	y	NE
Czech Republic	y	NE
Hungary	y	NE
Ireland	y	NE
Netherlands	y	NE
United Kingdom	y	NE
No. of countries	6	
Per cent of the 10	60%	

Country	*1.6*	*SC*
Armenia	y	SWA
Azerbaijan	y	SWA
Bangladesh	y	SWA
India	y	SWA
Kazakhstan	y	SWA
Sri Lanka	y	SWA
No. of countries	6	
Per cent of the 7	86%	

America, southern Africa and South-east Asia listed heavy rainfall as a problem. Classification at the sub-continent scale was clearly important for identifying centres of action; 67 per cent of southern Europe listed heavy rainfall as significant – some 47 per cent greater than northern Europe.

The 57 countries in the survey fell into one of four major climate divisions and there were noted differences between these divisions as well. Only 48 per cent of the countries which had their major agricultural production areas classified as moist climates with mild winters (Köppen code C) reported problems with heavy rainfall. Meanwhile, 88 per cent of the 16 countries which were classified as moist tropical (A) had heavy rainfall problems, as might be expected. Sixty-seven per cent of countries classified with either dry (B) or moist with severe winter (D) climates listed heavy rainfall as an agricultural problem.

One hundred per cent of all countries with specific climate division classifications of AF (tropical rain forest), AM (tropical monsoon) or CW (dry winter, but moist overall climate) reported heavy rainfall problems. Only 50 per cent of countries with a CS (Mediterranean), and 60 per cent of countries with a BW classification listed heavy rainfall.

Table 5.3a
Main climate division and floods

Country	*1.6*	*MCD*
Bangladesh	y	A
Belize	y	A
Colombia	y	A
Ecuador	y	A
Fiji	y	A
India	y	A
Malaysia	y	A
Myanmar	y	A
Nigeria	y	A
Philippines	y	A
Solomon Islands	y	A
Sri Lanka	y	A
Thailand	y	A
No. of countries	13	
Per cent of the 16	81%	

Country	*1.6*	*MCD*
Argentina	y	B
Azerbaijan	y	B
Egypt	y	B
Iran	y	B
Kazakhstan	y	B
Peru	y	B
Sudan	y	B
Swaziland	y	B
Chad	y	B
No. of countries	9	
Per cent of the 12	75%	

Country	*1.6*	*MCD*
Armenia	y	C
Australia	y	C
Austria	y	C
Chile	y	C
Czech Republic	y	C
France	y	C
Hungary	y	C
Ireland	y	C
Italy	y	C
Japan	y	C
Moldova	y	C
Morocco	y	C
Netherlands	y	C
Portugal	y	C
Republic of Korea	y	C
Romania	y	C
Slovakia	y	C
Turkey	y	C
United Kingdom	y	C
United States	y	C
No. of countries	20	
Per cent of the 25	80%	

Country	*1.6*	*MCD*
Canada	y	D
Ukraine	y	D
No. of countries	2	
Per cent of the 3	67%	

5.1.1.4 Survey conclusions

Extreme agrometeorological events are pervasive worldwide. The most significant problems arise from either too little or too much water. In many cases, with sufficient water, many temperature-related problems can be ameliorated, although not always. Severe local storms are a significant problem in most areas of the world and their agricultural impacts are often due to their combined forces (e.g. rainfall plus wind).

Table 5.3a
Specific climate division and floods

Country	*1.6*	*SCD*
Fiji	y	AF
Malaysia	y	AF
Solomon Islands	y	AF
No. of countries	3	
Per cent of the 3	100%	

Country	*1.6*	*SCD*
Myanmar	y	AM
Philippines	y	AM
No. of countries	2	
Per cent of the 2	100%	

Country	*1.6*	*MCD*
Bangladesh	y	AW
Belize	y	AW
Colombia	y	AW
Ecuador	y	AW
India	y	AW
Nigeria	y	AW
Sri Lanka	y	AW
Thailand	y	AW
No. of countries	8	
Per cent of the 11	73%	

Country	*1.6*	*SCD*
Fiji	y	BS
Malaysia	y	BS
Solomon Islands	y	BS
Fiji	y	BS
Malaysia	y	BS
Solomon Islands	y	BS
No. of countries	6	
Per cent of the 7	86%	

Country	*1.6*
Chile	y
Italy	y
Morocco	y
Portugal	y
Turkey	y
No. of countries	5
Per cent of the 6	83%

Country	*1.6*
Republic of Korea	y
No. of countries	1
Per cent of the 1	100%

Country	*1.6*	*SCD*
Egypt	y	BW
Kazakhstan	y	BW
Peru	y	BW
No. of countries	3	
Per cent of the 5	60%	

Table 5.3b
Continent and heavy rainfall

Country	*1.7*	*CC*
Madagascar	y	AF
Nigeria	y	AF
Swaziland	y	AF
Chad	y	AF
No. of countries	4	
Per cent of the 8	50%	

Country	*1.7*	*CC*
Barbados	y	NA
Belize	y	NA
Canada	y	NA
United States	y	NA
No. of countries	4	
Per cent of the 8	50%	

Country	*1.7*	*CC*
Armenia	y	AS
Azerbaijan	y	AS
Bangladesh	y	AS
Malaysia	y	AS
Mongolia	y	AS
Myanmar	y	AS
Philippines	y	AS
Republic of Korea	y	AS
Sri Lanka	y	AS
Thailand	y	AS
Turkey	y	AS
No. of countries	15	
Per cent of the 18	83%	

Country	*1.7*	*CC*
Argentina	y	SA
Colombia	y	SA
Peru	y	SA
No. of countries	3	
Per cent of the 6	50%	

Country	*1.7*	*CC*
Australia	y	AU
Fiji	y	AU
Solomon Islands	y	AU
No. of countries	3	
Per cent of the 3	100%	

Country	*1.7*	*CC*
Austria	y	E
Italy	y	E
Moldova	y	E
Portugal	y	E
Romania	y	E
Ukraine	y	E
United Kingdom	y	E
No. of countries	7	
Per cent of the 17	41%	

Table 5.3b
Sub-continent and heavy rainfall

Country	*1.7*	*SC*
Australia	y	AU
Fiji	y	AU
Solomon Islands	y	AU
No. of countries	3	
Per cent of the 3	100%	

Country	*1.7*	*SC*
Barbados	y	CA
Belize	y	CA
No. of countries	2	
Per cent of the 2	100%	

Country	*1.7*	*SC*
Japan	y	EA
Mongolia	y	EA
Republic of Korea	y	EA
No. of countries	3	
Per cent of the 3	100%	

Country	*1.7*	*SC*
Moldova	y	EE
Romania	y	EE
Ukraine	y	EE
No. of countries	3	
Per cent of the 4	75%	

Country	*1.7*	*SC*
Iran	y	ME
Turkey	y	ME
No. of countries	2	
Per cent of the 5	40%	

Country	*1.7*	*SC*
Nigeria	y	NAF
Chad	y	NAF
No. of countries	2	
Per cent of the 5	40%	

Country	*1.7*	*SC*
Canada	y	NNA
United States	y	NNA
No. of countries	2	
Per cent of the 2	100%	

Country	*1.7*	*SC*
Colombia	y	NSA
Peru	y	NSA
No. of countries	2	
Per cent of the 3	67%	

Country	*1.7*	*SC*
Madagascar	y	SAF
Swaziland	y	SAF
No. of countries	2	
Per cent of the 2	100%	

Country	*1.7*	*SC*
Italy	y	SE
Portugal	y	SE
No. of countries	2	
Per cent of the 3	67%	

Country	*1.7*	*SC*
Malaysia	y	SEA
Myanmar	y	SEA
Philippines	y	SEA
Thailand	y	SEA
No. of countries	4	
Per cent of the 4	100%	

Country	*1.7*	*SC*
Argentina	y	SSA
No. of countries	1	
Per cent of the 3	33%	

Country	*1.7*	*SC*
Austria	y	NE
United Kingdom	y	NE
No. of countries	2	
Per cent of the 10	20%	

Country	*1.7*	*SC*
Armenia	y	SWA
Azerbaijan	y	SWA
Bangladesh	y	SWA
India	y	SWA
Kazakhstan	y	SWA
Sri Lanka	y	SWA
No. of countries	6	
Per cent of the 7	86%	

Table 5.3b
Main climate division and floods

Country	*1.7*	*MCD*
Bangladesh	y	A
Barbados	y	A
Belize	y	A
Colombia	y	A
Fiji	y	A
India	y	A
Madagascar	y	A
Malaysia	y	A
Myanmar	y	A
Nigeria	y	A
Philippines	y	A
Solomon Islands	y	A
Sri Lanka	y	A
Thailand	y	A
No. of countries	14	
Per cent of the 16	88%	

Country	*1.7*	*MCD*
Argentina	y	B
Azerbaijan	y	B
Iran	y	B
Kazakhstan	y	B
Mongolia	y	B
Peru	y	B
Swaziland	y	B
Chad	y	B
No. of countries	8	
Per cent of the 12	67%	

Country	*1.7*	*MCD*
Armenia	y	C
Australia	y	C
Austria	y	C
Italy	y	C
Japan	y	C
Moldova	y	C
Portugal	y	C
Republic of Korea	y	C
Romania	y	C
Turkey	y	C
United Kingdom	y	C
United States	y	C
No. of countries	12	
Per cent of the 25	48%	

Country	*1.7*	*MCD*
Canada	y	D
Ukraine	y	D
No. of countries	2	
Per cent of the 3	67%	

Table 5.3b
Specific climate division and heavy rainfall

Country	*1.7*	*SCD*
Fiji	y	AF
Malaysia	y	AF
Solomon Islands	y	AF
No. of countries	3	
Per cent of the 3	100%	

Country	*1.7*	*SCD*
Argentina	y	BS
Azerbaijan	y	BS
Iran	y	BS
Swaziland	y	BS
Chad	y	BS
No. of countries	5	
Per cent of the 7	71%	

Country	*1.7*	*SCD*
Myanmar	y	AM
Philippines	y	AM
No. of countries	2	
Per cent of the 2	100%	

Country	*1.7*	*SCD*
Kazakhstan	y	BW
Mongolia	y	BW
Peru	y	BW
No. of countries	3	
Per cent of the 5	60%	

Country	*1.7*	*SCD*
Bangladesh	y	AW
Barbados	y	AW
Belize	y	AW
Colombia	y	AW
India	y	AW
Madagascar	y	AW
Nigeria	y	AW
Sri Lanka	y	AW
Thailand	y	AW
No. of countries	9	
Per cent of the 11	82%	

Country	*1.7*	*SCD*
Italy	y	CS
Portugal	y	CS
Turkey	y	CS
No. of countries	3	
Per cent of the 6	30%	

Country	*1.7*	*SCD*
Republic of Korea	y	CW
No. of countries	1	
Per cent of the 1	100%	

Survey results found that while the number of countries falling into any particular category typically was not statistically significant, nevertheless some useful information about susceptibility to either flooding or heavy rainfall damage and the relationship to various classifications was gained. A similar approach could be used to discern regional and climatic differences in the susceptibility of agricultural and livestock production to other extreme events, including wind, frost and drought. In this case, it is evident that flooding and/or heavy rainfall are serious problems plaguing agricultural production in many parts of the world.

5.2 THE IMPACT OF FLOODING AND HEAVY RAINFALL ON AGRICULTURE

5.2.1 OVERVIEW

In 1995 the World Meteorological Organization (WMO) commissioned a Working Group on Agrometeorology Related to Extreme Events. This Working Group was charged with investigating the nature and magnitude of the impacts of extreme weather and climate events on agriculture and with evaluating the various preparations and monitoring strategies for, and responses to, these events in nations throughout the world. This has included reviews of literature on the subject, surveys of various national problems and responses and the development of possible ways of mitigating the detrimental effects of extreme events on agricultural production.

Two of the principal hydrometeorological events that often have deleterious effects on agriculture are flooding and heavy rainfall. It is recognized that in some cases these events can have positive effects. Examples include heavy rainfall from a tropical storm ending a long agricultural drought, or recurring, annual flooding that replenishes topsoil and soil nutrients, as was the historic situation along the lower stretches of both the Nile and Ganges rivers. However, it is extreme events that damage agriculture and agricultural production that is the focus of this discussion.

5.2.1.1 Definitions and background

First, a working definition of an extreme agrometeorological event is needed. In the introduction to *Extreme agrometeorological events* (WMO CAgM Report No. 73, 1997), these events are described as being “at the interface between a vulnerable agricultural system and extreme weather conditions”. Susman *et al.* (1983) similarly defined a disaster as “the interface between an extreme physical event and a vulnerable human population”. The WMO report further states that “the definition of extreme agrometeorological events is broader, as they include as well weather conditions conducive to the development of agents (such as pests and diseases) that negatively affect agriculture (the term, according to FAO definition, includes crop agriculture, livestock and pastures, forests and fisheries, both ocean and inland fisheries)”.

Webster’s New Riverside University Dictionary of English Language defines flood as “an overflowing of water onto normally dry land” (noun form), or “an abundant flow or outpouring; to become inundated or submerged” (verb forms). The American Meteorological Society’s Glossary of Meteorology (1970) defines a flood as “the condition that occurs when water overflows the natural or artificial confines of a stream or other body of water, or accumulates by drainage over low-lying areas”.

These definitions give the broad, generalized scope of flooding. Floods also have temporal characteristics; those that occur in a short period of time or come quickly are called flash floods and are defined by the glossary to be, “Floods that rise and fall quite rapidly with little or no advance warning, usually as the result of intense rainfall over a relatively small area. Other possible causes are ice jams, dam failure, etc.”.

Floods are thus excessive water and in this report the focus is on submerged agricultural areas that normally (in time and space) are not flooded. They may be caused by excessive or heavy rainfall, but this is not a necessary prerequisite for a flood. The glossary definition of flash flooding mentioned ice jams and dam failures as two possible sources of flash flooding that can occur in the absence of precipitation. Other, non-rainfall-induced causes of flooding include rapid snowmelt due to warm temperatures and/or relatively high dewpoints and the release of water from an upstream impounding structure.

In most situations, however, flooding does not occur unless extremely heavy rain falls. This may or may not be at the location of the flood. We thus define heavy rainfall to be abnormally large amounts of liquid precipitation, in time and/or space. Heavy rainfall is often considered in a point spatial context, as measured by a single rain-gauge. However, it is important to include both spatial and temporal aspects of a rainfall event, and its impact, to properly qualify it as a heavy rainfall-induced extreme agrometeorological event.

The interaction between spatial and temporal scales is important in determining impacts. Typically, as the temporal characteristics of a rainfall event decrease, the potential for significant agricultural impacts decreases as well, without an accompanying increase in spatial dimensions. However, significant and even catastrophic, local damage can occur from a very intense rain storm that covers a very small area. This usually occurs in very intense convective storms that have negligible movement or move laterally down a watershed. In general, as the spatial dimensions of a storm increase, the amount of precipitation per unit area decreases. Similarly, a large river basin is relatively insensitive to small, isolated storms but is largely affected by weather systems that cover a major portion of the region, like a monsoon depression.

Looking only at temporal characteristics of storms and their consequent impact on agriculture, the concept of intensity-duration-frequency (idf) becomes important. If any of these three storm characteristics increases, the potential for agricultural impacts increases. Heavy rainfall at a location can thus be defined using the idf convention and is framed by the agroclimatology of a location or region in question. Very intense (extreme) rainfall can result in catastrophic flood damage even though it occurred for a relatively short period of time, and/or at the proper location, at the proper time of year, etc.

The same intensity of rainfall (given in mm/hr, say) resulting in the same amount of total storm precipitation (amount = intensity x duration) can have remarkably different results given a number of factors, all comprising the location's agroclimatology. In general, greater direct damage to agriculture occurs from storms having higher intensities with sufficient duration, compared with low intensity, long duration storms.

For the purposes of this discussion relative to agriculture and extremes, heavy rainfall must include not only the strict meteorological definition (idf), but what impact it has. One important factor determining the impact is antecedent conditions. If soil conditions have been quite dry due to limited prior precipitation and/or lack of irrigation, the potential for water absorption becomes greater, resulting in less run-off and potential flood problems. However, if prior rains, or frozen soils, or other factors limit infiltration, then the same heavy rainfall event can cause significant damage.

Other factors include the soil, vegetation and terrain characteristics of the location. Bare, hard, sloping surfaces reduce infiltration and therefore increase run-off and potential erosion, on that surface as well as downstream. Accumulating, low-lying areas can be high risk zones for flooding. However, here it is important to discuss the frequency issue, since these zones may normally be wet (i.e. wetlands) and flooding is neither unexpected nor unwelcome and damaging.

Economic and political factors increase the vulnerability of agricultural lands to extreme weather events, as well. Due to population pressures and other factors, there is a move towards using more marginal lands for agriculture in some developing countries, for example. These lands may be much more susceptible to flooding damage than traditional farmlands nearby.

Thus, relative to flooding and heavy rainfall, it must again be emphasized that any hydrometeorological event needs to be put into the full agricultural context to truly be considered an extreme agrometeorological event.

5.2.2 Characteristics of flooding and/or heavy rainfall as extreme agrometeorological events

Flooding and/or heavy rainfall often has significant, deleterious effects on agricultural production. The impacts can be wide ranging, both temporally, spatially, economically and even culturally and politically. The severity of their impacts is often a function of many factors.

Effects of these phenomena on agriculture can be classified as direct or indirect (Gommes and Negre, 1992). Direct effects are those that affect the property and income of individuals, enterprises and the public sector. An example would be the loss of a current crop of maize due to severe flooding. Indirect effects are slower and often more widespread (geographically, economically, etc.) than direct effects and result from decreased income, environmental degradation, and other factors. In general, direct effects are much easier to quantify, while estimates of indirect effects are often incomplete due to their complicated impacts throughout society.

With this in mind, the following lists give a sampling of the numerous examples of both direct and indirect effects that flooding and heavy rainfall can have on agriculture. The lists are by no means exhaustive, but represent some of the more significant problems that can result:

Non-growing season or fallow period:

- Loss of topsoil
- Loss of soil nutrients
- Soil compaction
- Soil erosion
- Deposition of undesirable materials
- Permanent damage to perennial crops, trees, livestock, buildings and machinery
- Displacement of persons
- Breakage of levees and other retention structures
- Anaerobic processes
- Permanent cessation of farming in floodplains
- Permanent diversion/realignment of rivers, streams, other bodies of water and settlements
- Loss of livestock and/or habitat

Growing season:

- Waterlogging of crops
- Lodging of standing crops
- Loss of soil nutrients
- Loss of pasture use
- Soil erosion
- Greater susceptibility to diseases and insects
- Interruptions to tillage, planting, crop management, harvesting
- Permanent damage to perennial crops, trees, livestock, buildings and machinery
- Soil temperature reduction and/or retardation
- Necessity of installation of expensive drainage systems
- Loss of livestock and/or habitat
- Transportation interruptions
- Grain spoilage, in-field and off-site
- Feedback effect, enhancing precipitation due to large, free-water evaporative surfaces

5.2.2.1 Mechanisms of flood damage; some examples

The prevailing agriculture in a region is largely determined by the climate. This includes temperature (winter minimum, summer means and maximums, ranges, variability), precipitation (total amounts, temporal distribution, extremes, variability), wind, solar radiation, humidity, and other factors. Sustainable agricultural systems are designed to function effectively a high percentage of the time so that production losses are relatively rare, or never occur. Thus, crops like rice that can function effectively in saturated and even submerged conditions are appropriate for locations that flood regularly and the system becomes dependent upon regular flooding. Many other crops (e.g. corn) would not be adaptable to such conditions and would not be appropriate alternatives to rice.

Extreme flooding events – those that occur outside anticipated average conditions and the typical variability about the mean – can cause varying amounts of agricultural damage. The damage can be direct, as to standing crops, or indirect, such as long-term changes to the landscape and soil.

Direct damage to growing plants is most often caused by depletion of oxygen available to the plant root zones. Flooding creates anaerobic soil conditions that can have significant impacts on vegetation. Root and shoot asphyxia, if prolonged, typically leads to plant death. Chemical reactions in anaerobic soils lead to a reduction in nitrate and the formation of nitrogen gas. This denitrification can be a significant cause of loss of plant vigour and growth following flooding (Foth, 1978). In the extreme case of regularly flooded areas, like rice paddy fields, or long duration floods, harmful chemicals like ammonium, hydrogen sulphide and methane develop and can build up to toxic levels, requiring special (and sometimes expensive) action to insure their timely removal from the soil.

Flood severity should be measured by both its direct and indirect effects. One important determinant of severity is flood duration. In a study by Ritter and Beer (1969) in which they surface-flooded an area of poorly fertilized corn with several centimetres of water when the corn was 76 cm high, yield reductions were 14 per cent after 24 hours of continuous flooding, but increased to 30 per cent after 96 hours of flooding. For fields with much better fertilization, the decrease was significantly less (only 16 per cent after 96 hours). During severe floods, nutrients are often flushed rapidly from the soil, though, so both factors act to create significant damage (see section on fertilizing after the California floods – page 93 – for reference).

The timing of a flood is critical, too, for its impact. Floods and excessive soil moisture during spring planting, germination and establishment periods are typically more damaging to final crop yields than is drought during this same period (Raper and Kramer, 1983). Floods during this period result in soil temperature retardation and/or seed destruction. Even in cases where flooding is used intentionally, as for frost protection of some horticultural crops, the drying-out period afterwards can severely depress soil temperatures and can result in as much or more damage than from frost alone (Lowry, 1972). As plants become larger and more established, minor flooding becomes less damaging than severe water deficits, especially during critical pollination periods (Shaw, 1977). Extreme flooding can be catastrophic during this time as well, though, as evidenced by the Midwest USA flood of summer 1993 (see page 85).

Preconditioning of an area is very important for determining how significant and damaging a flood will be. Important considerations here are soil, vegetation and water supply factors. Soils that are saturated prior to an extreme weather event will more likely result in a damaging flood than soils that are relatively dry. Fields that have recently been tilled and are devoid of vegetation are much more susceptible to soil erosion. Vegetation that is able to use much of the water and that can act as a barrier to moving water (horizontally and vertically) can reduce flood severity and impacts. Water storage systems (rivers, lakes, reservoirs, etc.) that are able to capture and hold most of the incoming water will be effective in reducing flood damage. Thus, water supply managers in snow-fed water supply regions of the world typically draw down reservoirs as much as possible prior to the normal beginning of the snowmelt run-off season. In rain-fed agricultural systems, managers typically anticipate rainfall during the growing season sufficient to naturally or artificially irrigate crops. In both situations, however, there is often a balance needed between retaining enough water for agricultural production and environmental health and maintaining enough available storage volume to capture incoming water and prevent floods. Here, analyses of past weather and water data are critical for estimating average conditions and inherent variability.

Significant floods in temperate to subpolar regions often occur in the winter and spring seasons when warm temperatures and moderate to heavy rainfall follows a period of cold and/or snowy weather (see California, 1997 example below). Heavy snows can contain significant snow water equivalent (potential liquid water) which, if melted rapidly, can cause rapid and voluminous runoff. A further complicating factor is frozen soils which can act as a barrier, much like an impervious subsoil layer or pavement, to water. Instead of infiltrating, this rain or rain-and-snow-fed water is forced to run off, often rapidly reaching main stream channels. The Pacific north-western USA and portions of Europe are two regions where this phenomenon has created the most significant and widespread flooding events.

There are several major problems that may reduce agricultural production in a region for many years following a flood. For instance, if sea water or salty lakes flood a region, the soils may become salinized for many years to come and a significant effort may be needed to effectively flush these salts from the soil. There may also be significant siltation and deposition of large quantities of less desirable topsoils. In the Midwest USA flood of 1993, as much as 150 cm of sand and other soil was deposited on top of rich topsoil in the region near the confluence of the Missouri and Mississippi rivers. Significant effort and major economic cost was needed to remove this material from a highly productive agricultural region, albeit one that was created by dyking long stretches of major rivers.

The destruction of protective dykes is often the cause of catastrophic flooding of agricultural zones, with numerous examples worldwide (Bangladesh; California and Mississippi, Missouri and Red River regions of the USA; China). Dyking is often desirable, in spite of the typically large expense, because the resulting farmland is extremely productive. However, the risk of damage in these regions is significant and resulting damage is usually either minimal (dykes hold) or catastrophic (breakage, with total submerging; e.g. California 1997; China 1998).

A striking irony is that floodplains often are among the most desirable of farm lands. Many of these areas have vast hectares of aquic soils that typically require drainage for productive farm use. Extensive soil drainage systems have been built in river and coastal plain flood regions, with notable examples in The Netherlands, south-central Asia, China, the Atlantic coast of the USA and floodplains of major rivers, including the Mississippi in the USA and the Red River of Canada and the USA. However, nearly all of these regions are vulnerable to floods, in spite of the extensive use of dykes, dams, land contouring and shaping, together with surface and sub-surface drainage systems. The economic cost associated with flooding in these areas continues to escalate due to rising land prices, rising costs of maintaining impounding structures, population pressures, higher costs of production and the introduction of higher value agriculture. It is therefore important that future flood planning looks not only to structural solutions but also to land-use planning, zoning and other solutions that encourage agricultural production in less vulnerable areas.

5.2.2.2 Mechanisms of heavy rain damage

In this brief section attention is restricted to damage from heavy rainfall that occurs in the absence of significant or widespread flooding. Soil erosion, disruptions to critical agricultural activities, the lodging of crops, increased moisture leading to increased problems with diseases and insects, soil moisture saturation and runoff, soil temperature reduction, grain and fruit spoilage and transportation interruptions are among the more significant agricultural impacts from heavy rainfall.

As discussed earlier in the definition section, rainfall can be described as heavy for several reasons. Convective storm systems typically produce short duration, high intensity rainfalls that can have significant erosive power on soil and damage standing crops. Some convective systems are longer lived, however, and can be particularly destructive. Tropical storms or hurricanes also produce very intense rainfall. Slow moving systems can dump enormous amounts of water over a period from one to several days. These tropical systems are also accompanied by high winds, especially in regions where they first make landfall or on isolated islands, which compounds the problems created by heavy rainfall. Trees, crops and even buildings are structurally weakened by saturated or flooded ground and are subject to blow-down from accompanying winds.

As mentioned, heavy rain on frozen or snow-covered soils is a significant problem. In some cases, snowpack is able to absorb a vast percentage of the incoming rain, but if rains are significant and persist, the pack will begin to melt and will lead to substantial run-off problems.

Many agricultural systems are sensitive to any rainfall during critical periods, especially the maturation and harvest phases of certain crops. For instance, harvests of grapes for raisin production and other fruit crops, depend on dry, sunny weather during the final harvest and drying period and this type of agriculture has developed in areas that have an extremely low probability of rainfall at this time of year. Any rain during this period can be severely damaging. Heavy rainfall in these cases may be less than 10 mm in a single day, or only 20 mm over several days. Similarly, any rain after ball-bursting and during harvest of the cotton crop can be quite detrimental to crop quality and yield.

Heavy rainfall that has a long duration (several days to several weeks) can delay crop maturity and delivery to market. The weather systems that cause these conditions usually cover a relatively large region. This may make for regional differences in product delivery and reduce or eliminate normal market advantages for the affected region. In smaller, agriculturally-dependent countries, these weather systems may cause delays and production reductions nationwide, creating significant economic hardship throughout the economy.

Usually, agricultural systems are well adapted to recurring (anticipated) heavy rainfalls appropriate for the specific climate of a region. For instance, throughout most of the interior north-western USA extreme 24-hour recorded rainfalls are less than 50 mm in most locations, even in a 100-year record. Conversely, many interior south-western USA locations (many of which receive less annual rainfall than their north-western counterparts) have recorded 24-hour rainfalls exceeding 120 mm, due to a different climate regime (highly convective, tropical-origin air during the summer months). Obviously, the design of agricultural systems, structures and other infrastructure is different in these two regions because of this difference in precipitation.

5.2.3 Geographic and topograhic considerations

There are important local to regional-scale factors that should be considered when planning for heavy rainfall and/or flooding. These include geographic factors (latitude, spatial dimensions of area of concern, culture and politics, economics, etc.) and topographic factors (elevation, slope, aspect, spatial scales, etc.). These factors help frame not only how much precipitation will fall, for how long, and how frequently, but also assist in determining its impact especially related to flooding.

For risk analyses and planning purposes hydroclimatological data typically are employed. These studies are usually conducted using point data, however, there is limited availability of spatial climate data sets, particularly ones that are relevant on the timescales of heavy rainfall or flooding events. Thus, studies that examine the topographic relationships with rainfall and flooding are needed.

For instance, maps of depth-duration-frequencies (ddf) have traditionally been based on point data, usually measured at relatively low elevation climate stations. Such maps may give an incomplete picture, however, of true ddfs in mountainous regions. Consider the data collected from two sites, only 20 km apart, on a 2 502-km watershed in Idaho, USA, as part of a study of precipitation characteristics in high relief areas (Hanson and Johnson, 1997).

Table 5.4
2- and 100-year return period precipitation depths (mm) for given durations

2-year storms				
Duration	*Low elevation site (1 200 m)*		*High elevation site (2 170 m)*	
(hours)	*Observed*	*NOAA Atlas*	*Observed*	*NOAA Atlas*
0.5	9.7	9.0	9.6	9.0
1.0	12	12	12	11
6.0	18	16	31	18
24.0	26	23	69	32
100-year storms				
Duration	*Low elevation site (1 200 m)*		*High elevation site (2 170 m)*	
(hours)	*Observed*	*NOAA Atlas*	*Observed*	*NOAA Atlas*
0.5	31	24	29	25
1.0	35	31	29	32
6.0	47	46	53	48
24.0	60	66	140	71

The low elevation site receives 275 mm of annual precipitation, 22 per cent in the form of snow, while the high elevation site receives more than 1 100 mm of precipitation annually and 76 per cent in the form of snow. The NOAA Atlas values refer to the US Department of Commerce's NOAA Atlas 2 publication, which contains standard reference maps of ddf for the western US (Miller, *et al.*, 1973). Clearly, the NOAA Atlas values are based on standard, mostly low elevation (dry), climatological stations that fail to capture the significant elevational changes in precipitation. from Table 5.4, it is noteworthy that for durations up to about six hours the differences in the observed versus Atlas-derived values are minimal at both 2- and 100-year return periods. However, for longer durations the differences become large. For 24-hour duration storms, both the 2- and 100-year recorded precipitation depths are approximately twice as great as the NOAA Atlas-derived values at the high elevation site (they are nearly the same at the low elevation site for all durations and return periods). For agricultural and hydrologic planning purposes these differences at longer durations are extremely important to understand. The NOAA Atlas 100-year storm depth is actually equal to the observed 2-year storm depth at the high elevation site.

This is an important example of the type of analysis that is required for proper agricultural management and placement. It points out the necessity of ascertaining topographic and geographic influences on heavy rainfall and consequent flooding. The message is clear – be aware that information recorded at one location may not be applicable for planning purposes at another site, in spite of their close proximity. Applicability lessens with increasing topographic and geographic complexity in a region.

Geographic Information Systems (GIS) can be extremely useful tools in the analysis of flood-prone areas. A GIS in conjunction with digital elevation model (DEM) data can quickly determine slope and aspect of a region and can be used to provide geospatial analyses of multiple spatial layers (elevation, slope and aspect – all at various scales or resolutions – along with soil characteristics, precipitation, temperature, vegetation, and other factors). GIS are being used to develop new floodplain maps (at various frequency and severity levels) and delineate wetlands in many regions and countries, using these types of spatial layers as well as others, including aerial photos. Such information will certainly assist in the best design of agricultural systems, while accounting for reasonable risk.

5.2.4 Data and analyses for assessments, planning and mitigation

A precursor to any substantive and useful planning for flood and heavy rain mitigation is an adequate database of meteorological, hydrological, agricultural, economic and other relevant information. Without thorough documentation of past events it is often difficult, if not impossible, to anticipate future conditions.

Reliable instrumentation for measuring rainfall, other types and forms of precipitation (including snow water equivalent), streamflow, lake and reservoir levels and soil moisture and temperature is absolutely essential for monitoring and understanding the impacts of heavy rain and flooding. For heavy rainfall documentation, hourly (good), 15-minute (better), or breakpoint (best) observations are needed. In drier climates with less frequent heavy rainfalls, a 30- or 50-year record may be required before a sufficiently robust estimate of return periods can be determined. In wetter climates and/or those with relatively frequent heavy rainfalls, some idea of recurrence intervals and other statistics may be obtainable from just 10–15 years of record. Ground-based instrumentation should be of sufficient quality to obtain accurate observations, even in very intense rainfalls.

Traditional, ground-based observation networks should be spatially dense enough to capture the horizontal dimensions of extreme storms. In regions where convective storms with relatively small horizontal size predominate, rain-gauges should be placed at key locations (often in and near important watersheds and basins) at spacings that capture most storms.

In regions where available, the use of radar and satellite-derived fields of estimated precipitation can be extremely useful. These images give a truer picture of the spatial complexity and variability of storm precipitation than available from most conventional rain-gauge networks. They are not perfect, though, and ground-based data are usually needed to confirm and calibrate these remotely sensed rainfall estimates. These remotely sensed data fields are keys to timely and accurate heavy rain and flood forecasts and warnings.

Statistical analyses can be performed on both point and spatial data sets. An ideal database management system would store temporally- and spatially-congruent data from a variety of instrumentation and sources, including rain-gauge networks, radar and satellite imagery, standard weather networks, special agricultural and hydrological networks and others. It also would be ideal to have forecasts and warnings stored. This ideal system would allow easy and timely analyses of extreme events and would be able to generate both real-time and historical synopses in any desired spatial or temporal framework.

Heavy rain idf statistics are essential for basic planning. Floodplain analyses (spatially, temporally) are also extremely useful. Both of these types of analyses should be integrated into a usable GIS for ease of interpretation and presentation of results. Floodplain maps with appropriate information about probabilities (return periods) of certain amounts of precipitation and/or depth of flooding water should be developed and used in risk assessments and agricultural planning. Based on these analyses, economic studies can be conducted to determine if certain types of agriculture are appropriate and justified in certain flood regions. For instance, even though analyses indicate a region is subject to significant flooding every five years, it may still be economically advantageous to farm the area, due to its high value of return. Prudent planning would ensure that structures and other items that would be damaged or destroyed by these frequent floods would not be built in the flooded area, but in less vulnerable areas nearby.

Hydroclimatological statistics based on recent history (typically 10–100 years) are thus extremely useful for planning purposes. Even very short records can provide important information, especially if the data are from critical and/or data scarce regions, and users are aware of the data and interpretation limitations. It must be cautioned, however, that these statistics may sometimes give an incomplete or misleading view of the future. In many cases, reliable hydrometeorological records are no more than 100 years long and often much shorter. Statistics about low frequency events (e.g. 100 or 500 year floods) can thus be in error due to the relatively short record upon which they were based. Of concern, too, is that conditions for the most recent decade or two may not adequately reflect the coming decade. Recent climatological studies hint at changes in storms and return periods, such as the work by Karl, *et al.* (1996), which found an increase in the proportion of extreme (>50 mm/day) precipitation events during the time period 1900–1994 over large regions of the USA. In most cases, though, historical information and analyses derived from them provide the best available data upon which agricultural planning can be based.

5.2.5 Examples of flood and heavy rainfall impacts on agriculture focusing on the USA. Assessments, prediction, warning, monitoring and mitigation

This section provides recent examples of the type and scope of agricultural damage inflicted by flooding and/or heavy rainfall. These examples were chosen based on differences in the causative factors leading to damage, in the type of agriculture impacted and in the consequences of flooding and/or heavy rainfall – both short-term and long-term. The examples are:

- Wintertime flooding due to snowmelt and heavy rainfall in California, USA, January, 1997;
- Late winter and spring flooding in the Midwest USA, 1997;
- Summer (growing season) flooding in the upper Midwest USA, 1993; and
- A sampling of flood events and impacts worldwide in 1995.

5.2.5.1 Wintertime snowmelt/rain-induced runoff and flooding impacts on agriculture – California, USA (1997)

A good illustration of the advection of water downstream into (often lowland) agricultural regions is the fertile Central Valley region of California, USA. Melting snows and/or heavy rainfall in the Sierra Nevada mountains immediately to the east sometimes transport significant volumes of water into the valley, in excess of normal spring runoff. This was the case in January 1997, when unseasonably warm and copious rainfall fell for several days, even at high elevations. All snowcover melted in just a couple of days at elevations below 2 000 m and up to 800 mm of rain fell in just 48 hours. The result was catastrophic damage to many agricultural regions of the Central Valley. In several cases, dykes that had been built to with-hold river water in floodplain areas reclaimed for agriculture ruptured, putting thousands of hectares under water for days. The following reports, compiled and issued from several sources including the California Department of Food and Agriculture (CDFA) and the California Department of Water Resources (CDWR), underscores the significance of this flood event to agriculture and chronologically describes the events leading to the January 1997 floods. Record streamflows were experienced on many of the Central Valley rivers and streams and were much more widespread than experienced in 1986.

Chronological hydrometeorological summary

October precipitation in the northern Sierra was about 75 per cent of average, but a storm at the end of the month brought unseasonably heavy rains to the central and south coast and in the San Joaquin Valley.

The first half of November was quite dry but a major storm during the third week saturated the watersheds; the month ended with above average rainfall (120 per cent in the northern Sierra).

The first 12 days of December saw major storms, with relatively high snow levels, which pushed many major reservoirs into flood control operations and caused local flooding on some Northern California streams. In the Sacramento Valley, overflow into the flood bypass system began during the second week of December.

- 21–23 December – a major storm brought snow to low elevations in the mountains.
- Flood control storage in the Sacramento Valley was maintained by releasing excess water and inflow as it occurred. However, in the San Joaquin Valley, inflow to many reservoirs exceeded the more limited downstream channel capacity and encroachment into flood control storage gradually occurred in late December.
- A few days after Christmas, computer models indicated a very large, warm storm was building in the Pacific Ocean. Media attention gradually began to take note of the predicted storm.
- The predicted storm seemed to delay for a couple of days and media stories began to question whether it was really coming.
- On 29 and 30 December, heavy rains began at relatively high elevations, primarily in the Sierra, melting the snowpack and releasing additional runoff.
- The most intensive precipitation occurred on 31 December and 1 January in the northern Sierra and on January 1 and 2 in the southern Sierra.
- Inflow to Oroville Reservoir set a new flood peak of record on 2 January, rising to about 300 000 cfs. The 3-day volume was also a record, at 167 per cent of Oroville's flood control storage. Similar records were broken on many other Sierra rivers, including the Sacramento River at Shasta Dam.
- 2 January – flows on the Feather River below the Yuba River exceeded design capacity by 5–10 per cent. A levee broke near Olivehurst.
- Estimated peak inflow to the delta from the Sacramento River system exceeded 600 000 cfs.
- January 4 – the west levee of Sutter Bypass west of Yuba City failed, inundating an estimated 37 000 acres. The town of Meridian was subsequently saved by constructing a ring dyke around the town.
- 3 January – the Tuolumne River at Modesto reached a new peak of record, swollen by water spilled from a full New Don Pedro Dam. A similar spill occurred on the San Joaquin River below Friant; a series of levee breaks occurred downstream from Highway 99. The San Joaquin River Flood Control System was overwhelmed and caused increased potential for levee failures.
- 4–6 January – all but one of the reclamation districts on the lower San Joaquin River, from the Tuolomne River to Manteca (Mossdale Bridge), were inundated by floodwater after levees broke from the excess flow.
- Mid-January – most Sacramento River region flood control reservoirs regained flood control storage; San Joaquin River region reservoirs only regained about half their flood space because of more restricted downstream channel capacity.
- 21–27 January – a new series of Pacific storms brought a new round of flood flow but runoff was not as large. The Sacramento Basin reservoirs regulated runoff to within channel capacity, including the two channels that had reduced capacity because of levee breaks that were under repair.

- 30 January – the lower San Joaquin River crested for the second time, setting a new record at Newman, but less than early January levels downstream at Vernalis and Mossdale, where multiple levee breaks reduced the river stage.
- The Blue Canyon weather station (elevation 1 610 m) north-east of Sacramento reported 1 900 mm of precipitation for December and January, (1 090 mm in December and 810 mm in January). December was the second wettest on record, only exceeded by December 1955 which saw 1 150 mm and was also a flood year. The December–January total was a new record. The two-month average at this station is around 625 mm.

Short-term flood response actions

After the initial flood emergency response by many local, state, and federal agencies the Department of Water Resources (DWR) directed short-term efforts firstly to facilitate requests for the United States Army Corps of Engineers (USACE) assistance to repair damaged flood control facilities, and secondly to continue coordination of reservoir operations in the Central Valley to minimize further flood damage. Numerous levee breaks on both systems necessitated an extraordinary effort to develop and implement a short-term strategy for bringing the flood control system up to at least a 20–25 year level of flood protection.

Local Reclamation Districts and the DWR quickly assessed the most critical elements of the Sacramento-San Joaquin flood control systems and, where appropriate, requested the USACE – under its authority – to provide flood fight and levee rehabilitation. An unprecedented level of cooperation between DWR and USACE in responding to local requests resulted in agreements made literally in hours and contracts being prepared and let sometimes on the same day. Consequently, several levee breaks were temporarily repaired and many were brought back into service, albeit at a reduced level of protection. During the weeks following the initial floods, continued high water levels in the rivers saturated levees causing further damage – in some cases requiring emergency flood fights by the USACE – and in most areas a heightened alert level was required to monitor the condition of levees.

The January 1997 floods revealed deficiencies in the flood telemetry network. Flood forecasters were without critical stream and river flow information at several key locations during this event. These gaps in the existing flood network can be filled quickly to provide better warning and to better coordinate reservoir flood control releases in conjunction with uncontrolled runoff entering the major river systems. Many of these sites have existing stream gauges, but need telemetry equipment to send data to the California Data Exchange Center computers.

Due to flood control system limitations caused by levee failures, an extraordinary effort to coordinate reservoir operations throughout the Central Valley was required on a daily basis to safely carry flood control releases from upstream reservoirs. This effort, carried out through the State-Federal Joint Operations Center, and the USACE, in cooperation with San Joaquin Valley Reservoir operators, was successful in limiting further damage to areas downstream of reservoirs. The high level of encroachment of most San Joaquin River system reservoirs necessitated a continued high level of coordination among reservoir operators for the remainder of the rain and snowmelt season.

The DWR was also directed by California Governor Wilson to assist local agencies in removing residual flood waters from inundated delta islands and other catastrophically flooded areas within the Sacramento-San Joaquin flood control systems that remained after emergency levee repairs. This effort was essential to protect public health and welfare and the integrity of the remaining flood control system. The interior portions of the levee system were not designed to withstand wave wash and saturation from standing flood water which can seriously deteriorate already stressed levees and lead to further levee failures. Additional levee failures could severely compromise the integrity of the flood control system and put more communities at risk of flooding, in addition to causing millions of dollars worth of damage to this key public safety infrastructure. The failure of delta levees would seriously jeopardize the range of options available to state and federal governments under the Bay-Delta Accord and potentially disrupt the water supply of millions of

Californians in the Bay Area, Central Valley and Southern California. Residual floodwaters continued to cause millions of dollars worth of agricultural damage, and affected jobs and agribusiness-supported activities vital to many communities in the Central Valley. Traditionally, the Federal Emergency Management Agency (FEMA) reimburses the cost of pumping delta islands as it recognizes the serious damage caused by wave wash.

The February 1986 floods in the Sacramento Valley were a reference point for the 1997 flood. For most northern Sierra streams, this was the flood-of-record prior to 1997. There was one major levee break, near the town of Linda on the Yuba River, and five islands in the northern delta were flooded.

Immediately following the 1986 floods, the state asked the USACE to re-evaluate the Sacramento River levee system. This evolved into a five-phase rehabilitation programme. The first phase, upgrading levees in the Sacramento area, was essentially accomplished between 1989 and 1993. Recognizing the poor condition of many delta levees, the California Governor and the Legislature worked together to develop a 10-year levee rehabilitation programme for delta levees. More than US$ 75 million had been spent by the late 1990s to rehabilitate and strengthen delta levees.

Flood damage estimates to California agriculture in 1997

Flood damage to California agriculture from the winter rains in 1997 are summarized in Table 5.5, issued by the California Department of Food and Agriculture.

California Department of Food and Agriculture (CDFA) Secretary, Ann M. Veneman, testified before the Senate Budget and Fiscal Review Committee on 29 January 1997 and released new figures estimating flood and rain damage to the state's agriculture at US$ 245 million. The figures were up from initial estimates of US$ 155 million, which were released on 10 January.

"These preliminary estimates are based on reports compiled by County Agricultural Commissioners", said Veneman. Infrastructure damage, along with the impact of flooding to land, private levees, farm equipment, buildings and irrigation systems, appeared to be most significant at this time, with nearly US$ 124 million in reported damage. Damage to infrastructure, buildings, farm equipment, land, irrigation systems and private levees were significant long-term concerns.

According to the county reports submitted to the CDFA, 24 000 hectares of crops had been lost, with an additional 38 500 hectares damaged by the rain and flooding, at an estimated loss of US$ 89 million. Commodities most affected were walnuts (US$ 16.8 million); livestock and dairy (US$ 16.5 million); nursery products (US$ 16 million); alfalfa (US$ 15 million); wine grapes (US$ 13.8 million); wheat (US$ 8.1 million); plums/prunes (US$ 6.1 million); and peaches (US$ 5.8 million).

Governor Wilson appointed a Flood Emergency Action Team (FEAT) to make recommendations on the various aspects of the flood response efforts and future flood protection needs in the state. In addition, the State Board of Food and Agriculture held a public forum on 6 February 1997 at CDFA Headquarters in Sacramento to discuss the impact of the floods on California agriculture.

Government-sponsored relief programmes for California agriculturists, 1997

Various types of assistance were made available to farmers for disaster relief, and for the development of mitigation strategies to deal with future floods in California.

The Federal Emergency Watershed Protection Program (EWPP) brought assistance to many California farmers in 1997. Through the EWPP, the USDA Natural Resources Conservation Service (NRCS) provided technical and financial assistance to prevent damage from flooding, runoff and erosion to safeguard people and protect property. Landowners who experienced severe property damage due to flooding were eligible for assistance. All projects required a governmental sponsor, such as a city, county or flood control district. Local sponsors of the EWPP were responsible for obtaining the necessary permits, providing 25 per cent cost-share and providing for the operation and maintenance of completed emergency measures.

The Farm Service Agency (FSA) provided emergency funds for sharing with farmers and ranchers the cost of rehabilitating farmland damaged by natural disasters through the Emergency Conservation Program (ECP). Emergency practices included debris removal, fence restoration, grading and shaping of farmland and restoring structures. Cost-share levels up to 64 per cent were set by county committees. Eligibility for ECP was determined by county committees on an individual basis. Cost-sharing over US$ 20 000 had to be approved by the Deputy Administrator, Farm Programs. Technical assistance was provided by the NRCS.

Table 5.5
Summary of January rain/flood damage by commodity, April 1997

Summary of January Rain/Flood Damage by Commodity, 4/30/97

FRUIT, NUT, FIELD & VEGETABLE CROPS	ACRES LOST	ESTIMATED COST	ACRES DAMAGED	ESTIMATED COST	TOTAL LOSSES
ALFALFA (Existing fields, incl. seed)	23,020	$19,695,966	5,340	$2,669,590	$22,365,556
ALMONDS	693	$3,482,840	590	$950,760	$4,433,600
APPLES	141	$2,999,690	164	$131,050	$3,130,740
APRICOTS	43	$75,613	82	$371,180	$446,793
ARTICHOKES	180	$558,000	0	$0	$558,000
ASPARAGUS	924	$1,412,260	63	$131,250	$1,543,510
BROCCOLI	839	$1,532,200	1,255	$1,987,500	$3,519,700
CABBAGE	33	$207,100	18	$144,900	$352,000
CARROTS	14	$84,000	0	$0	$84,000
CAULIFLOWER	0	$0	0	$0	$0
CELERY	0	$0	0	$0	$0
CHERRIES	12	$276,000	108	$165,760	$441,760
COTTON	19,252	$15,661,502	3,500	$1,837,500	$17,499,002
GARLIC	521	$775,000	400	$20,000	$795,000
LETTUCE	40	$60,000	74	$449,723	$509,723
HAY, Stacked Alfalfa/Oat	5,589	$868,349	865	$187,825	$1,056,174
ONIONS/POTATOES	27	$64,800	0	$0	$64,800
ORANGES/LEMONS	0	$0	5	$3,629	$3,629
PEACHES	331	$5,792,205	2,204	$17,220,000	$23,012,205
PEARS	107	$1,102,980	1,074	$828,600	$1,931,580
PERSIMMONS	1	$18,000	99	$71,700	$89,700
PLUMS/PRUNES	385	$8,905,250	5,499	$4,147,064	$13,052,314
RADISH	0	$0	0	$0	$0
SPINACH	5	$5,500	3	$15,000	$20,500
STRAWBERRIES	44	$580,000	0	$0	$580,000
SWEET CORN	30	$17,000	0	$0	$17,000
TOMATOES	5,416	$794,189	2,620	$1,406,276	$2,200,465
WALNUTS	1,644	$14,679,842	6,836	$3,939,128	$18,618,970
WHEAT/BARLEY	42,165	$11,061,711	17,470	$2,260,880	$13,322,591
WINEGRAPES	1,541	$8,574,605	14,590	$4,759,500	$13,334,105
OTHER	18,646	$7,366,239	23,235	$4,926,247	$12,292,486
SUBTOTAL	*121,642*	*$106,650,841*	*86,088*	*$48,625,062*	***$155,275,903***
NURSERY	**TYPE OF LOSS**	**ESTIMATED COST**			**Nursery Totals**
Cut flowers, field flowers, turf	Various	$4,017,400			$4,017,400
Sod, Greenhouse commodities					
FORESTRY	Various	$10,000,000			$10,000,000
OTHER	Various	$1,717,470			$1,717,470
SUBTOTAL		*$15,734,870*			***$15,734,870***
LIVESTOCK	**HEAD LOST**	**ESTIMATED COST**	**LIVESTOCK-RELATED DAMAGES**		**Livestock Totals**
BEEF CATTLE	925	$944,800		$10,000	$954,800
DAIRY CATTLE	276	$551,500	Milk Production	$4,909,354	$5,460,854
HORSES	102	$152,000		$10,000	$162,000
POULTRY	1,003	$4,000		$0	$4,000
SHEEP	39	$1,200		$0	$1,200
OTHER	467	$4,342,850	Various	$6,679,560	$11,022,410
SUBTOTAL	*2,812*	*$5,996,350*		*$11,608,914*	***$17,605,264***
OTHER DAMAGES		**ESTIMATED COST**			**Other Damages Totals**
FARM BUILDINGS		$8,786,309			$8,786,309
FENCES		$3,236,390			$3,236,390
INFRASTRUCTURE		$28,818,996			$28,818,996
ROADS		$22,767,000			$22,767,000
PROCESSING BUILDINGS		$27,090,000			$27,090,000
OTHER		$18,114,600			$18,114,600
SUBTOTAL		*$108,813,295*			***$108,813,295***
TOTAL LOSSES					***$297,429,332***

Through the Emergency Loan Assistance Program (ELAP), FSA provided emergency loans to help farmers cover production and physical losses in counties declared as disaster areas by the President or designated by the Secretary of Agriculture. The ELAP loans were made to farmers and ranchers who could not immediately obtain commercial credit but who could provide collateral to secure the loan and were able to make the repayments. Borrowers were required to return to conventional credit sources. Loan limits were 80 per cent of the calculated actual production loss and 100 per cent of the actual physical loss, or US$ 500 000, whichever was less.

Through the Non-insured Crop Disaster Assistance Program (NAP), FSA provided crop loss protection to growers of commercial crops for which federal crop insurance was not available. The NAP came into operation where the "area" had suffered a minimum of 35 per cent yield loss per crop. The NAP payments were made to individual producers within these designated areas when individual crop losses were in excess of 50 per cent of the individual approved yield at 60 per cent of the crop's average market price. Payments to individual producers could not exceed US$ 100 000 per year.

Loan guarantees available up to US$ 200 000 per business, or 95 per cent of the loan amount, whichever is less, were granted through the Loan Guarantee Program. Guarantees were provided to local lenders who made interim funds available to businesses at prime lending rates with no loan fees. Applicants must have applied to the Small Business Administration (SBA) for disaster assistance in order to be eligible. Interim loan guarantees, or "bridge" loans were designed to bridge the gap between the application and receipt of funds from the SBA. Once the applicant's permanent SBA loan was funded, the state guarantee was repaid. When the SBA funded its loans quickly, the need for a bridge loan through the State of California lessened.

The Farm Disaster Program (FDP) was designed for farmers whose crops were impacted by the 1997 floods and was a straight loan guarantee instrument with a maximum seven-year term at variable interest rates. Repayment of these loans comes from normal operating income after farmers are able to return to profitability. The maximum guaranteed amount was US$ 500 000.

Strategies for dealing with the impacts of winter flooding on California farmland – the loss of soil nutrients

The following is a report outlining steps to deal with the significant impacts of severe flooding on agricultural land following the California floods in January of 1997. It includes recommended strategies for dealing with the severe loss of soil nutrients during the flood and provides a perspective on the development of flood mitigation strategies in the future. It was written approximately one month following the end of the severe flooding.

FERTILIZING AFTER THE FLOODS
Dr A.E. Ludwick, Potash and Phosphate Institute
February, 1997

Winter flooding is over, so it is back to business as usual... or maybe not. Record rainfall in California will have an impact into the coming season and beyond. The immediate damage to trees, vines and winter vegetables is obvious, as is field damage caused by erosion. But there are also negative effects of wet soils and flooding that are not so visible.

How were soils impacted and what does this mean for future crops? Growers, crop consultants and fertilizer dealers need to understand how flooding affects their fertilizer management decisions for 1997.

Nitrogen

Do not expect much nitrate (NO3) to be left in the soil profile. Whatever was present in the fall most assuredly has been leached from the crops' rooting zone or denitrified (lost to the air as a gas). Either way, more nitrogen (N) fertilizer will be required than normal to obtain expected yield levels.

The ammonium form of N (NH4) is not denitrified, nor is it lost by leaching in all but very sandy ground. So some fall applied fertilizer N may have survived the floods. The question is, had the applied ammonium (anhydrous ammonia, aqua ammonia, urea, urea-ammonium nitrate solution, etc.) had sufficient time for significant quantities to be converted to nitrate before the soils became saturated? Time and temperature are important to this answer – more time and higher temperatures mean more of the ammonium has been converted to nitrate. Since soil temperatures are warmer in October and November than in December, more N may have been lost by denitrification with the earlier application. If three or four weeks elapsed from the time of fertilizer application to flooding with soil temperatures mostly above 50°F, probably 50 per cent to all of it was lost.

Another source of N comes from crop residues and soil organic matter. Nitrogen is released as these materials decompose. The prolonged wet conditions will slow the decomposition process, so this source may provide less than usual amounts of N for crop use.

Testing for residual nitrate in the profile is an especially good idea this year. Consult your soil testing laboratory for sampling details. Sample the whole rooting zone to obtain the complete picture.

Phosphorous

Phosphorous (P) does not leach from soil as does nitrate, but is lost through erosion of fertile topsoil. Also, reduced microbial activity and chemical transformations in saturated soils reduce P availability.

Most crops have a beneficial fungus called mycorrhizae colonizing their root system. This fungus enhances phosphorous absorption by crop roots. Mycorrhizae is often depressed after flooding, resulting in severe phosphorous deficiency in following crops. Mycorrhizae also influences plants' abilities to take up zinc (Zn).

Prolonged flooding of soils causes several physical, chemical and biological changes, some of which are not reversible. Phosphorous availability to plants is affected by reactions with iron (Fe) and manganese (Mn), both of which are made more reactive by waterlogging. As soils dry out, the forms of Fe and Mn phosphates change, but the P availability remains low.

Slower organic matter decomposition, as mentioned for N, will also supply less P than usual. And finally, eroded soils offer additional problems in that the organic matter content will be lower, accentuating the potential for P deficiency.

Soil testing for available P is a generally reliable guide, at least with the Olsen bicarbonate test commonly used in California. However, P deficiency may be more severe or more difficult to correct than in drier years. Higher rates of P fertilizer and additional starter P are suggested to help overcome these conditions. Banding P to maximize its concentration in the root zone could be especially effective this year.

Potassium

Flooding soils over the winter will not directly affect potassium (K) availability. The exceptions are some K was undoubtedly lost through leaching of sandy soils and some was lost from erosion of topsoil.

Reduced K availability will result when anxious growers return to their fields and attempt to work them while too wet, causing compaction. Compaction reduces availability of K (and other nutrients) to plants. This is compounded by cool, wet conditions contributing to poor root development.

Besides the obvious nutritional benefit of supplying K in adequate amounts, K also enhances the crops' ability to resist disease. It could be especially important to build up soil K for perennials weakened by prolonged flooding and especially prone to development of disease problems.

Soil testing will indicate a potential problem of K in soils that have been flooded and eroded. Besides rebuilding soil test levels on leached soils, starter K is particularly beneficial when soils are compacted, wet and/or cold.

There is no doubt that the 1997 season will offer many challenges for nutrient management on soils damaged by flooding and erosion. It may be a cliché, but it is true, "A fertile soil is not always a productive soil, but a productive soil is always a fertile soil". Many California fields are going into the 1997 cropping season with less fertility than usual. Experience tells us that a programme of balanced fertilizer inputs will likely give excellent returns. Don't forget to consider secondary and micronutrient needs as determined by soil testing. Nutrient management will need special consideration as we recover from the winter of 96/97.

5.2.5.2 Flood damage to the USA corn belt, late winter to spring, 1997

A significant flood event occurred as a result of heavy rainfall and snowmelt in the Midwest USA in 1997. The event began with copious rainfall on saturated, frozen, semi-frozen or snow covered soils in early March and continued for more than two months. To provide a brief overview of the scope of the problem, including specific flood-related damage to mid-western agriculture, and to gain some perspective on mitigating strategies adopted or proposed, several brief news reports during and following the actual flooding are supplied here:

Flood Damage Assessed (*Associated Press*, 17 March). Officials are concerned flooding by the Ohio River could wipe out this year's crop for some farmers because it stripped so much topsoil from their lands. The article outlines losses of equipment, infrastructure and livestock that resulted from the flooding.

President Seeks Flood Aid Funds (*Reuters/Associated Press*, 19 March). President Clinton asked Congress for US$ 2 billion to deal with the effects of a number of natural disasters. The article outlines the funding sought, including US$ 126.1 million for USDA to deal with soil erosion and the problems the flooding caused farmers and ranchers.

Potential Flood Impacts Examined (*Bridge*, 19 March). USDA weather analysts said they can't tell at this time whether the predicted flooding in the Midwest will affect crop planting. Although the flood threat to delay planting is very real, it is not certain.

(*Bridge,* 19 March). The American Corn Growers Association said flooding in the Midwest could result in corn prices quickly rising to US$ 4/bu.

(*Des Moines Register,* 19 March). While national forecasters Tuesday warned of widespread flooding across the upper Midwest this spring, a slow thaw had reduced the risk in Iowa.

(*New York Times*, 20 March). Wheat prices surged on fears flooding in the northern Plains may delay planting.

Examples of reports of flood damage in 1997 including the western North Dakota flooding, 27 March 1997

Preliminary Damage Assessments for seven counties and two Indian reservations in western North Dakota are under way for flood damage. The assessments are being conducted in Dunn, Grant, Hettinger, Mercer, Morton, Sioux, and Stark counties as well as the Fort Berthold Indian Reservation and Standing Rock Sioux Indian Reservations.

Several rivers in the Missouri basin have or will crest above flood stage causing damage to numerous communities and their infrastructure. The Missouri River near Williston (Williams County) crested at 24 feet yesterday, four feet above flood stage. The National Weather Service (NWS) expects the river to remain at that level for some time due to high runoff in eastern Montana that eventually feeds into the Missouri River.

Flood waters along the Cannonball, Heart and Knife rivers are beginning to recede as runoff flows towards the Missouri River. Yesterday, the Cannonball River at Regent (Hettinger County) was at 8.42 feet, well below its 22-foot flood stage. The Heart River at Mandan (Morton County) was recorded at 15.6 feet, 1.4 feet below the flood stage of 17 feet. The Knife River at Golden Valley (Mercer County) was measured at 15.29 feet, 8.71 feet below flood stage.

The Cannonball River destroyed an 80-foot steel truss bridge north-east of Hettinger (Adams County) on March 25. Traffic has been detoured four miles around the bridge. The emergency manager for Dunn County reports 80 roadbeds in the county damaged by floodwater. In Mercer County, a Beulah resident reported that 200 gallons of fuel oil spilled and mixed with water in his basement, flooded by the Knife River.

Impact of the flooding includes damage to roads, bridges and flooded basements. Evacuations are described as minimal with a few isolated families forced from their rural homes. No shelters are reported open at this time.

In Grant County, a farmer reported 50 pigs drowned and a rancher said he is unable to feed his cattle because they are stranded by high water on the Cannonball River.

Illinois flooding and disaster aid, 21 March 1997

The head of the Federal Emergency Management Agency (FEMA) announced today that federal disaster aid has been made available to help people in five southern Illinois counties recover from the effects of the recent Ohio River Valley floods.

FEMA Director, James Lee Witt, said President Clinton authorized the assistance under the major disaster declaration issued for the state this afternoon because of damage to private property from severe storms and flooding that struck the state starting 1 March. Similar aid was ordered earlier this month for the flood-plagued states of Indiana, Kentucky, Ohio, Tennessee and West Virginia.

Immediately after the President's action, Witt designated the counties Alexander, Gallatin, Hardin, Massac and Pope eligible for federal funding to supplement the recovery needs of stricken residents and business owners.

The aid, to be coordinated by FEMA, can include grants to help pay for temporary housing, minor home repairs and other serious disaster-related expenses. Low-interest loans from the Small Business Administration also will be available to cover residential and business losses not fully compensated by insurance.

Under the declaration, Witt said federal funds also will be available on a cost-shared basis to the state and affected local governments in the five designated counties for approved projects that reduce future disaster risks. He indicated that additional forms of assistance and more counties may be designated later based on the results of ongoing damage assessments.

5.2.5.3 Flood and heavy rainfall damage to the Upper Midwest, USA, summer (growing season), 1993

This heavy rainfall and flood event was centred on the Upper Midwest USA states of Iowa, Minnesota, Illinois and Missouri. It was different from the above-mentioned floods, with the heaviest rainfall and worst flooding occurring during the growing season. For this reason, the impact was more immediate and direct. In some cases the flooding interrupted spring planting, while in other cases the heaviest rains arrived after plant establishment and interrupted growth through the critical pollination phase, and into harvest in some locations. It was by far the most significant agricultural rain and flood event, measured in economic as well as meteorological terms, during the 20th century in the USA.

This was a rain-driven flood. Rainfall totals for most of the region were the largest of the 20th century for the 2-, 3-, 4- and 12-month periods that encompassed peak summer rainfall months (Kunkel, *et al.*, 1994). Estimated return periods for most of these totals were over 200 years.

Several factors were identified as chiefly responsible for the unprecedented flooding. Rainfall totals for up to two months were more than 100 mm/week, which previous studies identified as a critical threshold for flooding. Abnormally cloudy weather reduced evaporation and kept incoming solar radiation and maximum temperatures at unseasonably low levels. Preconditioning was significant, with most of the hardest hit region reporting above normal soil moisture levels and high streamflows prior to the event (early June). The spatial dimensions of the heavy rainfall were extreme, covering most of the four states. Nearly all of the rainfall that went into runoff eventually flowed into the Mississippi River, which reported its highest river levels in history from Cairo, Illinois, to the Quad Cities of Illinois and Iowa. The axes of heaviest rainfalls were often aligned along major riverways, including the Missouri and the Mississippi.

Meteorologically, the wet pattern was extremely persistent and abnormally strong. For most of June and July, 1993 an unseasonably strong upper level trough was centred just west and north of the impacted region. This resulted in copious amounts of moisture being drawn northward from the Gulf of Mexico, along with abundant cloudiness and temperature reductions.

This flood and heavy rainfall event was catastrophic in proportion and decimated much of the vast corn and soybean production area in the United States. In parts of Iowa, Minnesota and Missouri the persistently heavy rains and accompanying floods were unprecedented since records began. Total agricultural production losses in all affected states were estimated to be US$ 8.4 billion (the direct losses), with total economic losses associated with agriculture (indirect as well as direct) over US$ 18 billion (Changnon, 1995). The entire rural economy of these states was significantly affected. Crop insurance losses totalled more than US$ 1.7 billion (Changnon, *et al.*, 1997).

Insured losses are no trivial matter and are a growing concern where agricultural insurance is becoming more commonplace. Between 1991 and 1994, nine smaller insurance firms in the USA became insolvent directly as a result of weather extremes. Chief among these were the 1993 Midwest flood and the heavy rainfall and wind associated with Hurricane Andrew in southern Florida in 1992. The international insurance companies have rapidly acquired an appreciation for agricultural extremes, especially flooding, and are becoming leaders in the analyses of these events and in planning for the future. In fact, these extreme agrometeorological events, chiefly driven by the 1993 flood, led to the creation of the Insurance Institute for Property Loss Reduction which initiated several key activities including a database of claims paid on catastrophes, and the development of databases relating weather perils to the potential for damage (Insurance Institute for Property Loss Reduction, 1995; Changnon, *et al.*, 1997). Clearly, well-documented and thorough databases are essential for flood and heavy rainfall mitigation.

5.2.5.4 Flooding impacts throughout the world – a short sample of events

To conclude, an example of the widespread nature of flooding and heavy rainfall devastation caused by floods is provided below. This is a synopsis of reports on flooding and/or heavy rainfall from around the world in just a six month period (late 1995), from Global Disasters. There can be little doubt that these extreme agrometeorological events are pervasive, and cause significant damage every year in nearly every part of the cultivated world.

Azerbaijan
- 5 October 1995
- Type: Rains
- Stage: Evolving
- Affected: Dead: 5; Homeless: 3 000
- Current activity: National response (early)
- Date of last report: 12 October 1995

Bangladesh
- 24 August 1995 (03:47)
- Type: Monsoon rains/floods
- Stage: Ongoing
- Affected: Unknown
- Current activity: International response (early)
- Date of last report: 24 August 1995

Benin
- 10 October 1995 (12:12)
- Type: Torrential rains/floods
- Stage: Evolving
- Affected: 86 000 people
- Current activity: International response (early)
- Date of last report: 10 October 1995

China
- 10 August 1995 (04:30)
- Type: Floods
- Stage: Evolving
- Affected: 11.1 million people; 2 million marooned, 3.04 million evacuated
- Current activity: National response (advanced)
- Date of last report: 10 August 1995

Costa Rica
- 10 October 1995
- Type: Floods
- Stage: Evolving
- Affected: 3 262 persons
- Current activity: International response (early)
- Date of last report: 27 October 1995

El Salvador
- 5 October 1995
- Type: Floods
- Stage: Evolving
- Affected: 5 dead: 8 000 people incurred localized losses
- Current activity: National response (early)
- Date of last report: 5 October 1995

Ghana
- 25 September 1995
- Type: Floods
- Stage: Aftermath
- Affected: No data
- Current activity: International response (advanced)
- Date of last report: 25 September 1995

Guatemala
- 9 August 1995 (10:41)
- Type: Floods/landslides
- Stage: Evolving
- Affected: Approx. 7 100 people
- Current activity: National response (early)
- Date of last report: 9 August 1995

India
- 9 September 1995 (12:13)
- Type: floods
- Stage: Evolving
- Affected: More than 10 000 persons
- Current activity: National response (early)
- Date of last report: 9 September 1995

Korea
- 15 July 1995 (10:27)
- Type: floods
- Stage: Ongoing
- Affected: Missing: 70; Homeless: 100 000 families (500 000 persons)
- Current activity: Internationall response (early)
- Date of last report: 13 September 1995

Lao PDR
- 19 September 1995 (06:25)
- Type: Floods
- Stage: Evolving
- Affected: No information
- Current activity: Nationall response (early)
- Date of last report: 25 September 1995

Morocco
- 17 August 1995
- Type: Flash floods
- Stage: Evolving
- Affected: Dead: 230; missing: 500
- Current activity: National response (early)
- Date of last report: 20 August 1995

Myanmar
- 12 September 1995
- Type: Floods
- Stage: Evolving
- Affected: 50 deaths and 15 persons missing
- Current activity: National response (early)
- Date of last report: 27 September 1995

Philippines
7 September 1995
Type: Floods
Stage: Aftermath
Affected: 48 dead, 7 injured, 382 missing
Current activity: National response
Date of last report: 11 September 1995

Somalia
7 November 1995
Type: Floods
Stage: Evolving
Affected: 20 dead
Current activity: National response (early)
Date of last report: 7 November 1995

Sri Lanka
7 October 1995
Type: Floods
Stage: Evolving
Affected: Approx. 20 000 people
Current activity: National response
Date of last report: 11 October 1995

Thailand
31 October 1995
Type: Floods
Stage: Evolving
Affected: 68/76 provinces (4.2 million people); 231 dead
Current activity: National response (early)
Date of last report: 8 November 1995

Turkey
4 November 1995
Type: Floods
Stage: Evolving
Affected: 62 dead; 16 missing; 60 injured
Current activity: National response (early)
Date of last report: 8 November 1995

Vietnam
13 October 1995
Type: Floods
Stage: Evolving
Affected: 7 provinces; 108 dead; 316 homes flooded
Current activity: National response (early)
Date of last report: 13 October 1995

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Appendix — Table A.1

Questionnaire on agrometeorology related to extreme events

Yes/No responses

No.	*Question*	*Argentina*	*Armenia*	*Australia*	*Austria*	*Azerbaijan*	*Bangladesh*
CC	Continent code	SA	AS	AU	E	AS	AS
SC	Subcontinent code	SSA	SWA	AU	NE	SWA	SWA
MCD	Main climate division code	B	C	C	C	B	A
SCD	Specific climate division code	BS	CF	CF	CF	BS	AW
1	Does agriculture and/or livestock in your country get affected by one or more of the following extreme events:						
1.1	Drought	y	y	y	y	y	y
1.2	Desertification	y	y	y	n	y	m
1.3	Extreme hot and dry (heat waves, etc.)	y	y	y	y	y	y
1.4	Extreme cold weather	y	y	y	y	y	m
1.5	Frost	y	y	y	y	y	m
1.6	Floods (including coastal erosion, sea-level rise and inundation, salinization, waterlogging)	y	y	y	y	y	y
1.7	Heavy rainfall (monsoons, etc.)	y	y	y	y	y	y
1.8	Storm surges	n	n	y	n	y	y
1.9	High winds	n	y	y	y	y	y
1.10	Local severe storms (including severe thunderstorms, hail storms, snow storms, ice storms, tornadoes, sand storms, squalls)	y	y	y	y	m	y
1.11	Tropical storms (cyclones, hurricanes, typhoons)	y	n	y	n	m	y
1.12	Heat stress and cold injury	y	y	y	y	y	m
1.13	Forest and bush fires	y	y	y	n	m	m
1.14	Locust and grasshopper invasions	y	y	y	n	m	m
1.15	Volcanic eruptions and earthquakes, including tsunamis	y	y	y	n	m	m
1.16	Excessive water pollution	n	y	y	n	m	m
4	Has your country developed methods/models to:						
4.1	Predict the extreme events?	y	y	y	n	n	y
4.2	Monitor these events?	y	n	y	y	n	y
4.2.2	Are remote sensing technologies used?	y	m	y	y	m	y
4.3	Provide warning services regarding extreme events?	y	y	m	y	y	y
5	Does your country adopt any method(s) to alleviate or minimize the loss to agriculture/pasture/livestock due to extreme events?	y	y	y	n	m	y
6	Does your country have a system to quantitatively measure the intensity of the extreme meteorological events?	n	n	y	m	n	y
6.3	Are these instruments adequate to measure the extreme events?	m	m	m	y	m	y
7	Does your country have a system to assess socio-economic impact and Benefit of the extreme events on agriculture/livestock/forests?	y	n	m	n	n	y
8.4	Do you feel it necessary to conduct public awareness training on how to cope with the above mentioned events in your country?	y	y	y	m	y	y
9	Does your country have a problem of desertification?	y	y	y	n	y	n
9.5	Any awareness training conducted aimed at combating desertification?	y	n	y	n	y	m

Barbados	*Belize*	*Canada*	*Chad*	*Chile*	*Colombia*	*Czech Republic*	*Denmark*	*Ecuador*	*Egypt*	*Fiji*	*Finland*	*France*
NA	NA	NA	AF	SA	SA	E	E	SA	AF	AU	E	E
CA	CA	NNA	NAF	SSA	NSA	NE	NE	NSA	ME	AU	NE	SE
A	A	D	B	C	A	C	C	A	B	A	D	C
AW	AW	DF	BS	CS	AW	CF	CF	AW	BW	AF	DF	CF
y	y	y	y	y	y	y	y	y	n	y	y	y
n	n	n	y	y	y	n	n	y	y	n	n	n
m	y	y	y	y	y	n	n	n	y	n	n	y
n	n	y	y	y	n	n	n	n	y	n	y	y
n	n	y	y	n	y	y	y	y	y	n	y	y
m	y	y	y	y	y	y	n	y	y	y	n	y
y	y	y	n	y	y	n	n	n	n	y	n	n
y	y	y	n	n	m	n	n	n	n	y	n	n
y	y	y	y	y	m	y	n	n	y	y	n	y
y	y	y	y	y	y	y	y	n	y	y	y	y
y	y	y	n	n	y	n	n	n	n	y	n	n
m	y	y	y	y	y	y	n	n	y	n	y	y
y	y	y	y	y	y	y	n	n	n	y	y	y
n	y	y	n	y	y	n	n	n	n	n	n	n
n	n	y	y	n	y	n	n	n	n	n	n	n
n	n	y	y	n	y	n	n	n	n	n	n	y
n	n	y	n	n	n	y	n	n	n	y	y	y
y	y	y	y	y	y	y	n	m	y	y	y	y
y	y	y	n	y	y	y	m	n	m	y	y	y
y	n	y	y	y	y	y	n	n	y	y	y	y
y	n	y	y	y	y	n	y	n	y	m	y	y
y	n	y	y	y	y	y	n	n	y	y	y	m
n	m	n	y	y	y	y	m	m	y	y	y	m
m	n	y	y	y	n	n	n	n	m	y	n	y
y	y	y	y	y	y	m	m	y	y	y	m	m
n	n	n	y	y	y	n	n	y	y	n	n	n
n	m	m	y	y	n	m	m	m	y	m	m	m

Gabaon	*Germany*	*Hungary*	*India*	*Iran*	*Ireland*	*Israel*	*Italy*	*Japan*	*Kazakhstan*	*Kyrgyzstan*	*Madagascar*	*Malaysia*
AF	E	E	AS	AS	E	AS	E	AS	AS	AS	AF	AS
NAF	NE	NE	SWA	ME	NE	ME	SE	EA	SWA	SWA	SAF	SEA
A	C	C	A	B	C	C	C	C	B	B	A	A
AW	CF	CF	AW	BS	CF	CS	CS	CF	BW	BS	AW	AF
n	y	y	y	y	y	m	y	y	y	y	y	y
n	n	n	y	y	n	m	y	n	y	m	y	n
n	n	y	y	y	n	m	y	y	y	m	n	n
n	y	y	y	m	n	m	y	y	y	m	n	n
n	y	y	y	y	y	m	y	y	y	m	y	n
n	n	y	y	y	y	m	y	y	y	m	m	y
n	n	n	y	y	n	m	y	y	y	m	y	y
n	n	y	y	m	n	m	n	y	y	m	n	n
n	n	y	y	m	y	m	y	y	y	m	n	n
n	y	y	y	m	y	m	y	y	y	m	y	y
n	n	n	y	m	n	m	n	y	m	m	y	n
n	n	y	y	y	n	m	y	y	m	m	y	n
n	y	y	n	y	y	m	y	y	m	m	y	y
n	n	n	y	m	n	m	n	n	m	m	y	n
n	n	n	y	m	n	m	n	y	m	m	n	n
n	n	y	y	m	n	m	y	n	m	m	n	n
n	y	y	y	n	y	y	y	y	y	n	y	n
n	m	y	y	n	y	y	y	y	n	y	y	y
n	m	n	y	n	n	n	y	y	m	n	n	m
n	y	y	y	y	y	y	y	y	y	n	y	y
n	m	n	m	n	n	y	m	y	n	y	y	y
n	n	n	m	n	n	y	m	y	n	n	y	y
m	m	m	m	m	m	y	y	y	m	m	y	n
n	n	n	y	n	n	n	m	m	n	n	n	n
y	m	n	y	y	y	y	y	y	y	m	y	n
n	n	n	y	y	n	m	m	n	y	n	y	n
n	m	n	y	y	n	m	m	m	n	n	y	m

Moldova	*Mongolia*	*Morocco*	*Myanmar*	*Netherlands*	*Nigeria*	*Oman*	*Peru*	*Philippines*	*Portugal*	*Republic of Korea*	*Romania*
E	AS	AF	AS	E	AF	AS	SA	AS	E	AS	E
EE	EA	NAF	SEA	NE	NAF	ME	NSA	SEA	SE	EA	EE
C	B	C	A	C	A	B	B	A	C	C	C
BCF	W	CS	AM	CF	AW	BW	BW	AM	CS	CW	CF
y	y	y	y	n	y	y	y	y	y	y	y
y	y	y	n	n	y	y	y	n	y	n	y
m	y	y	y	y	y	y	y	n	y	n	y
y	y	n	y	y	n	m	y	n	n	n	y
y	y	y	y	y	n	m	y	n	y	y	y
y	m	y	y	y	y	m	y	y	y	y	y
y	y	n	y	n	y	m	y	y	y	y	y
m	m	n	y	n	y	m	m	y	n	n	y
y	y	y	y	n	y	m	m	y	y	y	y
y	y	y	y	y	y	m	y	y	y	y	y
m	m	n	y	n	y	m	m	y	y	y	m
m	y	y	y	y	y	m	m	y	y	y	y
m	y	y	y	n	y	m	m	y	y	y	y
m	y	y	n	n	y	y	m	y	n	n	m
y	m	n	y	n	n	m	m	y	y	n	y
m	m	y	n	n	n	m	y	y	y	y	y
y	y	y	n	m	m	n	n	y	y	y	y
n	y	y	y	m	m	n	n	y	y	y	y
n	y	y	n	m	m	n	y	y	y	m	y
y	y	y	y	m	y	n	y	y	y	y	y
y	y	y	y	y	y	y	y	y	y	y	y
y	n	m	m	y	y	n	y	y	y	y	y
n	m	y	m	m	n	m	y	n	y	y	n
m	n	n	n	m	m	n	n	y	y	n	y
y	m	y	y	m	y	y	m	y	n	y	y
y	y	y	n	n	y	y	y	y	y	n	y
y	m	y	n	m	m	n	y	y	y	n	y

Slovakia	*Solomon Islands*	*Sri Lanka*	*Sudan*	*Swaziland*	*Switzerland*	*Thailand*	*Turkey*	*Ukraine*	*United Kingdom*	*United States*	*Unknown*	*Uruguay*
E	AU	AS	AF	AF	E	AS	AS	E	E	NA		SA
EE	AU	SWA	NAF	SAF	NE	SEA	ME	EE	NE	NNA		SSA
C	A	A	B	B	C	A	C	D	C	C		C
CF	AF	AW	BS	BS	CF	AW	CS	DF	CF	CF		CF
n	y	y	y	y	y	y	y	y	y	y	y	y
n	n	n	y	y	n	n	y	n	n	n	n	m
y	y	y	m	y	n	y	n	y	y	y	y	m
n	n	y	m	y	y	y	n	y	y	y	y	m
y	n	y	m	y	y	n	y	y	y	y	y	y
y	y	y	y	y	n	y	y	y	y	y	y	m
n	y	y	m	y	n	y	y	y	y	y	n	m
n	y	y	m	n	y	n	n	y	y	y	n	m
y	y	y	m	y	y	y	y	y	y	y	y	y
y	n	y	m	y	y	y	n	y	y	y	y	y
n	y	y	m	y	n	y	n	n	n	y	n	m
y	n	y	m	y	y	n	n	y	y	y	y	m
y	n	n	m	y	y	n	y	y	y	y	y	y
n	n	y	y	y	n	y	n	n	n	y	n	m
n	n	n	m	n	n	y	y	n	n	y	y	m
n	n	y	m	y	n	y	y	y	n	y	y	m
n	n	y	m	n	y	y	n	y	y	y	y	m
n	n	y	y	n	y	y	n	y	y	y	y	m
n	n	y	y	m	y	y	m	y	y	y	y	m
y	y	y	y	y	y	y	n	y	y	y	y	y
y	n	y	y	m	y	y	n	y	n	y	y	m
n	n	y	y	m	n	y	n	y	y	y	y	m
n	n	n	y	n	m	y	m	n	y	y	m	y
n	n	n	m	n	y	n	n	m	y	y	y	m
m	y	y	y	y	y	y	y	y	n	y	m	y
n	n	n	y	y	y	m	y	n	m	n	n	y
m	n	m	y	y	y	m	n	m	m	n	m	m

No. of Yes's	*Per cent of Yes's*	*No. of No's*	*Per cent of No's*	*No. of missing data*	*Per cent of missing data*
52	91.2%	4	7.0%	1	1.8%
25	43.9%	28	49.1%	4	7.0%
37	64.9%	14	24.6%	6	10.5%
31	54.4%	19	33.3%	7	12.3%
42	73.7%	10	17.5%	5	8.8%
45	78.9%	5	8.8%	7	12.3%
36	63.2%	16	28.1%	5	8.8%
21	36.8%	26	45.6%	10	17.5%
41	71.9%	9	15.8%	7	12.3%
47	82.5%	4	7.0%	6	10.5%
21	36.8%	24	42.1%	12	21.1%
37	64.9%	10	17.5%	10	17.5%
38	66.7%	10	17.5%	9	15.8%
19	33.3%	28	49.1%	10	17.5%
17	29.8%	29	50.9%	11	19.3%
22	38.6%	24	42.1%	11	19.3%
32	56.1%	21	36.8%	4	7.0%
39	68.4%	13	22.8%	5	8.8%
30	52.6%	14	24.6%	13	22.8%
48	84.2%	7	12.3%	2	3.5%
38	66.7%	12	21.1%	7	12.3%
30	52.6%	19	33.3%	8	14.0%
22	38.6%	12	21.1%	23	40.4%
14	24.6%	32	56.1%	11	19.3%
40	70.2%	5	8.8%	12	21.1%
26	45.6%	27	47.4%	4	7.0%
17	29.8%	15	26.3%	25	43.9%

Overall per cent of:

Yes	No	Missing
56.3%	28.4%	15.3%

Total number of countries responding: 57

CHAPTER 6

HAIL, HIGH WINDS AND COLD INJURY

(by T.I. Adamenko)

6.1 HAIL

Hail causes significant damage to agriculture – damaging crops, vineyards and fruit trees over large areas.

Hailstones are particles of dense ice falling from powerful cumulonimbus. The phenomenon usually occurs during the warm season. The appearance of hail clouds is associated with upward air flows, thermal convection or temperature differences between the upward moving air and the surrounding air. Thermal convection, as a result of the unstable stratification of the atmosphere, can be caused by the passage of a front or by the heating of an air mass by the underlying surface in intra-mass processes. Hailstorms of the greatest intensity occur when both processes combine, for example, the passage of a cold front through a region with an unstable stratified atmosphere.

Hailstorms are usually accompanied by thunderstorms, showers and squalls. Hail occurs with showers and thunderstorms in 40–45 per cent of cases and with squalls in only 7 per cent of cases. Hail is a rarer phenomenon than thunderstorms. On average one case of hail is recorded for every 10 to 15 thunderstorms.

In the Ukraine 53 per cent of hailstorms occur with the passage of atmospheric fronts, the remaining 47 per cent of cases fall as a result of intra-mass processes. In summer, hail usually occurs with the passage of fronts – 75 per cent with cold fronts, 20 per cent with occluded fronts and 5 per cent with warm fronts. In April and September the majority of hail is caused by intra-mass processes.

Hail is most detrimental to agriculture during the second half of the growing season, the significant damage to winter cereals taking place during the maturation period. Spring cereals, however, are damaged at both grain maturation and at earlier stages of growth. Hail can ruin vegetable crops as well. Fruit orchards and vineyards suffer from the adverse impact of hail during flowering, fruit formation and fruit maturation.

The amount of damage depends on the size of the hailstones, their density, intensity of fallout and the type and stage of agricultural crop. Hailstones of 20 mm and more in a diameter always damage crops. Hailstones of 30 mm and more in diameter are able to destroy crops completely. The largest hailstones fall during the warm part of the year.

The process of hailstone generation is dependent upon relief. Even on plains, damage done by hail is usually caused by air turbulence strengthening in the boundary layer above small hills and undulating land.

In Ukraine the most frequent hail fallout occurs in the mountainous regions of Crimea and the Carpathians, where, on average there are 4–6 days per year with hail. Here it is vineyards that suffer most. On the plains in Ukraine the average number of days with a hail is 1–3. South of the steppes experiences least hail. Here temperature inversions formed under conditions of breeze circulation in the coastal zone make convection easier. Areas situated close to the coast and water reservoirs see a significant drop in the number of hailstorms recorded.

The frequency of days with hail over a territory is quite stable, varying little from year to year.

In general, calculating the number of days with hail annually, by Poisson's Law, accords quite well with actual data sets (see Table 6.1), though actual frequency exceeds that given by Poisson's Law in all cases.

Hail is observed mostly during the warm season. From April the number of days with hail gradually increases to a maximum in May or June on the plains. In mountainous regions the greatest number of days with hail shifts to June or July.

Table 6.1
Annual frequency of days with hail

Calculation	*Number of days with hail (%)*										
	0	1	2	3	4	5	6	7	8	9	10
	KIEV (plains)										
Actual data	22	29	22	11	8	3	3		1	1	
By Poisson	14	27	27	18	9	4	1				
	L'VOV (mountains)										
Actual data	17	23	7	27	10	7	3	3	3		
By Poisson	5	15	23	22	17	10	5	2	1		

During May–July the damage done by hail covers vast regions. After August the number of days with hail reduces significantly. In winter hail is a very rare event. In mountainous areas hail occurs once every ten years during the winter months, in the rest of the territory it take place even more rarely.

The duration of hail fallout can vary from a few to 15 minutes. The probability of such duration may reach 20–30 per cent in specific regions, and it amounts to 30 per cent and more in mountain regions (see Figure 6.1). Long-duration hail fallout – more than 45 minutes – takes place very rarely. In southern regions long-duration hail does not occur at all.

Table 6.2
Kiev – frequency of days with hail during the warm season

No.of hail days	*April*	*May*	*June*	*July (%)*	*August*	*September*	*October*
0	90	60	67	78	88	91	93
1	5	23	24	22	8	9	7
2	1	8			4		
3	2	4	1				
4	2	1					
5	1						

Hail falls mainly in the afternoons when thermal convection development is at its maximum. The greatest probability of hail (25–40 per cent) is from 2–4pm (some regions 4–6pm) on the plains. In the foothills and mountains the frequency of hail is greatest between noon–2pm (30 per cent of cases). Hail is rare at night and in the mornings.

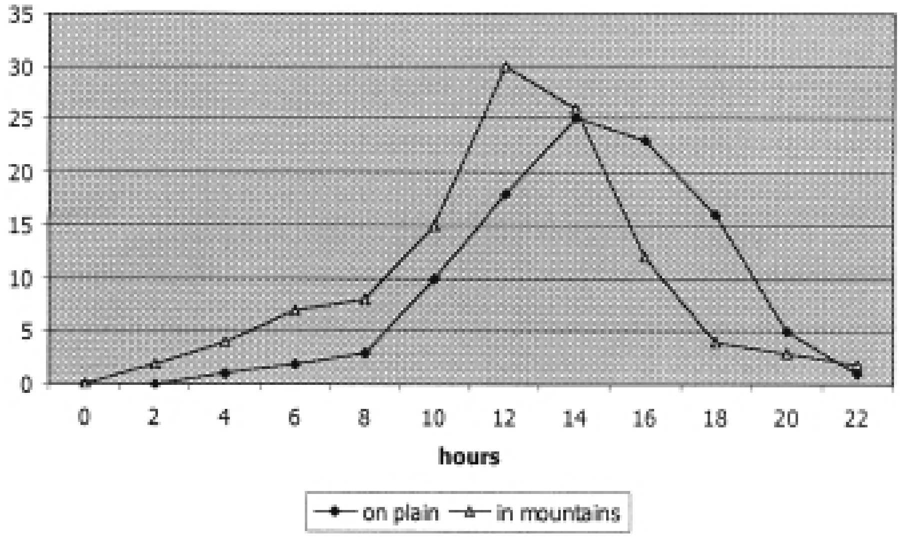

Figure 6.1
Probability of hail at various hours (%)

During the warm season the probability of hail falling in one region or state is 57 per cent; in two regions 30 per cent; and in five and more regions only 2 per cent. Intensive hail does not occur over the whole territory but in scattered showers. Hail is a local phenomenon. It mostly falls in isolated spots and occasionally in hail pathways. These pathways can extend over several hundred square kilometres. The distribution of hailstones over land is not uniform.

Hailstones of 20 mm and more in diameter and intensive hailstorms with smaller sized stones cause the most significant damage economically and are extremely dangerous. In Ukraine small but intensive hailstorms occur most commonly (more than 70 per cent – see Table 6.3).

Table 6.3
Probability (%) of different size hailstones

Hailstones characteristic (diameter in mm)	*Probability (%)*
Small, intensive	71
20–29	15
30–39	10
>50	4

Usually, large hailstones fall from the end of April/early May to the end of August/mid-September. In Crimea a fallout of large hailstones may occur at any point in the year, even winter.

An especially dangerous hailstorm occurred in western regions on 25 June 1969 between 4–5pm. The fallout lasted 15–20 minutes. The diameter of hailstones in some cases was 100 mm. The hail destroyed and damaged agricultural crops over vast areas. The depth of hail cover on the ground reached 15 cm in some places. On the same day eastern regions of the country experienced hailstones of 80 mm in diameter falling for 10–15 minutes. This hailstorm was generated with the passage of a cold polar front.

On the basis of data for Ukraine on hail frequency it is possible to define three types of hailstorm:

(*a*) Type 1. Hail covering small areas. This is the prevailing type;

(*b*) Type 2. Hail exhibiting a scattered fallout pattern. The areas affected by hail vary in shape and can range from ten to several hundred square kilometres. Such hailstorms may occur simultaneously in a number of regions; and

(*c*) Type 3. Hail falling in a strip. These strips vary in width from a few hundred metres up to ten kilometres. Sometimes strips can even extend a few hundred kilometres.

In summer hail occurs every other day in some region of Ukraine. In some years hail falls every day in May. Hail rarely covers large areas.

In order to prevent the damage done by hail it is important to know the frequency and range of hailstorms in a given territory. In the steppe zone of Ukraine the number of days with hail is 7 within an area of 300 square kilometres. When the area assessed is increased from 2 800 to 3 750 square kilometres, the number of days with hail increases from 18 to 24. When ever larger areas are included, there is no statistically significant increase in the number of storms.

Analyzing the density of the meteorological network is of interest. Such analysis reveals that 11 days with hail annually are recorded where there is one meteorological station for 107 square kilometres; 24 days are recorded where there is station for 16 square kilometres. With a further increase in the density of stations, the number of days with a hail becomes less. A network of one station per 7–10 square kilometres makes it possible to record almost all occurrences of hail.

In the majority of cases of hail in Ukraine, westerly or northwesterly winds prevail (35–45 per cent of cases) and clouds are mainly cumulonimbus.

Hail occurs at a surface air temperature of 18–22°C. In mountain regions hail occurs at temperature ranges of 10–14°C and 14–18°C (with 50 per cent probability). The probability of hail falling at low temperatures is less than 15 per cent. At temperatures higher than 30°C hail very seldom occurs (8 per cent probability). Hail is accompanied by a significant decrease in temperature (6–10°C).

When spout clouds are generated, hailstones may be particularly large. This can be explained by the strong turbulence within these clouds. The upward flows of air reach great heights and it is here where the hailstones are generated. These flows within a spout are whirling in nature. They are characterized by great power and stability, and are therefore able to keep hailstones at great heights for considerable lengths of time. The hailstones gradually build up new layers of ice. Thus, hailstones from spout clouds are unusually large and fall in abnormally great amounts.

The hailstones of the greatest size occur in the central part of North America, where spout clouds are most widespread. Hailstones of 130–150 mm in diameter have been recorded. Such huge hailstones cause extreme damage to crops and orchards.

Methods to counteract hailstorms centre around regulating the ice particle concentration in clouds – in the zone of hailstone growth – attempting to restrict their growth. In recent years much effort has been deployed in this direction and it can be shown that in those areas which use anti-hail protection the damage done by hail is significantly reduced.

6.1.1 Measures to protect against hailstorms

The most effective regulation of hailstone growth is carried out by the injection of crystallizing reactants. To prevent the growth and fallout of hailstones it is necessary to detect the hail centre in a cloud at the right time (using a radio-locator) and then to inject crystallizing reactants. Logistically, it is necessary to ensure the capability of injecting reactants in any part of the region being protected. The injection of reactant into clouds is carried out in two ways: (i) bombarding clouds by artillery projectiles containing the crystallizing substance; (ii) using counter-hail rockets. Silver iodide and lead iodide are used as crystallizing reactants, which promote cloud growth rather than hailstone development. Effective anti-hail protection is dependent upon reliable, accurate forecasting. Recent years have witnessed a downward trend in the generation and fallout of hailstones of large size.

6.2 HIGH WINDS

Wind affects agriculture significantly. The degree of its effect on crops depends on its speed, time of occurrence and duration.

Wind with speeds of more than 15 m/s is classified as a severe weather phenomenon; speeds of 25 m/s constitute an extremely dangerous phenomenon.

Strong winds dry the upper layers of soil and plants. High wind speeds cause increased transpiration in plants and can break the supply of water via the roots. In the case of high air temperature and low air humidity combined with high winds, plants dry up even if soil moisture is adequate.

High winds in spring hinder flying insects and bees decreasing possibilities for pollination. High winds with showers cause crops to be flooded, cutting of leaves, loss of flowers and fruits, and they hinder harvesting operations.

High winds in winter may encourage snow removal from fields if special barriers such as tree belts and windbreaks are absent. This can cause an irregular covering of snow. Snow is blown into ravines and gullies, the root systems of plants become exposed which can lead to frost damage. Re-distribution of snow is possible in high wind when the density of snow cover is less then 0.25–0.30 g/cm^3.

High winds cause intensive evaporation from the soil which sharply reduces soil moisture and lowers the water level in reservoirs. Water loss in this way can be effected by relatively moderate winds.

Wind speed depends on the horizontal barometric gradient. It has been discovered that the mean barometric gradient for the day prior to the start of wind strengthening runs to 1.5 mb, and that at the moment of wind strengthening it exceeds 3.0 mb per 1 degree of a meridian. Wind speed is also affected by the physical and geographical features of the territory: elevation, shelter features, etc.

Squalls are whirls with a horizontal component and short-term strengthening of wind speed. They exhibit sudden changes of direction. Squalls are usually accompanied by showers and thunderstorms, less often by hail. Local squalls which cause crop destruction are classified as dangerous local winds.

Most parts of Ukraine have between 10 and 25 days of high wind per year. In the uplands to the east the mean annual number of days with high wind increases to 40–50, and even 70–80 per year, in some places. South of the steppe region experiences 50–100 days.

The frequency of high winds varies from year to year. In 30–60 per cent of years the number of days with a high wind deviates from the mean value by 1–10. Using historical data it can be shown that the since the 1936 the number of days with high wind has been decreasing.

The mean duration of high winds varies from 2–12 hours. Those lasting less than 3 hours prevail in 60–80 per cent of cases. The greatest speeds in Ukraine are generally 20–30 m/s though in rare cases they can reach 40 m/s. High winds of the greatest duration occur in the south and southeast of Ukraine. In Kherson, in

December 1946, the high winds lasted 143 hours, and the maximum speed of the wind reached 25 m/s. In the high mountainous regions of the Carpathians in February 1965 the wind lasted more than five days, and its speed exceeded 40 m/s at times.

The detrimental effects of wind are increased by other dangerous meteorological phenomena which occur when the wind is strengthening. In the warm season thunderstorms and showers often accompany squally strengthening of a wind. In southern and southeastern regions the high wind results in dust storms and hot dry winds. In the cold period the strengthening of a wind may be accompanied by blizzards and snow drifts.

6.2.1 Dust storms

High winds affect plants unfavourably. Most dangerous are winds with speeds above 10 m/s, bringing plenty of dust and destroying the surface soil layer. These winds, called dust storms, are a phenomenon characterized by the transportation of large volumes of dust and sand by the high winds. During dust storms visibility is impaired significantly. Their occurrence has both natural and human causes. Agricultural management, not ideally suited to the climatic zone, can encourage dust storms.

The drying of the upper soil horizon, absence of crop cover, low relative air humidity (below 50 per cent) and absence of snow cover or ice crust in winter as well as a poor cementation of soil and non-deep freezing constitute a complex range of factors which increases the probability of dust storms. This range of factors occurs in the steppe zone. Dust storms mostly occur in spring, when the wind strengthens, and fields are in a ploughed state or contain poorly developed vegetation.

Soil structure, moisture conditions, presence of snow cover and relief are important factors in the formation of dust storms. When the soil moisture content in the ploughed layer is 25 mm, dust storms may be formed at wind speeds above 15 m/s. When this content is below 10 mm, dust storms occur even at wind speeds of 8–10 m/s. In stable air conditions particles of sand and dust may be lifted up to great heights under the influence of convective mixing.

Dust storms generally form between March and September, however, in the south and southeast they can develop in winter. The maximum number of days with dust storms usually occurs in the June–August period. A spring maximum is observed at some southern meteorological stations. This is caused by an early reduction in snow cover, an intensive rise in air temperature and the absence of good grass cover.

Dust storms may also happen in the steppe zone at the end of summer, when the soil dries up, and the fields begin to be ploughed after harvesting of the early spring cereals. Winter dust storms are a rare phenomena.

The upper soil layers in convex forms of relief begin to be blown away on windward slopes with wind speeds of 8–10 m/s. The light soil particles move as a dust great distances; the relatively heavier particles fall out and dislodge other soil particles, which are then taken up by the wind. Thus, there is a “chain reaction”.

The intensity of the blowing of soil is proportional to the speed of the wind raised to a third power. For example, when the wind speed changes from 12 to 15 m/s, the intensity of the blowing of soil is increased approximately twofold

Barriers, such as tree belts and buildings, cause a slackening of the wind and the heavier particles to fall out, forming land-drifts. The lightest particles of soil can remain suspended in the atmosphere for a long time. And so, during a dust storm visibility and light penetration worsen. Sunshine hardly gets through the dust-screen.

The horizontal extent of regions covered by dust storms varies markedly – from several hundred metres to a thousand kilometres and more, and the vertical extent varies from several metres to several kilometres.

Dust storms cause great damage to agriculture. They destroy and damage crops. High wind may remove significant volumes of earth, leading to reduced soil fertility.

In the steppe zone 1–5 days with dust storms are recorded annually. A higher frequency (6–10 days) is observed in the southwest (Odessa, Crimea and Kherson regions), around Zaporozhye and Dnepropetrovsk to the east and in the Lugansk region in the southeast.

In Ukraine strong dust storms were recorded in the spring seasons of the following years: 1886, 1896, 1890, 1891, 1892, 1893, 1898, 1899, 1928, 1936, 1939, 1947, 1948, 1949, 1953, 1957, 1960, 1969 and 1984. The most intensive were in 1886, 1928, 1960. The wind erosion and deflation of soils caused by these dust storms were disastrous and resulted in huge losses to agriculture.

During the dust storm of 1886, in the east of Ukraine, the land-drifts reached 2–3 metres and the soil depth decreased 25 cm in many places.

The dust storm of 1928 (26–28 April) caused great devastation over large areas of Ukraine. It affected the steppe and forest-steppe regions. The wind lifted more than 15 million tons of dust to heights of 400–750 metres from an area of 1 million km^2. Vast amounts of dust fell out over Ukraine, Romania and Poland. In areas, where the dust fell its depth ran to 12–25 cm. Incidences of dust deposition in Denmark, Sweden and Finland were recorded.

In the spring of 1960 wind speed reached 25–35 m/s. The low layers of atmosphere were so saturated with dust that visibility decreased to 100–200 metres. The dry soil layer of 6–7 cm was affected by soil drifting. Transportation of the dust beyond Ukraine's borders was less than had been the case in 1928 despite the greater wind speeds. This can be explained by the presence of forest strips. Poorly developed winter cereals were killed in some regions and covered by small particles of soil in others. More than 50 per cent of the winter cereal crop perished and extensive re-sowing was required.

In 1969 a dust storm of extreme force and intensity occurred in January and February. It was a winter of exceptionally low snow levels. High winds demolished the upper dry layers of soil revealing tillering nodes. Crops poorly developed since the autumn, located in watershed sites and the slopes of non-forested fields were destroyed; those on flat sites were buried. The tillering nodes were exposed 1–2 cm above the surface. Exposed crops and those buried by dust drifts perished. The phenomenon was accompanied with strong frosts. The loss of winter cereals reached 62 per cent in some places.

The more structured the soil the more susceptible it is to blowing. Therefore wind erosion begins at different wind speeds for different soil textures.

Light-textured soils (sandy, sandy-loam, light-loamy) are most susceptible to blowing. These soils freely pass moisture to the deeper layers. Therefore, their surface rapidly dries up and when exposed to relatively low wind speeds can be lifted up. The large particles of soil gather in dips in the relief or around obstacles such as buildings, forest strips etc.

Table 6.4 gives the wind speed which causes wind erosion for different soil types and textures.

Table 6.4
Wind speeds causing wind erosion for different types of soil

Soil type	*Wind speed (m/s) at 15 cm above a surface*
Sandy	2–3
Sandy-loam	3–4
Light-loamy	4–6
Heavy-loamy	5–7
Clay-textured	7–9

The main agrometeorological factors which define dust storms occurrence are wind, soil moisture, presence of snow cover, relative air humidity and oscillation of the air temperature during 24-hour periods.

The likelihood of dust storms in the different seasons varies (see Table 6.5). Observational data shows that for eastern regions of Ukraine for the period 1945–1996 dust storms in the winter and spring were continuous (more than 5 days) in 14–20 per cent of cases. These dust storms covered a large territory. In the majority of regions 80–100 per cent of the dust storms occurred under easterly and southeasterly winds.

During the summer and autumn dust storms tend to exhibit a local character and occur less frequently under easterly and southeasterly winds. So, greater

Table 6.5 percentage of dust storms 1946–1996

Meteorological station	*Dust storms (%)*			
	Under easterly and southeasterly winds		*5 days or longer*	
	Winter and spring	*Summer and autumn*	*Winter and spring*	*Summer and autumn*
Svatovo	100	55	20	0
Starobel'sk	91	70	14	14
Belovodsk	93	46	14	0
Lugansk	81	55	14	10

attention should be paid to the most severe dust storms which occur in the winter and spring periods. In winter and early spring dust storms occur when there is little snow cover and low soil moisture. Blowing of soil in winter (black storms) takes place when the relative air humidity is low and soil moisture is deficient. However, in some years dust storms in winter and spring take place even when there is good humidity in the upper soil layer, when there are strong daily oscillations in air temperature and mechanical destruction and drying of soil can be observed.

Dust storms are often associated with droughts. Such a combination causes major losses to a national economy. Wind destruction or deflation of soils takes place; crops are ruined as a result of seeds and poor developed seedling being blown away; fields, roads, canals, water reservoirs, irrigation systems are covered by sand and dust; all kinds of infrastructure and communication networks are adversely affected. Wind erosion may remove soils huge distances. In 1960 dust from Ukraine and the Northern Caucasus of Russia was deposited in Romania, Bulgaria, Hungary and Yugoslavia; and visibility was badly affected in Bielorussia, eastern Poland and at the Baltic coast.

Dust storms – a negative effect of winds – are widespread all over the world. They occur in the central regions of western USA. In the 1930s they affected the Great Plains from North Dakota to Texas. The dust storm of 1934 removed hundreds of millions tons of soil thousands of kilometres. On one day Chicago was under a dust layer of 12 million tons. Even remote New York experienced drought. Cereal yields decreased 75 per cent. Hundreds of thousands people affected by the dust storm left their homes and migrated west.

The largest dust storms occur in sandy deserts. Here they are responsible for putting large volumes of dust into the atmosphere and moving great masses of sand on the earth's surface. As a result of selective blowing, soil with a high sand particle content is created and the organic element (the main source of nutrients for plants) decreases. Thus in places the dust storm causes loss of soil fertility and a change in the chemical structure of the soil. The physical properties of the soil are changed too with changes in soil structure. In dry areas, steppes and deserts, dust storms are observed usually in spring and early autumn in connection with dry soil.

Dust storms may be classified by the colour of the lifted dust – white, yellow, brown, red or black, depending on soil type.

The centre of a dust storm forms, at ground level, where the wind force is sufficient to start wind erosion. Then it develops over a wider area. Dust storms can be described as local or advective according to the source of their suspended sand-dust. Advective dust storms extend far from the centre of their origin. Satellite images show the movement of dust clouds from the Sahara over the Atlantic Ocean to Central America. Each summer 60–200 million tons of dust are deposited over the Atlantic.

In the southern Sahara dust storms can cover areas of 2 500 x 600 km, stretching from the Senegal River to Lake Chad. They form latitudinal strips. Here wind speeds can reach 25 m/s and more.

Dust storms have exceptionally strong, sometimes disastrous, effects on Kazakhstan and its neighbouring region. Wind speeds of 22–25 m/s and even 34–40 m/s are recorded. These winds can be classified as hurricanes. In the aftermath of such storms it is common to have complete fields with emerging seedlings covered by sand.

Similar dust storms occur in the central states of North America. During long droughts and high winds dust storms extend over enormous areas. Dust can be transported to the Atlantic coast. In the USA the worst and most extensive wind erosion occurred in 1933–1935. Crops were damaged in almost one-third of cultivated lands in the country and millions of people were affected. In the mid-1970s 100 million acres of land suffered from wind erosion, 10 million acres of which became practically unusable for agriculture. The situation was similar in Canada, where wind erosion of soils became widespread, especially in the central agricultural belt.

Winter dust storms do not reach the destructive levels of the autumn and spring storms. In the winter the snow cover protects the soil from blowing. In winters when the snow cover is light or absent and the soil is rather loose, dry and easily subjected to deflation soil particles can be moved together with snow – snow-dust storms. Research shows that winter deflation is not particularly rare and there are regions where blowing of soil takes place all year.

To prevent or decrease losses to the national economy due to extreme natural phenomena it is necessary firstly to detect the distribution and frequency of such phenomena over a region.

6.2.2 Counteracting dust storms

In most countries, field afforestation is the main measure to protect the soil from dust storms. Improving soil resistance to erosion can be achieved by careful selection of cultivation methods, applying mineral and organic fertilizers, sowing grass and spraying various substances which enhance soil structure. It is also important to reduce the areas where dust can gather, especially in tracts in areas characterized by erosion. One major protection strategy is to establish well developed plant cover before the dust storms period. This can encourage a reduction in the wind speed in the layer next to the ground by forming an effective buffer.

When assessing the impact of a dust storm on agricultural crops it is necessary to take into account the degree of development of the plants. On well-tilled crops the deposition of soil moved by airflow is observed more often than soil carried by wind erosion over long distances.

When looking at the conditions in which dust storms develop and data on storm-induced damage it is evident that measures to reduce the wind speed at the soil surface and to increase the hooking of soil particles are both crucial. Such measures include the establishment of tree belts and windbreaks. Leaving stubble in fields, non-mouldboard ploughing, application of chemical substances promoting the hooking of soil particles, soil-protective crop rotation using perennial grasses and seeding of annual crops are also important.

In planning and implementing protection measures it is necessary to take into account the direction of prevailing winds, relief, microclimatic details and soil properties.

In regions with intensive wind erosion, especially on wind-shock slopes or on light soils, strip cultivation may be used. On fallow lands bare fallow strips of 50–100 m can be alternated with strips of grain crops or perennial grasses; spring crops can be alternated with winter crops. The direction of strips should be perpendicular to the damaging winds.

To reduce the oscillations of soil temperature and protect soil from wind erosion during the winter–spring period cultivating without turning over furrows and retaining a cover of stubble from previous crops are two important measures.

6.3 EXTREME COLD WEATHER INCLUDING COLD INJURY

Temperatures of –10°C are extremely damaging to crops. In regions where winter cereals are grown low air and soil temperatures are the main causes of plant loss.

The low air temperatures experienced in Ukraine and in most of northern Europe are caused by the intrusion of polar air, usually via anticyclones from the north, northeast or northwest. Cold anticyclonic weather forms over Ukraine and polar air is exposed to additional radiative cooling. Air temperatures may fall to –30–40°C.

Long periods of air temperatures below –10°C combined with other meteorological phenomena are detrimental to many sectors of the economy, especially agriculture. Periods below –20°C can result in the loss of winter crops, fruit crops and vineyards due to frost injury. Frost injury is the most widespread type of cold injury to affect crops.

Low soil temperatures at the depth of plant roots can cause frost injury. Such reductions in soil temperature occur with strong frosts, in the absence of snow cover and with deep freezing of the soil. The soil temperature around the plant roots is critical. Below a certain temperature irreversible processes take place in the plant tissues, killing plant cells.

Most frost injury to winter crops takes place in the first half of winter before sufficient snow cover which would afford protection has formed. In the second half of winter frost injury happens in regions with unstable snow cover.

There have been many studies of plant injury caused by extreme cold weather. Under low temperatures basically a plant dries out. The protoplasm (the living part of cells) dies. This happens because the concentration of cell sap rises, the distance between macromolecules is altered and the processes of energy interchange are disrupted. The toxic products of metabolism accumulate within the plant’s tissues and it is this which causes the protoplasm to die.

Firstly, extremely low temperatures damage the leaf primordia. As a result of frosts they becomes brown and deformed, lose rigidity, and the shoot and sometimes the whole plant perishes. Secondary younger sprouts suffer less from frost injury. The degree of damage depends on the intensity and duration of dangerous frosts as well as the stage of the plant’s development. Damage to part of a plant does not always result in damage or destruction of the whole plant. A determining factor is the degree of frost injury to a tillering node – if it is heavy the whole plant will prerish.

The temperature at which a plant perishes varies from species to species and with the variety. For the same variety this temperature depends on a status of plants in autumn as well as on changes to their frost-resistance under influence of agrometeorological conditions during the winter period. Frost resistance in winter crops is reduced if there are long, intensive thaws when the plant’s rest is interrupted. Following a thaw, if the temperature falls abruptly crops perish at relatively warmer temperatures than is the case if the decrease in temperature is more gradual.

The depth of the root system and degree of tilling have a large effect. Well-tilled hardened plants with tillering nodes deeper than 3 cm withstand much stronger frosts compared with underdeveloped plants in the early phases of their development.

In the winter of 1968–1969, when the majority of winter crops in Europe were lost to cold injury many studies were undertaken. In 35 per cent of tests on plants the leaf promordia had been damaged or completely lost.

Tillering nodes of winter rye are the most hardy to frosts. Well developed and hardened crops in a condition of winter rest or dormancy can withstand temperatures of –24°C and lower at the depth of the tillering node. The tillering nodes of winter wheat are less cold-resistant. They perish completely at temperature of –22°C. Plants of winter barley perish at temperature of –13–16°C. At the beginning and end of winter plants perish at higher temperatures.

The winter crops most frequently destroyed by frost are those grown on uplands, where snow cover is less and the depth of soil freezing greater.

Very dry, dense and over-humidified soil conditions impact unfavourably on the crops status and their dormancy. At optimum soil moisture the degree of thinning out of winter wheat as a result of injury by low soil temperatures is only 4.5 per cent. At insufficient soil moisture 26 per cent are lost and at excess soil moisture 48 per cent perish.

The main agrometeorological factor influencing frost damage in winter crops is low soil temperature at the depth of the tillering node. Cooling to the critical temperature of frost injury, even for one day, and especially after a thaw, results in thinning out of crops. Long (three days or more) and intensive cooling causes complete devastation.

The critical temperature at which frost injury occurs does not remain constant. It varies throughout the autumn–winter season decreasing through autumn to winter and then rising at the end of winter. Thus, frost-resistance of winter crops is low at the end of winter and lost almost completely at the spring renewal of vegetation. Therefore, spring frosts of –10–12°C can injure plants.

To acquire high resistance to extremely low air temperatures winter crops need dry sunny weather with a well-expressed diurnal range in air temperature during the week before entering the dormant phase. The air temperature range should start from +10°C in the daytime down to –1°C at night, followed by a gradually decreasing daily average air temperature into negative values and transition to the winter weather regime. If such weather is broken by significant warming, any gain in hardening is lost, and the injured plants go to winter. The critical temperature for frost injury rises to –10–12°C and frost-resistance decreases.

From variations in air temperature and soil temperature around the roots it is possible to predict the frost-resistance of winter crops, as well as the level of critical temperature attained by plants at the beginning of winter. For Ukrainian conditions the following relations between critical temperatures of frost injury and accumulated negative soil temperatures at a depth of 3 cm for the period since crossing the mean daily air temperature from 0°C to –10°C at the beginning of winter can be given:

Accumulated negative soil temperature	°Ñ	0	–25	–40	–60	–70
Critical temperature	°Ñ	–13.5	–17.0	–17.5	–18.5	–19.0

These relationship between accumulated negative air temperatures and critical temperatures of winter wheat apply, if they are received in early winter and with snowless conditions or snow cover not exceeding 2–3 cm.

In assessing the agrometeorological impact of low air temperatures on plants it is necessary to know not only the critical temperature, but also the length of duration of the critical or low temperatures. If soil temperature at the depth of the tillering node is equal –20°C for 26 hours, then 43 per cent of the winter wheat crop will be destroyed; after 36 hours 65 per cent will be lost and after 46 hours 96 per cent.

These data show the destructive impact of low soil temperatures. The absolute values can vary depending on the variety of the plant, degree of hardening, nature of the previous weather etc.

The temperature of the upper soil layer depends on air temperature and height of snow cover above the frozen soil. Research has shown that the deeper the soil freezing, the lower the temperature at the depth of the tillering node. Deep soil freezing reduces the size of temperature fluctuations in the upper soil layers. This protects winter plants from the harmful impact of sharp temperature fluctuations.

A drop in soil temperature below the critical level depends on many factors, the combination of which widely changes. The basic components are air temperature, height of a snow cover and depth of soil freezing.

A key factor in protection from cold injury is stable air temperatures and snow cover throughout the winter. Thaws, resulting in packing or disappearing snow cover, worsen dormancy conditions and reduce or destroy the protective properties of snow cover. Long thaws can result in the renewal of vegetation, which is accompanied by the consumption of carbohydrates and hence by an increase in critical temperature and decrease in winter-resistance.

In regions with unstable winters the frost-resistance of winter crops does not remain stable, however, after thaws frost injury seldom occurs.

Cold injury, including complete destruction, can take place at the beginning of winter when strong frosts occur before there is a good snow cover. At this time soil temperatures drop below the critical level.

Strong frosts in mid-winter are often accompanied by winds which remove snow from fields, or they come after a thaw, when the snow has melted or strongly packed. This can cause frost injury. Finally, frost injury can occur at the end of winter or early spring, when with dormancy over winter crops may be subjected to effects of low temperatures.

The likely impact of frost injury can be interpreted from forecasts of extremely low temperatures and the critical temperatures of frost injury for the various crops. This can be determined experimentally or calculated. Calculations are derived from average minimum soil temperatures at a depth of 3 cm. The equation is as follows:

Tcr = 14.056 + 1.916t + 0.172t2

Tcr = critical temperature of frost injury (°C)
t = average minimum soil temperature at the depth of the tillering node

The critical temperature marks the limit of a plant's frost-resistance. By comparing this temperature with the actual minimum soil temperature at the depth of the tillering node, it is possible to predict the results of dormancy. If the critical temperature is lower than the soil temperature, frost injury will not occur. Losses may be significant, however, when soil temperature is equal to the critical temperature or lower. The ratio of the absolute minimum soil temperature at the depth of the tillering node to the critical temperature is called the frost-risk factor.

K = t/Tcr

K = frost-risk factor
t = minium soil temperature at the depth of the tillering node (°C)
Tcr = critical temperature (°C) resulting in injury to more than 50 per cent of a crop

With meteorological data it is possible to determine a status of a crop at any given time.

The relationship between frost-risk factor (K) and injury to the crop (M) in per cent is expressed thus: M = 77.94K79. Table 6.6 was compiled using this equation.

Table 6.6

K	*M (%)*
0.55–0.75	1–20
0.76–0.87	21–40
0.88–0.96	41–60
>0.97	<61

Conditions on the lands on the left bank of the Dnieper River during the winter of 1968/69 were extremely unfavourable. At the end of January and into February air temperatures dropped to –29°C. Soil temperature at a depth of 3 cm was –17–20°C; this was equal to or below the critical temperature for frost injury. Around 60–70 per cent of the crop was destroyed.

Unfavourable dormancy conditions result in retarded development and growth of injured plants in spring and summer. The initial formation of wheat ears is slowed down. In spring the growth and development of injured plants can be seen, however, the subsequent differentiation of their generative organs may be abnormal, the process of ear formation may be damaged, flowers are underdeveloped and the overall growth of the plant is slowed down. Such plants, even at optimum agrometeorological conditions in spring and summer, have much reduced yields.

Damage and destruction due to extreme cold weather in winter results in great economic losses – reduced grain harvests and great expenditure on re-sowing of destroyed winter crops.

The main measures to protect winter cereals from cold injury are retention of snow cover and introduction of frost-resistant varieties.

The average annual absolute minimum air temperature (Tmin) is a good agroclimatic index of conditions for agricultural crop dormancy in Europe, especially for climates with mild winters without a stable snow cover (most of Central and Eastern Europe).

Snow cover significantly reduces the detrimental impact of low temperatures on winter crops. To make the correct predictions regarding conditions for winter crops it is necessary to know the duration of standing snow cover. The number of days with snow cover varies regionally and is determined by the intensity of cyclonic processes. In the northern part of Western Europe the passage of cyclones at rather high average temperatures in winter is fairly frequent. At Tmin –2°C the number of days with snow cover is 20 days, at Tmin –15°C 40 days and at Tmin around –17°C it exceeds 50 days. In regions with a more continental climate such as eastern Hungary, Romania, Ukraine and the southern European part of Russia, the small number of days with snow cover is recorded at lower values of Tmin. Here 30 days snow cover are experienced at Tmin of –16–17°C and 40 days with Tmin of –18–19°C.

In the majority of cases strong frosts occur as a result intensive advection of a cold air mass often accompanied by abundant snowfalls and followed by radiative cooling of air. Therefore in much of Western Europe the detrimental impact of strong frosts on winter crops is softened by the presence of snow cover during the most dangerous period.

For a correct assessment of the importance of low temperatures in winter it is necessary to know the temperature at which crops are affected.

During the period of winter dormancy the frost-resistance of fruit crops is increasing. They can withstand temperature down to –25°C and lower without damage. Although it depends on the variety and the degree of hardening, the critical temperatures which are detrimental to the majority of fruit with stones and pears are–25–30°C; many apple varieties can withstand temperatures down to –35°C. Some cherry species have great frost-resistance, though some peach and apricot species are very sensitive to low temperatures – temperatures between –20 –25°C being detrimental for them.

Depending on the variety and stage of growth, winter crops can withstand temperatures down to –18–20°C without snow cover.

Minimum temperatures down to –10°C during the period of winter rest are, as a rule, not harmful to plants.

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CHAPTER 7

LOCUSTS
(by R.G. Gommes)

7.1 INTRODUCTION

WMO includes pests which devastate crops in the list of "agrometeorological disasters", because their development is largely conditioned by agrometeorological conditions. The principal pest species in this group, for example locusts, grasshoppers, armyworms (Spodoptera, etc.) and the red-billed quelea (*Quelea quelea*), cause spectacular damage on a local scale, but are generally less damaging than strictly climatic disasters.

There are very few global studies on the economic impact of these phenomena, and it is difficult to determine if the monitoring, or even large-scale control operations, are economically justified (van Huis, 1993 and FAO, 1995). The relative advantages of prevention and control measures remain a debated subject.

A swarm of locusts consists of 40 to 80 million individuals, each of which consumes its own weight in plant material daily (approximately 2.5 g making a total of 100 to 200 tonnes). If we consider that locusts don't feed preferentially on crops (except off-season crops), that they develop more often during favourable conditions when both wild and crop biomass is flourishing, and that they feed mostly on foliage (rather than on grains), it is clear that even large swarms can only cause limited damage on a regional level. Local damage, however, can be serious.

7.2 DEVELOPMENT OF LOCUSTS

Various locust species are spread among several of the world's semi-arid zones, in Australia, Brazil, China and Africa, amongst others.

As they migrate in large swarms, their development is directly influenced by local and distant meteorological conditions. They go through several different phases, each of which poses a threat to crops.

7.3 LOCUST-CLIMATE INTERACTIONS

Very simply: we begin with a situation where the locusts are found at low population densities. Under favourable conditions (low predation and abundant food), populations develop until they reach a critical density at which individuals undergo morphological changes, often so dramatic that it is possible to mistake them for a separate species. This is illustrated in Figure 7.1 for the case of the desert locust found in the Sahel. Once populations have reached a sufficient size, they begin to move under the influence of winds, up to 850 hPa[1], until they reach an area, often thousands of kilometres away, where conditions are favourable for reproduction (e.g. moist soils). This whole process takes place may times and there are many generations within the area of the species' distribution; statistically it finishes with a return to the point of departure.

This migration is largely controlled by agrometeorological, climatatological and synoptic conditions:

(*a*) The geographic distribution is limited by climatic conditions and in general by environmental conditions (light, temperature, relative humidity and soil moisture

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1 The utilization and monitoring of data at 850 hPa are quite exceptional in agrometeorology, which normally confines itself to surface data.

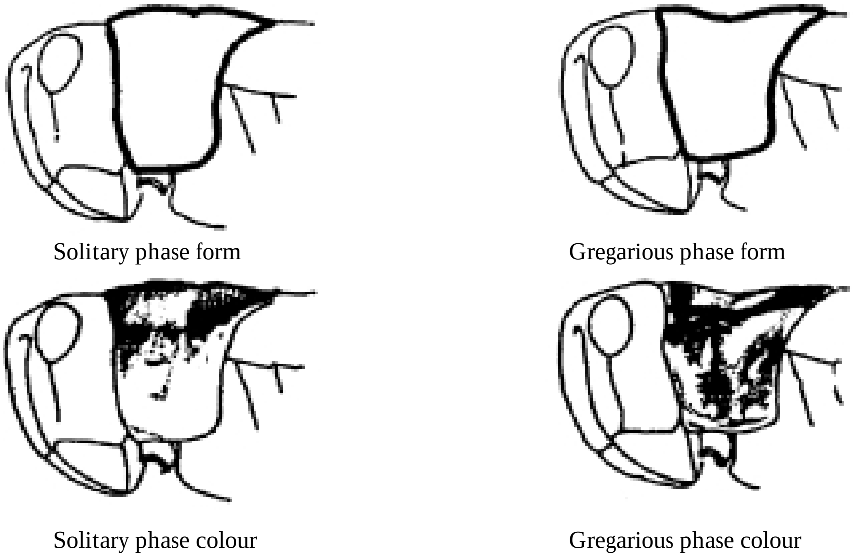

Figure 7.1
Transformation of a desert locust between solitary and gregarious phases [illustration reproduced from the Sécheresse glossary*, 1996]*

and chemistry). Moisture is, in general, favourable for the growth of a number of cryptogams and consequently damaging to many higher plants and insects. Locusts are no exception to the rule given in Gillon (1996) that high humidity is harmful overall. However, an input of water is necessary for several vital stages: ovogenesis, oviposition, the first days of embryonic development and rupture of diapause.

(*b*) Egg laying (oviposition) must be done into moist soil.

(*c*) Gregarization is initiated when the population reaches a critical density ("gregarization threshold"), which presupposes favourable feeding conditions (or more favourable ones for the locusts than for their enemies). The locust has a paradoxical relationship with drought. According to Gillon (1996), locusts proliferate in arid regions, but only those with sufficient rainfall, while in temperate climates, it is summer drought which favours locust development.

(*d*) Swarms literally move under the influence of synoptic conditions and on a synoptic scale, blown by the wind once the latter has reached the rather modest speed of 15 to 20 km/h. They can move 5 to 130 km in a day and cross the Red Sea (300 km) in several days. Exceptionally, as in 1988, locusts were able to cover the 5 000 km separating Mauritania and the Caribbean. Solitary adults move mostly at night, while swarms (gregarious phase) move mostly during the day.

It is interesting to note that, while many pest locusts are confined to semi-arid zones, it is often favourable rainfall conditions that promote the development of large swarms.

7.4 SOME LOCUSTS

7.4.1 DESERT LOCUSTS

The desert locust range is limited to the desert and semi-arid zones of Africa, the Near East, and south-west Asia which receive less than 200 mm of rain per year; this zone covers 16 million square kilometres over about 30 countries. During "scourge" periods, the area affected can reach 29 million km^2; that is to say 60 countries, close to a fifth of the Earth's surface and 10 per cent of world population[2]. These invasions do not occur cyclically, but are "pseudo-cyclic". For example, in Africa, the principal periods of activity have taken place in 1926–1934, 1940–1948, 1949–1963, 1967–1969 and 1986–1989.

7.4.2 AUSTRALIAN PLAGUE LOCUST

For the Australian locust (Hunter, 1996), swarming depends on rainfall occurring in the arid interior of the continent, which allows three or four generations to develop in a year, and so reach the densities necessary for gregarization. However,

2 Most of this information is given on the FAO internet web page (www.fao.org/news/global/locusts/locFAQ).

should rain not fall, the eggs are very resistant to drought, and the gain in total numbers can be transferred to the following year when the eggs are "reactivated" (Launois, 1996).

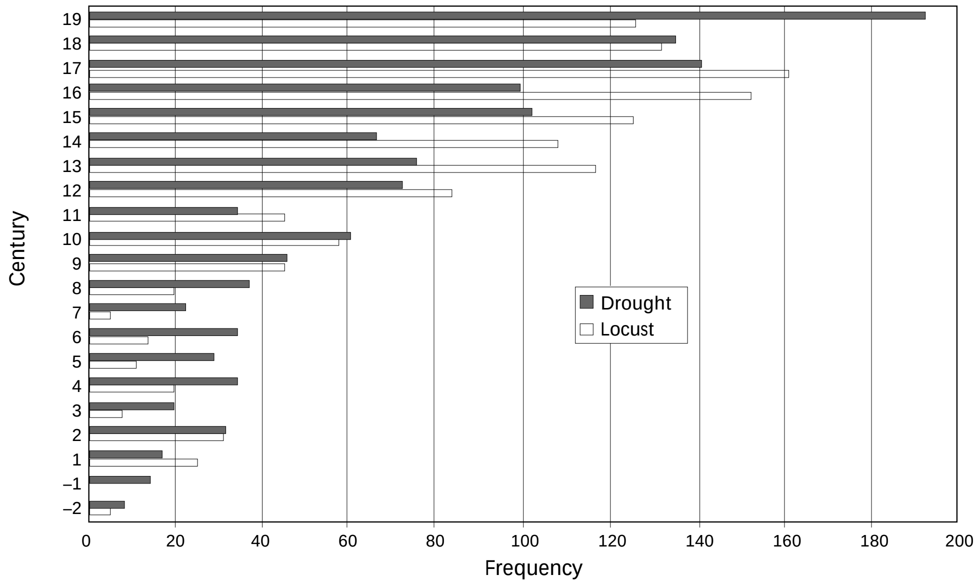

Figure 7.2
Frequency of drought and migratory locust periods in the north and east of China from the second century BC to the 19th century AD (data reproduced from a chart in Zibin Liu, et al.*, 1996)*

7.4.3 Migratory locust

The case of the migratory locust is very interesting and apparently paradoxical (Zibin Liu, *et al.*, 1996), given that they develop during dry years. There is, in fact, an excellent correlation over a remarkably long data series which covers 21 centuries (Figure 7.2).

This can be explained as follows:

(*a*) The main areas of reproduction in China are concentrated on the banks of rivers and lakes, zones little used by agriculture because of fluctuating water levels. These moist areas increase during dry years, thereby enlarging the zone suitable for locust reproduction. One method of locust control involves managing these zones.

(*b*) During a dry year, temperatures are generally higher than the normal, locusts are more active, and three generations can develop under good conditions (instead of two).

(*c*) During a dry year, vegetation is more scattered, which leads to relative concentrations and therefore higher densities, and hence to the threshold of gregarization being surpassed.

7.5 MONITORING OF ACRIDIAN SITUATIONS

The FAO and other organizations regularly monitor the acridian situation in Africa and Asia. This includes both monitoring conditions favourable to locust development (e.g. rainfall in zones with little precipitation) as well as the appearance of vegetation in potential gregarization zones.

This poses enormous logistical problems, because of the low density of meteorological stations in arid and semi-arid regions, and the difficulty in estimating rainfall by satellite in the absence of surface data. Even the satellites with the highest resolution are generally difficult to use for this application.

It is often asked if satellites can be used to directly observe swarms. Earth satellites do not have sufficient resolution. However, military satellites have very high resolution permiting the identification and localization of swarms. Unfortunately, their utilization is hampered by a number of practical difficulties:

(*a*) Images are not normally available for civilian use;

(*b*) High costs; and

(*c*) The quantity of data to process is enormous.

There are a number of studies which attempt to evaluate the monitoring and control operations for various locust species from an economic stand point, but no study has unambiguously concluded the utility of such operations, from this point of view.

In practice, this aspect is highly important, but we should take into account the following facts:

(*a*) Pest locusts and other migratory insect pests appear at very irregular intervals;

(*b*) The semi-desert zones where swarms reproduce are very difficult and costly to survey;

(*c*) Control operations are damaging to the environment; and

(*d*) Losses due to these pest species are, in practice, very difficult to evaluate quantitatively.

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CHAPTER 8

SPECIFICATION FOR A DATABASE OF EXTREME AGROMETEOROLOGICAL EVENTS

(by R.G. Gommes)

8.1 INTRODUCTION

Strictly speaking, extreme agrometeorological events include the direct and indirect impacts of extreme weather events on agriculture, taken in the broadest sense to include crops, livestock husbandry, fisheries and forestry. Extreme factors will eventually lead to extreme agrometeorological events and disasters only if they interact with a vulnerable agricultural system.

The discussion which follows attempts to cover, at least from a methodological point of view, the impact of other extreme events as well, including some man-made disasters such as chemical accidents and the consequences of earthquakes and volcanic eruptions.

This approach is justified because of:

(*a*) The existence of many borderline cases where non-agrometeorological events lead to situations very similar to those traditionally falling into the province of agrometeorology, or the interaction of an extreme agrometeorological event with another geophysical or other extreme factor. Examples are floods resulting from earthquakes or dam failures, or fires resulting from earthquakes or meteorite impacts. More examples are provided below.

(*b*) Extreme factors often result from a chain of consequences of which only one has an atmospheric component, but the proper assessment of the phenomena requires that they be analyzed as a whole.

(*c*) The need to take into account not only direct and indirect atmospheric effects on production, but also their impact on tools, infrastructure and even general marketing conditions (access to markets) and weather-dependent price fluctuations.

We also suggest that the wording extreme agrometeorological events is somewhat contradictory in that many extreme events become "agrometeorological" only insofar as they affect agriculture. For instance, a tropical cyclone may be an extreme geophysical factor, but it will become an extreme agrometeorological event only if it hits an agricultural area and quantitatively or qualitatively affects agricultural production. The unusual combination of moisture and temperature that eventually triggered the 1845/46 Irish potato famine (Bourke and Lamb, 1993) would not have been an extreme agrometeorological event had white potatoes not been introduced to Europe, etc.

By definition, a disaster is the result of the interaction between an extreme factor and a vulnerable system (Susman, *et al.*, 1983), a definition which should also lead to adopting consistent definitions of the related concepts of risk and vulnerability (Gommes, 1998).

A database of extreme agrometeorological events should thus more properly be called a database of agricultural disasters resulting from extreme geophysical factors.

The purpose of a database of extreme agrometeorological events is, of course, to identify patterns of impacts on agriculture with a view to improving impact assessments, including impact forecasting, mitigation, adaptation and emergency operations whenever feasible. The proposed database is thus to be seen essentially as an operational tool.

The following section, therefore, starts with an attempt to list extreme factors which can potentially interfere with agricultural production.

8.2 CATEGORIES COVERED

It is obvious that a database of extreme agrometeorological factors must include a hierarchial typology of such factors, accompanied by a precise and quantitative definition. The hierarchial structure also makes provision for poorly defined extreme events included within a relatively broad category. Only after a proper typology has been defined will it be possible to provide a more complete outline for the structure of a database.

The following provides a tentative list of factors, which should be taken into account, classified according to the highest categories of a potential typology, based on the "geophysical" source of the disasters. Other approaches are possible, for instance by detrimental factor, e.g. "mudslide" regardless of the cause of the mudslide (heavy rain, snow-melt associated with volcanic eruption, dam failure...). It would also be possible to categorize events by the type of impact (famine, production loss...), but this would pose some very serious, and possibly insurmountable difficulties because the impacts are often based on very subjective and insufficiently documented assessments, particularly with regard to the extreme factor which led to the disaster.

We also stress the fact that weather factors are correlated, so that, for instance, high sunshine and high temperatures usually occur together and need not be dealt with separately.

8.2.1 Direct natural atmospheric factors

This includes the natural atmospheric phenomena which directly harm crops by their instantaneous intensity or through longer term exposure. This covers the extremes (intensity, duration) of almost all meteorological elements: rain (torrential rain, drought, hail); strong winds (tornadoes, storms, tropical cyclones); and temperature (frost, heatwaves, high night-time temperatures). There do not appear to be obvious direct effects of high moisture. Lightning can be mentioned as the cause of human and cattle death.

The incidence of hail is usually limited, although some extreme cases were recorded. One such was the 1888 event in Uttar Pradesh, which caused about 250 deaths. The "1888 blizzard" caused about 400 deaths in north east USA. The storm of 12–15 March 1993 on the Eastern Seaboard of the USA and Canada killed 300 and affected 3 000 000 people, causing damage of US$ 1.8 billion. The storm, with record temperatures, wind, rain and snow, was nicknamed "the storm of the century" and is generally taken to have been worse than the "1888 blizzard".

8.2.2 Indirect natural atmospheric factors and complex interactions

The meteorological elements to be listed here are almost the same as the ones given in the section above, although the mechanisms of their detrimental action are different – rain (waterlogging of soils, floods, landslides, erosion); wind (abrasion by sand particles, soil erosion); temperature (increased water demand and resulting water stress, effect on sex differentiation of certain plants[3]); and moisture (incidence of diseases, conditions conducive to fires). Lightning is one of the causes of crop and forest fires.

Tropical cyclones constitute a perfect example of a complex interaction of factors, including strong winds, heavy rains, ocean spray, etc. Ocean spray is the salt water blown inland which may salinize agricultural land. Storm surges are even more harmful in terms of their impact on crop production. For a general account of salt effects in soils and irrigation water refer to Ayers and Westcot, 1976.

Unfortunately, sufficient information is not usually available on cyclones and their destructive power and the impacted agricultural system. For instance, cyclone Hugo (17–23 September 1989) is well documented for the deaths and damage caused in the north-eastern Caribbean and the south-eastern USA (the insured loss was US$ 4.9 billion). Though much property was damaged, it is not commonly

3 For instance for oil palm temperature at the time of differentiation of the flower primordia has an effect on the frequency of female flowers – the only ones which will eventually produce oil three years later. Another classic example is temperature-induced male sterility in rice.

known that most of the banana crop was also destroyed in Dominica, leading to long-term suffering.

Valuable methodological conclusions emerge from a comparison of the July and August 1993 floods in the Mississippi, Missouri and Kansas river valleys (USA), the 1981 Sichuan floods and the January and February 1995 floods in the Rhine and Meuse valleys. In the USA, although 1.7 billion ha were flooded, most damage to agriculture occurred as a result of the heavy rains in the whole basin through waterlogging of the standing crop. The Sichuan floods affected "only" 500 000 ha, but threatened the livelihoods of about 10 million people. The Rhine floods occurred outside the cropping season; they led to 250 000 people and most of their cattle having to be evacuated out of fear that the dams, many of them dating back to the Middle Ages, would break. In comparison, the July–August 1998 Yangtze floods affected 26 billion ha of land, because the Chinese Government decided to break dams and flood agricultural areas to protect downstream towns.

8.2.3 Man-made factors

8.2.3.1 Atmospheric pollution as a source of soil and water pollution

Man-made pollution[4] is a multi-faceted issue, with many direct and indirect effects. The atmosphere plays a part in the formation of secondary pollutants (which result from the reaction of normal atmospheric gases with pollutants) as well as in the dispersion and transport of pollutants and their transfer between compartments (industrial plants → atmosphere; industrial plants → water bodies; atmosphere → soil; atmosphere → water bodies, etc.). Note that agriculture also constitutes a source of pollutants, either phytochemicals, fertilizers (nitrate pollution of the watertable), manure and greenhouse gases. For an overview of atmospheric pollution effects focusing on European forests, see ECE, 1997; for an analysis of the threats to developing country agriculture, refer to Marshall, *et al.*, 1997.

Atmospheric conditions usually play an important role too in that they are responsible for the "contact" between pollutants and humans, farm animals and plants[5]. For example, high moisture increases the impact of pollutants such as ozone[6] and acids; and high temperatures favour the accelerated decomposition of organic liquids (manure), a process which consumes oxygen and which can result in severe anaerobic conditions in water or waterlogged soils.

Stomatal opening, and the eco-physiological factors which control it, condition to what extent pollutants such as ozone may enter and make contact with physiologically active plant tissue (Kersteins, *et al.*, 1992). According to their nature, pollutants can affect plants by altering the environment (pH of soil, leaching of nutrients and mineral nutrients in general) or by physiological and biochemical mechanisms.

8.2.3.2 Oil spills and well fires

Oil spills (either from platform or land wells, including during the 1991 Gulf War) have received a lot of attention by the media. Many, such as the Torrey Canyon (1967), Sea Star (1972), Amoco Cadix (1978), Ixtoc-I (1979), and Exxon-Valdez (1989; see Davis, 1996), have remained in the memory of people. Their effects tend to be localized and more detrimental to the environment than to fisheries.

A special mention can be made of the 1991 Gulf War oil spills and smoke from burning wells. This caused massive air pollution and contamination of agricultural land and water supplies throughout the Tigris and Euphrates valleys. Black-rain damaged crops over a wide area including Iran, Pakistan, Bulgaria and Afghanistan.

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4 Not all "pollution" is man-made. An example is provided by rivers flowing through ore-rich deposits, resulting in downstream heavy metal pollution.

5 A classic example of the combined effect of high moisture and toxic chemicals is the 1951 smog which killed about 3 000 people in London.

6 Tropospheric ozone is probably one of the most agriculturally harmful pollutants in terms of production loss (ECE, 1997).

8.2.3.3 Nuclear accidents

Although nuclear accidents are difficult to hide due to the ease of detection of radionuclides, they tend to be reported by governments only under media pressure and, as a result, data sets are not comprehensive.

Following the 1979 (28 March) nuclear meltdown at Three Mile Island (Pennsylvania), the 1986 (26 April) nuclear reactor accident at Chernobyl (Ukraine) eventually affected most of the immediate surroundings, Scandinavia and Western Europe (except Spain and Portugal) to varying degrees. This constituted a perfect example of the transport of pollutants over long distances (Wirth, *et al.*, 1987), their removal from the atmosphere and subsequent absorption by vegetation and the whole food chain (Marples, 1996).

8.2.3.4 Industrial accidents

A severe case of aquatic chemical pollution of the River Rhine affected Germany and France in November 1986. This was caused by mercury-based pesticides, fungicides and other chemicals, which had originated from Basel (Switzerland). For almost two days, none of the governments along the Rhine knew the true nature of the chemicals flowing down Europe's largest waterway. It was estimated at the time that a 350-km stretch of the upper Rhine was "practically dead" and that it would take 10–30 years for life to be restored. Similar estimates and statistics would be useful in a database of agrometeorological disasters, if only to improve long-term impact assessment methodologies.

8.2.4 Other geophysical factors

8.2.4.1 Volcanic eruptions

The agricultural consequences of volcanic eruptions can be categorized as "global" and "local", the magnitude of the former far exceeding that of the latter. Both largely depend on the main types of ejecta emitted. Volcanic eruption classifications range from Hawaiian (quiet eruptions with fluid lava) to Pelean[7] (very violent eruptions accompanied by nuées ardentes and avalanches of explosive lava); Stiegeler, 1976.

The nuées ardentes (literally "burning clouds") are high pressure and high temperature gas and ashflows moving at speeds of up to 100 km/h. They transport large amounts of debris and pose very serious threats. The most violent type of eruption – Pelean – leaves very little chance to escape, burns all living creatures and results in widespread destruction.

During 1783, over 12 km^3 of lava and 500 million tonnes of noxious gases erupted during the Laki Fissure eruption in Iceland (McGuire, 1997).

8.2.4.2 Global effects

Major volcanic eruptions blow large amounts of dust and gases into the lower stratosphere (15–25 km) where winds may distribute them over the globe in a matter of weeks or months. It is particularly sulphuric acid (derived from a combination of sulphur dioxide and water) that plays a significant role in lowering the Earth's albedo, usually resulting in lower surface temperatures. The effect may last for several years, as illustrated in Figure 8.1, which shows stratospheric aerosol concentrations between 1979 and 1995. During this time the following events

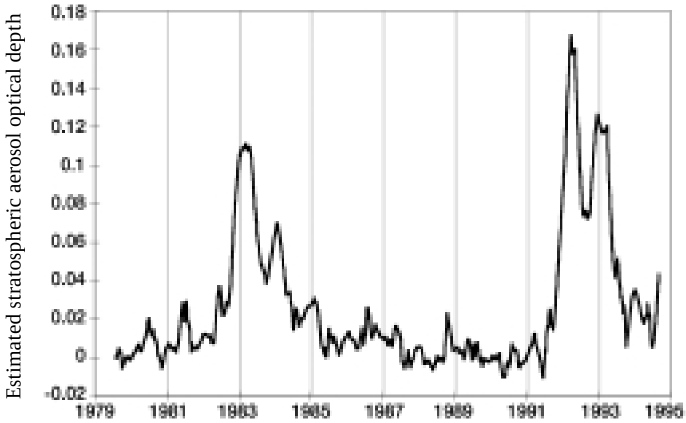

Figure 8.1
Distribution of stratospheric aerosol in association with volcanic eruptions. Based on the attenuation of the 785 nm radiation at Rattlesnake (46.4N,119.6W); data from Larson et al.*, 1996*

7 Named after Montagne Pelée, Martinique, which erupted on 8 May and 30 August 1902.

occurred: 1981 – Mount St. Helens eruption (USA), Alaid eruption (Aleutians); 1982 – Nyamuragira (Zaire), El Chicon (Mexico); 1983 – El Chicon (Mexico); 1986 and 1987 – Nevado del Ruiz (Colombia); 1988 – forest fires; 1991 – eruption of Pinatubo (Philippines); 1994 – forest fires (south-east Asia). In the case of Pinatubo (June 1991), a well studied event because of its magnitude (McCormick, *et al.*, 1995, Hansen *et al.*, 1996), the global temperature decrease was about 0.5°C.

One of the best known historical examples is the "year without a summer" (1816 in the northern hemisphere) that followed the eruption of Tambora (Java) in 1815 (Stommel and Stommel, 1979). The eruption was widely used as a small-scale analogue of a nuclear winter (Sagan and Turco, 1990). Additional details can be found in Schönwiese (1988), Briffa, *et al.*, 1998 and de Silva, *et al.*, 1998.

8.2.4.3 Local effects

The local effects of volcanic eruptions can also be devastating, for example, no terrestrial species survived the eruption of Krakatoa on 26 and 27 August 1883. The eruption caused more than 35 000 human victims as a result of the tsunami rather than the volcanic eruption directly (McGuire, 1997).

Effects tend to be relatively local only if the ash is not injected into the upper atmosphere. By way of an example, the 1989 (18 May) Mount St. Helens eruption in Washington State reached Idaho and Montana where large quantities of volcanic ash littered the soil to a depth of 1 m in places.

As shown by the eruption of Etna (Chester, *et al.*, 1985) lava flows have the potential to cause structural damage and will destroy any buildings in their path. But most important is the fact that prime agricultural land is rapidly "inundated" and becomes useless for agriculture and other related activities for hundreds of years.

A special mention should be made of the 1986 (21–24 August) "eruption" of Lake Nyos (north-west Cameroon) which was characterized by major CO_2 and H_2S emissions (Youxue Zhang, 1996). The toxic mixture caused about 3 000 deaths and in Nyos village only 2 of a population of 700 survived. Poultry and cattle experienced heavy losses.

The already mentioned Pinatubo eruption on Luzon in the Philippines (1991) covered villages and agricultural land with sterile ashes, to the extent that around 150 000 people were made homeless and 600 000 lost their livelihoods. The ash blanket reached a depth of several metres in the valleys close to the mountain, reducing to an average depth of 5 cm at a radial distance of 40 km. An estimated 5 000 km^2 was affected. Some of the most fertile land in the Philippines had to be abandoned, leading to immediate damage and loss of future income. Mudflows created havoc in flat areas up to 50 km from the crater, by, for instance, clogging fishponds. An estimated 326 000 ha of forest, 43 000 ha of cropland and 16 000 ha of ponds were damaged. Even in 1992, mudflows still occurred and buried crops (Rantucci, 1994).

On the positive side, it should be mentioned that where ash does not exceed 10 cm, it can be ploughed in and will increase productivity due to its pH, P, K, CA and Mg, even if Fe and S are excessive (according to Rantucci). Similarly, Besoain, *et al.*, (1992), found the deposits from the Lonquimay volcano in Chile between 1988 and 1990 had improved local soil quality.

Rantucci provides a detailed breakdown of the total loss incurred to the economy due to the Mount Pinatubo eruption (Table 8.1). Agriculture accounts for 59.7 per cent of the total economic loss, most of it in the forestry sector and in the form of lost revenue.

8.2.4.4 Earthquakes and tsunamis

Apart from disrupting infrastructure and destroying houses, earthquakes have little direct effects on crops. However, they often lead to secondary extreme events causing disasters with a major agricultural component, such as fires, floods, landslides and tsunamis[8].

8 Not all tsunamis are caused by earthquakes on land. The tsunami which badly hit 120 km^2 of coastal areas in West Sepik (Papua New Guinea) on 17 July 1998 was due to an earthquake that occurred in the sea.

Table 8.1
Losses (million US$) due to the July 1990 earthquake and the eruption of Mount Pinatubo in the Philippines. Data from Rantucci, 1994

	July 1990 earthquake		*Pinatubo eruption June 1991*	
	M US$	%	M US$	%
Crops	22.0	38.6	44.7	10.5
Fisheries	16.3	28.6	2.3	0.5
Livestock/poultry	1.6	2.8	4.8	1.1
Irrigation	4.0	7.0	10.6	2.5
Forestry			177.9	41.9
Others, incl. infrastructure	13.1	23.0	4.6	1.2
Foregone revenue			179.6	42.3
Agriculture total	57.0	8.9	424.5	59.7
Infrastructure	273.8	43.0	66.5	9.3
Private property	158.2	24.8	205.1	28.8
Industry/commerce	104.0	16.3	15.3	2.2
Mining	21.1	3.3		0.0
Tourism	22.9	3.7		0.0
Total	637.0	100.0	711.4	100.0

The 1995 (17 January) earthquake at Kobe triggered widespread fires which contributed significantly to the estimated US$ 100 billion damage. About 10^7 m^3 of debris were produced, which had to be disposed of. Also in Japan, the 1933 (2 March) earthquake at Miyagi, killed the same number of people (3 000) as a result of the tsunami that was caused by the earthquake.

Regarding direct losses, an interesting set of data is provided by Rantucci (1994) regarding the earthquake that took place on Luzon on 16 July 1990 (magnitude 7.7 on the Richter scale). Unusually large slip motions (up to 6.2 m in amplitude) were recorded, but most damage was due to liquefaction[9] and landslides. The earthquake is seen as part of the increased geological activity in the area which also includes the Pinatubo eruption.

Table 8.1 is interesting in that it compares the impact of the earthquake with the eruption of Mount Pinatubo which occurred in virtually the same area and at the same time of the year. Thus, the agricultural context is very comparable for both events.

Only 8.9 per cent of the total damage occurred in the agricultural sector, distributed as follows: crops, 38.6 per cent; fisheries, 28.6 per cent and irrigation, 7 per cent.

Rantucci also provides data on other disasters which have affected the Philippines[10]. During the period 1987 to 1991, the damage from cyclones amounted to US$ 1.5 billion, the same order of magnitude as that caused by the earthquake and the Pinatubo eruption of 1990 and 1991.

8.2.4.5 Snowstorms and avalanches

Snowstorms and avalanches normally occur outside the cropping season and, therefore, do not normally affect crops, except winter crops. However people, cattle, pasture, etc. are at risk. The February and March 1995 snowstorm in Nagqu prefecture (northern Tibet) affected 130 000 people, although financial damage was relatively limited due to the low development level of the region. Grasslands were hit badly by what was estimated to be the worst snowstorm in 50 years, leaving hundreds of people and just under 3 million head of livestock stranded and in danger of freezing to death.

One of the worst recorded avalanches occurred in 1970 in Peru, where 18 000 people died.

9 Some earthquakes cause fine-grained materials such as sand to behave like liquids, causing buildings and other objects to sink into the ground.

10 The cost to the Philippines (returning residents, increased oil price) of the 1990–1991 Gulf Crisis amounts to 380 million US$. The GNP of the Philippines was 28.6 billion US$ in 1990.

Landslides and mudslides are usually associated with heavy rains, but also with earthquakes, dam failures and volcanic eruptions. In the latter case, it is often rainfall on recently fallen volcanic ash that constitute the main source of the disaster, often entombing whole villages and sweeping away crops and agricultural land.

Two Central American examples of land- and mudslides associated with earthquakes are the following: in 1986 (10 October) in San Salvador, an earthquake and landslide made 300 000 homeless; in 1987 (5 and 6 March) an earthquake in north-east Ecuador was followed by mudslides which buried several villages.

One of the most well known examples of mudslides associated with a volcanic eruption occurred in 1985 (13 November) in Armero, Colombia, after the eruption of the Nevado del Ruiz, when 25,000 people died. The village of Armero was totally engulfed by a torrent of mud when the La Lagunilla River burst its banks. Around 11 000 ha of agricultural land was ruined. Snowmelt due to the lava flow was one of the main causes of the disaster (Nardin, 1989).

Landslides typically occur after long spells of heavy rain in areas of hilly terrain and marked seasonal rainfall patterns (dry/wet), as in Uttar Pradesh (India) during August 1998. At this time 200 people perished and “terrace cultivated” crops and the terraces themselves underwent serious damage.

8.2.4.7 Dam failtures

Databases of disasters include a number of examples of dam failures, and it is surprising that the subject does not receive more attention. In many cases, dams are not made from concrete and simply take the form of storage reservoirs holding less than 5 Gm^3 of water which is used for irrigation and drinking water. The failure of these structures leads to loss of land and often to loss of habitat, and sharply reduces irrigation potential.

Some of major dam failures have occurred in China, for instance in 1975 (August) at Banqiao and Shimantan, Huai River, Henan province. The number of deaths was 230 000. The two dams had been built in the 1950s. Within two hours of the nearly simultaneous bursts 85 000 people had died. An additional 145 000 succumbed in ensuing epidemics and famines.

In 1993 (27 August) there was a dam failure in Qinghai province, western China, north of Tibet. Although it held only 2.6 Gm^3 of water, the breaching of the dam at the Gouhou reservoir caused “big losses in lives and property” to nomadic herders and farmers in the semi-arid high-elevation plateau region.

8.5.2 Other non-geophysical factors

Epidemics are mentioned because they are frequently triggered by unfavourable conditions at least partially due to weather. The transmission of diseases – especially vector-borne diseases – is weather dependent. In addition epidemics are associated with other disasters such as floods. An example was mentioned above under the 1993 Gouhou dam failure.

Torrential storms in the early 1300s in Asia are often quoted as one of the remote causes of the plague which began in China and eventually reached Europe in the 1340s via trade routes. The disastrous black plague resulted which killed one third of the European population (McNeill, 1989).

Human epidemics are mentioned also because they interfere with almost all farming activities, frequently giving rise to secondary famine. For a general overview of human health and climate, refer to McMichael, *et al.*, 1996.

8.5.6 Very rare factors

Although they may affect agriculture, often with an indirect weather component, the following are probably not relevant in quantitative terms in the current context: transportation accidents (aeroplane crashes, railroad accidents), mining accidents and building collapse in urban areas.

Several cases of industrial explosions are known to have severely affected populations and farming. For instance, the 1984 (2 December) methyl isocyanate gas leak from a pesticide plant in Bhopal (India) killed 3 000, injured 100 000 and affected about 250 000 people. Agricultural impacts were limited (7 000 cattle killed) but damage to the natural environment remains largely unassessed (Shrivastava, 1996).

The well documented dioxin release at Seveso (Italy) on 1976 (10 July) affected 36 000 people but killed large numbers of domestic fowl and pigs population. The most affected area has been sealed off ever since (posing some novel institutional and legal problems). It is estimated that the dioxin will have biodegraded by 2040 (De Marchi, 1996).

A very rare event occurred in June 1908 at Tunguska where a meteorite impact took place in a deserted area of Siberia. The explosion of a stony asteroid, probably 10 km across, took place 10 km above the ground (roughly equivalent to 15 mega tonnes of explosive, or 1 000 Hiroshima bombs), levelling 2 000 km^2 of forest; its radiance caused widespread fires.

8.3 INFORMATION TO BE STORED IN THE DATABASE

The following is a proposal for a database of extreme agrometeorological events. As indicated in the introduction, we adopt a somewhat broader approach – that of a database of agricultural disasters of geophysical origin, including man-made disasters with an atmospheric or hydrological component.

The basic idea behind this section is that a database of extreme agrometeorological events should comprise three separate, but cross-linked, sections for each "event":

(*a*) The precise description of the geophysical factors that caused the event;
(*b*) The precise description of the impacted system before the event; and
(*c*) The precise description of the impact (losses), in quantitative terms.

All variables will be geo-referenced.

8.3.1 Definition of an event

The "event" is the elementary database unit (record). A disaster can be regarded as an event, or as a succession of events. For instance, the 16 July 1990 Luzon earthquake can be treated as a whole, or each of the successive shocks, which lasted for months, can be treated as a separate event.

The event thus defines the timescale of the database unit. In addition, the spatial scale must be provided: a disaster can be analyzed for the sake of convenience by administrative units or by physiographic or other logical units, including agro-economic or agro-ecological zones.

The event must be "impact oriented" to avoid difficulties when the source and the target of complex events are different. For instance, the "Chernobyl accident" occurred at precise geographic coordinates (130 km north of Kiev), but the impact, which constitutes the raison d'être of the database occurred all over Europe. Therefore, the event would be best defined a "Chernobyl impact in Ukraine", "Chernobyl impact in Germany", etc.

It might also be decided to treat impacts and extreme factors separately, particularly if impacts of the same extreme factors have been felt at different times and in different areas. This will, however, require a very comprehensive spatio-temporal description of the extreme event (which is not always possible or relevant).

8.3.1.1 Name/code of event

This is the conventional name of the event, for instance "1845–46 Irish potato famine", or "Chernobyl nuclear accident".

8.3.1.2 Type of event

The typology of extreme events has been discussed. It constitutes an essential description of the event. Included in this description must be references to the complexity of the event and the time and spatial scales.

8.3.1.3 Location of event

This can be a point or a polygon of coordinates.

8.3.1.4 Timing of event

The timing and duration of the event must be given including any long-term effects which sometimes extend over decades.

8.3.1.5 Links to other events

This item provides the opportunity of vertical and horizontal links. Vertical links can point to a major causal event (e.g. "1997–98 El Niño"), while horizontal links would include pointers to events due to the same cause, for instance tropical cyclone Gilbert (9–19 September 1988) affected Central America, Jamaica, Grand Cayman, Yucatan, Mexico, Texas and a number of other locations – which may all have been treated as separate events. Or the tropical cyclone which affected Bangladesh on 24 and 25 May 1985 may have been dealt with as a separate event from the accompanying tsunami, which would make a lot of sense since the affected areas were both different and rather well circumscribed.

8.3.2 The three database components – thematic description of impacted system

The wording "thematic" refers to the agricultural or environmental description of the impacted system, the spatial extent of which was covered under 8.3.1.3. This item constitutes one of the weak links in current impact assessments.

8.3.2.1 First component: description of the production system

In a previous CAgM report, we underlined the factors which must be taken into account (Gommes, 1997), in particular the types of crops (varietal information if possible) and the stage of growth.

It is essential that long-term effects, including recovery, be adequately covered.

The role of agricultural research stations in extreme-factor prone areas cannot be over-emphasized as they constitute one of the most valuable sources of data for quantitative impact data, risk assessments and impact forecasting. Contrary to a common practice, observations must be continued after the event hits the station. This is because 100 per cent loss is very rare. Many crops somehow recover under new agronomic and phytosanitary conditions; a situation which is difficult to model in the absence of data.

8.3.2.2 Second component: description of extreme factor

As with the description of the production system (8.3.2.1), it will be difficult to provide specific items under this heading until such time as an agreed typology is available. It should be stressed that the dynamic aspects of extreme factors must be properly covered, including an estimate of return periods.

In the absence of actual measures of the intensity of the most violent extreme factors such as tropical cyclones and earthquakes, impact-oriented intensity indices constitute invaluable tools. These indices can combine several aspects of the destructive power of the factor or a complex of factors. Palmer's Drought Index, or the Sapphir-Simpson Scale used for hurricanes are more useful in quantitative impact and risk assessment than for pure geophysical measurement. It is often overlooked that many common "scales" (Mercalli and Richter scales for earthquakes, or the Beaufort wind scale) are empirical impact-oriented scales.

The less violent extreme factors (drought, cold spells) can usually be expressed in terms of normal routine meteorological observations, although the above-mentioned indices are often very relevant as well.

8.3.2.3 Third component: impact assessment

Impact assessments currently constitute one of the weakest points on the path leading to a more quantitative and systematic approach. There does not appear to be a standard methodology and, even when assessments have been carried out objectively, the description of the impacted system and of the extreme factor are often insufficient. We stress again, the role of agricultural research stations in the acquisition of relevant data.

Production loss

This includes both the immediate loss and the long-term losses of agricultural production.

Damage indices would be extremely useful, for instance the Typhoon Damage Index for crops (DI_c) quoted by Jose (1994):

$$DI_c = 0.37\ V^{1.11}$$

where V is the sustained windspeed in km/h. Similar indices are available for a number of applications, including ozone effect on wheat (Finnan, *et al.*, 1997).

Environmental losses We include soil erosion, loss of biodiversity, etc. under this item.

Socio-economic impact Essentially the financial loss by agricultural sectors.

Other aspects Other aspects are important. It would be useful to include an analysis of how the disaster was managed, how the management increased or reduced losses, the quality of assessments that were done at the time, how the government managed the crisis – suppression, confidentiality, recognition, amplification, etc.

8.3.3 Sources of data

Understanding the sources of data is crucial. Comprehensive impact assessments are rarely available. Much contradictory information becomes available via the media while the event is happening but final figures are rarely broadcast. Impact assessments prepared by governments are often biased because they are conducted immediately after events in order to obtain assistance. Among other shortcomings, they rarely include long-term effects. It is common to find that different sources quote vastly different estimates of casualties, particularly for events that have affected extensive areas and more than one country (a good example is the tropical cyclone that affected West Bengal and Bangladesh on 12 and 13 October 1970, where the total number of casualties is virtually impossible to determine).

Part of the problem stems from the lack of commonly agreed terminology and typologies. Take "people affected", an indicator occurring in most existing disaster databases and, in one form or another, in most descriptions and analyses of disasters. The same applies to "hectarage affected" or "agricultural production loss" – not only do different authors adopt different definitions, but the area, to which the data refer, usually corresponds to administrative units where an official emergency has been declared, ignoring adjacent districts.

Finally, extreme care must be exercised for many man-made disasters, where non-technical motivations often dominate and for which a critical assessment of the reliability and neutrality of the sources is essential.

8.4 CONCLUSIONS AND RECOMMENDATIONS

As indicated in the introduction, it is suggested that a database of extreme agrometeorological events does not make much sense, as the event becomes "agrometeorological" only when it affects agriculture, i.e. when we have a disaster. The database should thus be one of agricultural disasters resulting from extreme geophysical and man-made factors with an atmospheric component.

Almost all extreme events are likely to affect agriculture, although geophysical factors, by their sometimes large geographic extent, have the potential to lead to the greatest damage in terms of instantaneous and medium-term production losses.

Regarding methodology, the following points are underlined:

(*a*) The need to develop a proper typology of impacts as the first step in the definition of data requirements and the improvement of impact and risk assessments and forecasting.

(*b*) The need to develop two types of indices, by typology, as tools for impact and risk assessments. One index describing the "global" intensity of extreme factors in the within a specific category of disaster; and the other relating elementary extreme events (for example maximum instantaneous wind speed) with observed agricultural damage.

(*c*) The need for agricultural research stations and agrometeorological stations to continue and intensify their observations after the occurrence of extreme events, in order to provide badly needed quantitative impact and factor data sets.

(*d*) Regarding the structure of the database, there should be three separate, but cross-linked, building blocks:

(*i*) The precise description of the geophysical factors that caused the event;

(*ii*) The precise description of the impacted system before the event; and

(*iii*) The precise description of the impact (losses) in quantitative terms.

All variables should be geo-referenced.

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CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS

(by H.P. Das)

9.1 CONCLUSIONS

Extreme events due to both atmospheric and non-atmospheric factors take a heavy toll in deaths and inflict much suffering, and there are consequent substantial losses in productivity, including to crops and livestock. Extreme natural events illustrate an important aspect of the complex process by which people interact with biological and physical systems. Every parameter of the biosphere is subject to seasonal, annual, or daily fluctuations – constituting hazards to people. But human adjustments to the frequency, magnitude, or timing of extremes are based on rather imperfect or inadequate knowledge. If there were perfectly accurate predictions of what would occur and when it would occur in the intricate web of atmospheric, hydrologic and biological systems, there would be no hazard. However, there would still remain the question of how to respond effectively to the completely predictable order of events. Ordinarily, extreme events can only be foreseen as probabilities whose time of occurrence is unknown.

The hazard accompanying the occurrence of the rains for dry-land farmers or the duration of peak river flow for a floodplain located manufacturer or the magnitude of the infrequent but certain earthquake for a fault-zone dweller is a significant element in decisions which many individual users of the environment must make on a daily, seasonal, or yearly basis. The more common extreme geophysical events are avalanche (snow), coastal erosion, drought, earthquake, flood, frost, hail, landslide, lightning, snow, tornado, tropical cyclone, volcano and wind.

The study of agricultural meteorology or climatology has enabled people to have an insight into the effects of weather and climatic elements on agriculture. The role of various extreme climatic events that affect agricultural production negatively has now been understood to some extent. In themselves, weather extremes are not necessarily hazardous, although they may become so if they prevail for prolonged periods of time. This accumulative effect of weather extremes is evident in cases of droughts, heatwaves and floods. The atmospheric factor may fulfil a variety of roles in the development of hazard situations. A broad distinction can be made between phenomena such as tropical cyclones, tornadoes and lightning which involve the sudden impact of massive amounts of energy discharged over an extremely short time, and those features which become hazards only if they exceed tolerable magnitudes within or beyond certain time limits. In this latter category can be included wind hazards associated with extra tropical low pressure systems, heatwaves, snow, heavy rain, frosts and droughts.

Thresholds and qualitative effects characterize a number of plants and animals with regard to their response to weather factors. Well-known examples are the effect of temperatures on rice sterility and the breaking of stems and branches of certain rubber cultivars by wind. Windstorms and tropical storms (hurricanes and typhoons) with very high winds can destroy fields of cereal within minutes and reduce the yield. It is also observed that plantations suffer more direct damage than natural forests. Of course, root and tuber crops and creeping plants suffer very little from hurricanes/tropical storms, while tree crops and cereals may be badly hit. Similarly floating rice varieties are characterized by very fast growing stem elongations which can keep pace with rapidly rising water during floods.

Other hazardous climatic events include widespread and local thunderstorms, tornadoes, squall lines, hailstorms and weather related wildland fires which sometimes cause havoc to agriculture and forestry. Climate and its extremes are also responsible for the growth and development of pests and locusts which can badly affect plants. Earthquakes, volcanic eruptions and landslides, although belonging to geological events, are likely to result in losses to forestry or agricultural operations.

By taking anti-disaster preparedness measures in advance and thereafter by undertaking systematic post-disaster rehabilitation, the effects of most of the dreadful natural calamities can be mitigated considerably. Valuable work in this direction is already being done in many countries. Although natural calamities cannot be averted, their destructive impact in terms of loss of human and animal life and the upset of the ecological balance can, no doubt, 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 the globe in disaster prone areas. In addition to local and national action, international and regional cooperation should be promoted for enhanced prevention and mitigation.

On account of the vast similarities of situations arising out of geographical factors, social and economic conditions, it would be advantageous to undertake specific case studies of work done in the prevention and mitigation of extreme events in different countries of the Asian and Pacific regions in particular, which are more prone to frequent disasters than to other regions. This will bring out features common to a number of countries, which can be duly considered.

Finding out how these responses to extreme events differ from place to place and from time to time helps understand the way one system affects another. It also alllows us to know how these relationships can be changed for the benefit of the people who suffer from severe events. If the means of enabling individuals to take intelligent action or governments to design and carry out effective programmes are to be improved, it is essential to gain greater knowledge of the processes by which people do, in fact, cope with the hazards of nature. That is the aim of the collaborative programme of research on natural hazards.

9.2 RECOMMENDATIONS

9.2.1 Information systems

(1) There is a need for the maintenance of observational networks and their enhancement to accurately depict extreme events and their impact on agriculture.
(2) Efforts should be made to strengthen the links between the information generators and the users of agrometeorological information and provide training to information users.
(3) Agrometeorological services in developing countries should be strengthened through the placement of more automatic weather stations to overcome the problems of data quality and observer biases. Remotely sensed data can be used to fill the gaps, where they exist.
(4) Reliable ground networks are still necessary in the light of the need to provide ground truth for remotely sensed observations.
(5) Radar coverage should be extended to more areas affected by extreme events.

9.2.2 Monitoring, early warning and remedial measures

(1) In addition to longer term strategies, short-term remedial programmes should be put in place for dealing with immediate problems such as soil erosion, salinization or famine, designed to alleviate their more immediate manifestations.
(2) The monitoring of certain extreme events should be undertaken continuously throughout the year and over the entire country. In this way early warnings can be made of anomalies in the hydrological conditions of the soil, the spatial extent of such anomalies can be plotted and governments can be alerted.
(3) In the case of extreme events such as tropical cyclones, warnings should be regularly updated and be more specific regarding time and place of landfall, maximum wind strength to be expected, the expected intensity of rains and the areas most liable to storm surge. By arrangement with the authorities, warnings should be so worded as to indicate clearly the nature of the action that should be considered by those to whom the warning is issued.

(4) In the event of disasters such as earthquakes, volcanic eruptions, floods, cyclonic storms, etc. it would be appropriate for each local authority to set up a permanent "Disaster Preparedness Committee" which would include appropriate experts from every sphere of life.

9.2.3 Methodology development

(1) Standard methods of impact assessment should be developed and disseminated for use by meteorological services.

(2) Practical applications should be generated from successful case studies on ways to combat extreme events, taking into full account matters of environment and sustainable development.

9.2.4 Training, education and increased awareness for the general public and decision makers

(1) Given emerging developments in the monitoring of extreme events, the evaluation of their impacts and the need for a rapid diffusion of this information, training sessions should be organized to train trainers, development agencies and NGOs and end users.

(2) There is a need to raise environmental awareness among the local population. Local environmental issues should be integrated into school curricula and local methods should be employed in the monitoring of the management of extreme events.

9.2.5 Collaboration and cooperation

(1) Collaboration with CIMO, FAO, GCOS and with conventions such as UNCCD and UNFCC should be enhanced.

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