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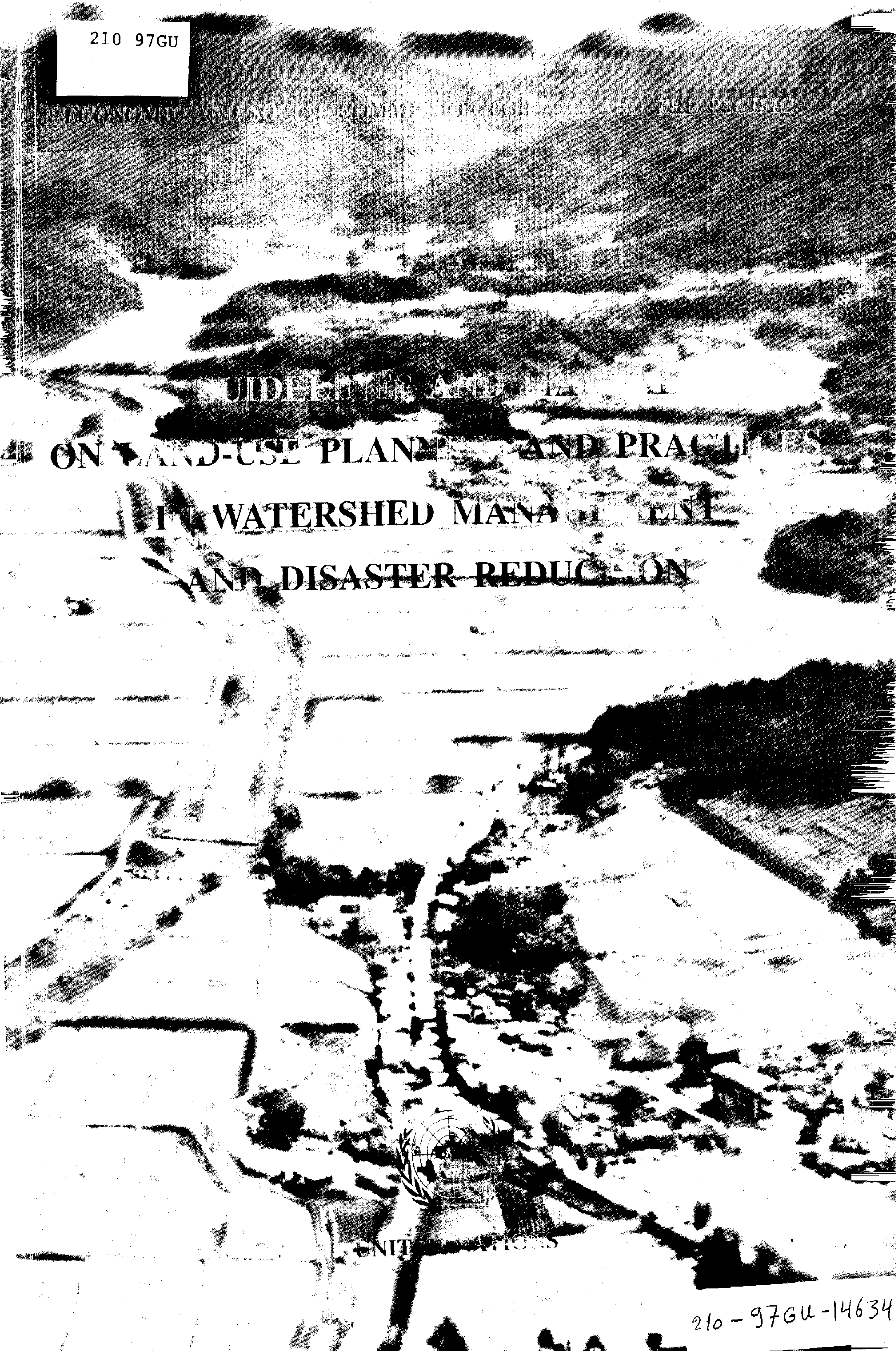

GUIDELINES AND MANUAL ON LAND-USE PLANNING AND PRACTICES IN WATERSHED MANAGEMENT AND DISASTER REDUCTION

UNITED NATIONS

ECONOMIC AND SOCIAL COMMISSION FOR ASIA AND THE PACIFIC

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Cover photograph: Woocheon Small Watershed Development Project, Haeng Sung County, Gongwon Province, Republic of Korea (courtesy of Farmland Rearrangement Division, Ministry of Agriculture and Forestry, Republic of Korea)

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PREFACE

Resolution 50/117 on the International Decade for Natural Disaster Reduction, adopted by the General Assembly on 20 December 1995, called upon Member States, relevant intergovernmental bodies and all other organizations involved in the Decade to participate actively in the financial and technical support of Decade activities, in order to facilitate the full integration of disaster reduction into the substantive efforts for sustainable development and environmental protection by the year 2000. The need to mitigate the effects of frequent natural disasters has become more and more acute in the ESCAP region, which in many parts has experienced, during the past two decades, rapid economic growth rates, together with rapidly growing populations. The need for integration of water-related disaster reduction measures into national water resources development and management programmes has therefore become more urgent.

Since the Earth Summit in 1992 that established Agenda 21, a great deal of progress has been made by many countries in the region in relation to water resources development and management and the integration of these activities into the national social and economic development process. In terms of development planning, the incorporation of land-use planning at the national, regional and local levels has added a new dimension to the planning process for the integrated development of water resources. Similarly, with respect to natural resources management, the adoption of river basins, instead of administrative divisions, as the units for water resources or watershed management, has introduced a new challenge in governance. In order to deal effectively with the new dimension in development planning and to meet successfully the new challenges in natural resources management, the promotion of improvement in land-use planning and practices for better watershed management and disaster reduction, on the one hand, and sharing of experiences among the countries in the region, on the other, is essential. The project on Land-use Planning and Practices in Watershed Management and Disaster Reduction was conceived and formulated in that context at the request of the Committee on Environment and Sustainable Development at its Second Session held in Bangkok in October 1994. With the financial support of the Government of the Netherlands, the project was implemented by ESCAP in 1996/1997 and this publication is one of the main outputs of the project.

In the implementation of the project, the great diversity of Asia and the Pacific has been reflected in new perspectives on land-use planning to a considerable extent. For this purpose, experiences in land-use planning and practices were drawn from the development processes in the region. The compilation of experiences in the region started with a detailed technical overview prepared by the ESCAP secretariat and the preparation of case studies based on experiences gained in the Republic of Korea by Mr Huh Yoo-Man, in Indonesia by Mr Mochammad Amron and in Malaysia by Mr Liew Chin Loong. Subsequently, a draft Guidelines and Manual on Land-use Planning and Practices was drawn up, based also on experiences in Australia, by Mr George Whitehouse, the international consultant, in association with Professor John Burton, for discussion at the workshop in Bangkok in March 1997 comprising experts nominated by the participating countries and collaborating international agencies. At the workshop, expert representatives presented the experiences of their respective countries, reviewed and finalized the draft Guidelines and Manual and recommended it for application in the participating countries.

It is hoped that the publication will contribute to strengthening the related mechanisms and networks to provide sustained support for the application of land-use planning and practices to the development process in the region. Such support is needed at the local, national and regional levels and it is expected that this project has played its part in linking the catalytic role of ESCAP to the existing mechanisms and networks at these three levels.

The contributions of all the expert representatives at the workshop to finalize the Guidelines and Manual, especially those included as the regional experiences, are deeply appreciated. Special acknowledgment is also made of the instrumental role played by Mr George Whitehouse as the project international consultant, and his associate Professor John Burton, for the timely completion of the Guidelines and Manual.

INTRODUCTION

Integrated watershed management has come to be recognized internationally as an important holistic approach to natural resources management, which seeks to promote the concept of sustainable development. Such an integrated approach has been recommended in Agenda 21 for all sectors dealing with the development and management of water resources. The present publication was initiated as part of the ongoing effort of the Water Resources Section of ESCAP towards the sustainable, integrated development of the water resource systems of the region. Such effort requires a systematic and strategic integration of water resources development and management activities into the social and economic development process. In that context, sustainable land use forms an overall planning framework, whilst sound land-use planning concepts, together with the adoption of appropriate land-use practices, provide key guidelines for land and water resources development and management, which should be undertaken with the integrated objectives of reducing natural disasters, boosting productivity and achieving sustainable development.

Sound land-use planning methods and practices can be developed from an end-use standpoint, such as social and economic development of national or regional planning, or from a sectoral point of view, i.e. in the context of development planning for various sectors such as agriculture, forestry, mining and water resources. There are strong linkages in planning between the two viewpoints; national and sectoral, between the two levels; national and regional, and among the various sectors. Integrated land-use planning aims to address these linkages. In this publication, an attempt is made to systematize important elements of these linkages, and especially the links between national and sectoral planning, to form a basis for better planning in the fields of land use and water resources development. The important elements of these linkages include the management system, financial resources, institutional and legal frameworks and community participation. The publication also identifies key areas which help to focus the land-use planning process towards the effective reduction of water-related natural disasters and also towards improved watershed management. Although it deals, to a certain degree, with land-use planning at the national development level, no attempt is made in the publication to consider regional development planning methodology as a guide for national socio-economic development. This step, however, is believed to be necessary to ensure that all land-use planning undertaken for watershed management and disaster reduction fully incorporates the main thrusts of national socio-economic development, as derived from regional development methodologies. The case studies of individual countries included in the publication are intended to provide useful examples of such a planning process.

The publication also attempts to make an overall, state-of-the-art review of appropriate land-use practices, in order to provide key information about watershed management and hazard assessment techniques as a basis for establishing future land-use options. In addition, the publication includes some details and references regarding advanced planning techniques.

The publication consists of six chapters, arranged in two parts. Part I contains the Guidelines, and Part II the Manual. The Guidelines comprise Chapter I, which discusses the relationships between land-use planning, disaster reduction and watershed management; Chapter II, which explains the categories of watershed degradation; Chapter III, which explains the categories of water-related natural disasters; and Chapter IV, which discusses the principles of integrated watershed management. The Manual comprises Chapter V, which is concerned with data collection and evaluation for watershed management and natural hazard assessment, and Chapter VI, which describes a variety of options for watershed management and hazard reduction.

This publication was prepared primarily to assist decision makers, planners and practising engineers to manage land and water resources in an integrated manner, in order to achieve better and sustainable watershed management, to coordinate land and water resources development activities with the development activities of other sectors, and to adopt an ecosystem-oriented foundation for the prioritization of water-related development activities. The publication is also intended to serve as a reference for planners and practising professionals working in other sectors when dealing with watershed-related development projects.

PART ONE

THE GUIDELINES

I. THE RELATIONSHIPS BETWEEN LAND-USE PLANNING, DISASTER MITIGATION AND WATERSHED MANAGEMENT

A. The role of land-use planning in environmental management and natural disaster reduction

To a greater or lesser extent, all countries in the ESCAP region are vulnerable to water-related natural disasters. Such disasters may be caused by cyclones, floods, land instability and drought. From time to time they cause widespread death and injury, extensive property loss, substantial environmental damage and serious disruption of the economies of the stricken countries. Despite significant efforts to reduce the effects of these disasters, their frequent occurrence continues to affect an increasing number of people, to result in the diversion of scarce capital for relief and rehabilitation services and activities, and to contribute to falling living standards.

Burgeoning population growth, along with intensified agricultural development and the accelerating expansion of urban centres, contribute to a steady increase in the magnitude of actual and potential disaster losses. An ever-increasing proportion of national populations live in areas which are susceptible to water-related disasters. These additional numbers of people put escalating demands on limited natural resources, leading to over-exploitation of resources and increasing degradation of the natural environment.

When basic natural resources such as land, forest and water are utilized to provide employment, yield sustenance to rural communities and contribute to export earnings, they may not be developed and managed in an environmentally sustainable manner. As most of the available good quality arable land is already densely populated and fully utilized, agricultural expansion is being forced into marginal and fragile lands which are susceptible to significant degradation. Unsound development in such areas has the potential to cause serious disturbance of natural ecosystems and produce major impairment of the natural environment.

A frequent consequence of poor land use, aggravated by the occurrence of such water-based natural disaster events as tropical cyclones and floods, is soil erosion. On upland watersheds, such developmental land-use practices as deforestation, cultivation and the destruction of native vegetation can lead to accelerated soil erosion. Steeply-sloping forested land, when cleared of the protective cover of vegetation, is highly susceptible to soil erosion and landslip. In areas where the soil structure is fragile, the extent of soil erosion can be so serious that the potential agricultural productivity is irreversibly impaired. Eroded material may be transported downslope into rivers and streams, leading to the choking of channels with gravel, sand and sediments. This in turn may influence the frequency and severity of flooding, increasing downstream damage.

The adverse effects of land degradation are both insidious and cumulative. Not only can urban and rural populations be directly affected, but these effects can also impact on overall national prosperity and welfare. Even in areas subject to more gradual and less obvious erosion, there will be an inevitable and progressive reduction in soil fertility and productivity unless the land is developed and managed within its capability.

In recent years there has been an increasing recognition of the need for new approaches to the management of land and water resources, aimed at the control of degradation, the long-term, sustainable utilization of natural resources and the maintenance of the quality of the natural environment. Efforts to understand the interaction between natural hazards and the environment, the choices societies may make to increase or reduce the risk of disasters, and the community's ability to predict, control and limit the impacts of disaster events, are all part of rational environmental management.

The periodical occurrence of water-based natural disasters cannot be avoided. It is far more rewarding and effective to direct government and community effort towards the mitigation of damage than towards disaster response, relief and recovery. Damage minimization approaches, such as the elevation and relocation of buildings, or the construction of flood protection works and other structural measures, can be integrated with a range of non-structural measures. By way of example, in urban areas with existing concentrated development where removal to another location is impracticable, a combination of structural and non-structural measures can be employed to protect existing development.

For such measures to be fully effective, an integrated, river-basin wide approach is needed. Such an approach, called integrated watershed management, involves the adoption of a coherent management system for land, water and vegetation which can ameliorate the adverse impacts of natural disasters and help to achieve the sustainable use of the natural resources within a watershed. This approach recognizes that such factors as urban and agricultural development, the loss of wetlands, land drainage schemes, forest clearance and other activities carried out in the watershed, even though well away from river channels, can increase the volume and rate of run-off and worsen flood conditions. Accordingly, integrated watershed management involves the coordinated use and management of land, water, vegetation and other bio-physical resources within the entire watershed with the object of ensuring minimal land degradation and erosion and causing minimal impact to water yield and quality and other features of the environment.

B. Mitigation of water-related disasters through integrated land-use planning and management

Although it is not possible to avoid the occurrence of natural disasters, their physical impacts can be reduced through appropriate mitigation strategies. In many circumstances, wise land-use planning and management can be effective in reducing the adverse consequences of water-related natural disasters. On the other hand, the vulnerability of land to such hazards as flooding or landslip can be increased as a consequence of environmental degradation resulting from unwise land use and the uncontrolled exploitation of natural resources.

By way of example, the indiscriminate clearing and cultivation of virgin lands and the extension of traditional farming practices may lead to extensive soil erosion, landslip and sedimentation. These forms of land degradation across a watershed may result in the rapid concentration of surface run-off and increased susceptibility to flood hazards and landslides. Alternatively, other kinds of land-use change can alter run-off behaviour by reducing the amount of long-term flow in rivers and streams and so increasing the severity of droughts.

Just as there may be adverse consequences of poor rural land use, intensive urban development may also contribute to increased disaster hazard. Such development can, for example, influence the hydrologic behaviour of small urbanized watersheds by concentrating run-off and increasing the peak rate of discharge. On the floodplains of large rivers, badly located urban development can expose lives and property to the increased risk of damage from inundation by floodwater.

One approach to the mitigation of the severity of floods is to retard the rate of run-off from natural watersheds. In rural areas, this can be accomplished by adopting conservation practices directed towards the increased infiltration of storm rainfall and the surface detention of flood run-off. In small urban watersheds, run-off can be retarded by providing onsite detention storage facilities, using such techniques as the provision of lot storage and the use of parking areas and sporting fields to detain storm run-off.

Land-use regulations can be used as an effective means of reducing the damage associated with natural disasters. In the context of floodplain occupation, land-use regulations attempt to minimize the effect of flood disasters by balancing land uses with flood risk. Restrictions are placed on the nature and location of urban and industrial development and the type and extent of agricultural activity. To be fully effective, such land-use control measures should be introduced in combination with other forms of disaster reduction drawn from the range of available structural and non-structural measures.

The most efficient way to deal with water-related natural disasters is to plan for their control or mitigation on a whole-of-catchment basis, taking a broad, catchment-wide view of the causes and effects of disaster occurrence. This approach is an aspect of what is termed integrated watershed management.

C. Requirements of a comprehensive watershed management system

The terms watershed, catchment, drainage area and river basin are all used to describe a land surface from which water flows downhill to a specified point on a watercourse. It is determined by topographical features which include a surrounding boundary or perimeter which is known as a drainage divide, beyond which water flows away into another catchment or catchments.

In North America, the term "watershed" is restricted sometimes to mean a comparatively small catchment, or sometimes to mean the upland, water-yielding portion of a larger river basin. In British Commonwealth countries it is sometimes restricted to mean "drainage divide". In this document we will use it to be synonymous with catchment or river basin, particularly in the context of "integrated catchment management", which clearly implies a whole-of-catchment approach to natural resources management.

Integrated watershed management can be defined as the coordinated, planned and sustainable management of the natural resources within a river basin. This approach to the management of land, water, vegetation and other natural resources seeks to maintain or enhance the quality of the catchment environment and, by adopting a variety of physical, social and economic policies and techniques, all aimed at minimizing the adverse consequences of natural disaster events, to improve and enhance the quality of life of the catchment community.

Watersheds are naturally occurring units of the landscape, which contain a complex array of inter-linked and inter-dependent resources and activities, irrespective of political boundaries. A watershed can be perceived as an integrated ecological system, and its effective management requires the adoption of a systems approach in which the complex interrelationships between the development of natural resources, the integrity of the ecosystem, and the quality of the watershed environment have to be understood and accounted for.

By way of illustration, the amount of watershed run-off is affected by precipitation rates and amounts, evaporation, transpiration and infiltration, as well as the nature and density of vegetation and the water-holding capacities of the soil. Activities such as logging, grazing, agricultural development and road building result in the removal of vegetation, which can result in increased run-off. This may produce soil erosion and salinity problems, which in turn affect water supply and quality. Chemical pollutants and effluent from agriculture and industry are transported by water run-off, often attached to eroded soil particles. Thus there is a clear association between land-use decision-making, natural resources utilization and the quality of the watershed environment – with a systems approach, the likely adverse consequences of mismanagement can be anticipated and appropriate precautions taken to minimize or avoid their effects.

A watershed is a dynamic and integrated social, economic and bio-physical system which may contain people, urban and rural communities, agriculture and forestry, primary and secondary industry, communications, services and recreational facilities. The land resources of soil, water and vegetation cannot be managed for quality and sustained availability in isolation from each other or from the watershed environment. The natural balance of these resources can be easily disrupted by changes in land use, by mismanagement or simply through bad planning.

The watershed is the logical unit for coordinated land-use planning and management and effective and sustainable resource and environmental management. Integrated watershed management should aim:

1. To encourage effective coordination of policies and activities of relevant agencies, authorities, industries and individuals which impinge on conservation and the sustainable use and management of the country's watersheds including soil, water and vegetation;

2. To ensure the continuing stability and productivity of soils, a satisfactory yield of water of high quality and the maintenance of an appropriate protective and productive vegetative cover; and

3. To ensure that land within watersheds is used within its capability in a manner which retains, as far as possible, options for future use.

If the preceding principles are adopted and implemented, the following benefits can be anticipated:

- reduction in the rate of sedimentation in major dams, rivers and harbours
- reduction of run-off and damaging floods
- conservation of soil fertility and the maintenance and improvement of agricultural productivity
- maintenance and improvement of water quality
- reduction in soil salinity and acidity
- protection of wildlife habitat
- increased public awareness of the inter-relationships within watersheds and identification of land capability
- maintenance and improvement of tree and vegetation cover.

D. Land-use planning principles

Land use constitutes a fundamental mechanism for development and land-use planning can therefore serve as a guiding tool to direct development efforts towards prosperity and sustainability. Over past centuries, interactions between man and nature have greatly influenced land-use planning philosophies, concepts, principles and methodologies. Land-use planning concepts have evolved from a single-purpose approach to a more complex orientation, first directed increasingly towards sectoral needs, resource management goals and ecosystem values, and then more recently incorporating integrated and holistic development approaches (see figure 1). This evolution in land-use planning has developed from the recognition that land-use planning provides a forum within which land-use management options can be identified and developed, on the basis of a coupling of the management needs of resources and watershed ecosystems with development objectives.

As the development objectives become more and more complex, land-use planning has to deal with complex and multi-dimensional interactions. In the spatial dimension, three scales are generally recognized as requiring the formulation of different but related sets of goals for land-use planning, *viz.*, (a) the national or international scale, (b) the basin or regional scale, and (c) the local or micro-watershed scale. Although these scales are only relative, they are set apart on the basis of the priority issues which require to be dealt with at each level. For example, at the national scale, the priority issues might include economic and social expectations, environmental aspirations and regional development patterns. At the basin scale, watershed management might be oriented towards ecosystem stability and biodiversity objectives. And finally, at the local level, issues may be more related to specific management options. Land-use planning is a process, and interaction between planning activities at all three levels is essential

FIGURE 1. TYPICAL LAND-USE PLANNING PROCESS

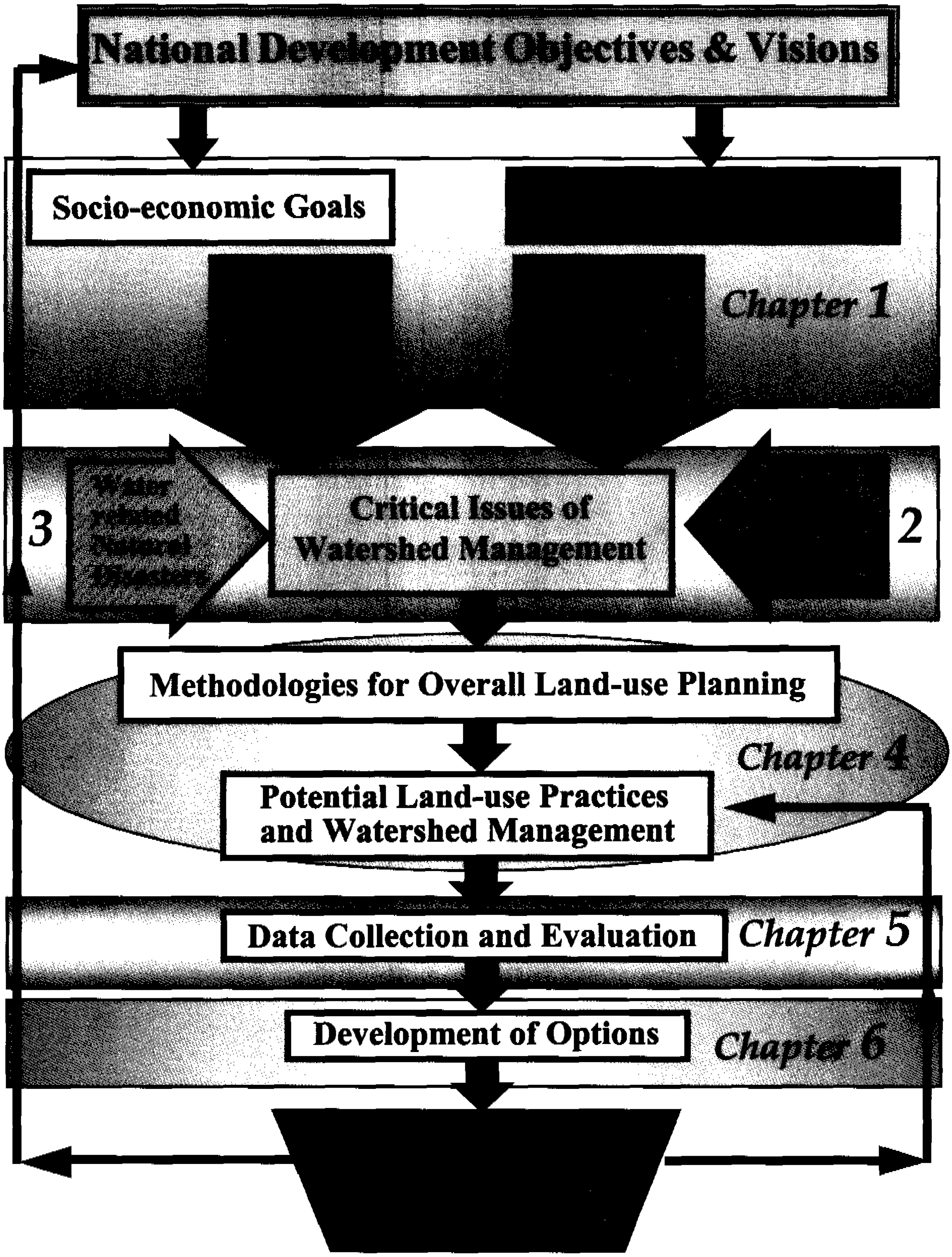


Photo 1: A typical model of integrated watershed development in the Republic of Korea

Photo 2: A recent flood in Cambodia

to ensure the effective achievement of development objectives and improved knowledge of the inter-related ecosystems. In essence, land-use planning should adopt both a proactive and a preventive approach towards integrated development objectives at all levels.

1. Land-use planning principles at the national scale

Past experience demonstrates that physical and socio-economic planning can no longer be undertaken independently, and attempts have been made to develop appropriate approaches for the integration of planning and resource management systems. Such approaches emphasize the introduction of spatial components into national strategies and policies, the integration of resource and environmental management activities, the inclusion of human/spiritual development, and ready access to decision-support information. These components are all in the processes of development planning at all levels of government administration.

Such approaches to land-use planning at the national level need to be based upon the following sets of principles:

(a) Principles for the planning process;

(b) Principles for the planning role;

(c) Principles for planning integration.

The planning process needs to observe the following principles:

(a) Adopt a holistic approach;

(b) Recognize man as the focus of development;

(c) Plan for multi-dimensional activities;

(d) Seek qualitative and quantitative changes;

(e) Ensure equitable distribution and utilization of resources.

Land-use planning forms an overall framework for physical planning towards the achievement of balanced development. The principles for the planning role include the following:

(a) Translate socio-economic and other policies into spatial and physical forms – to attain this strategy, all socio-economic policies have to be evaluated according to their spatial and physical implications;

(b) Emphasize the importance of environmental quality in physical planning;

(c) Provide facilities to ensure an equitable and higher standard of living for all;

(d) Planning policies should take into consideration the latest developments in science and technology, which in turn can help towards achieving a higher quality of living.

The principles for the integration of land-use planning need to focus on two integrating links:

(a) Integration between socio-economic development policies and physical planning – the interpretation of sectoral socio-economic policies in spatial form. This is achieved primarily through the preparation and implementation of various types of development plans at different levels of administration;

(b) Integration between environment and physical planning – undertaken in a holistic and systematic manner, and incorporating the necessary instruments to plan for sustainable development. At the local level, efforts will be made to minimise adverse environmental effects arising from development.

THE MALAYSIAN EXPERIENCE[1]

In the Malaysian context, a sustainable community is the fundamental objective of the Malaysian Vision 2020. To achieve Vision 2020, which is based upon the underlying premise of attaining balanced communities, a comprehensive and universal planning doctrine has been formulated. This "Total Planning Doctrine" is a guiding principle for development planning processes. The doctrine calls for the sustenance of three relationships – between man and his Creator, man and man, and man and his environment – in order to achieve balanced development, a prerequisite to achieving a sustainable community. The doctrine postulates that man is the focal point for development. As part of the planning processes, accurate and timely indicators for key policy variables, particularly performance indicators which measure conditions and changes in human settlements, are required. As such, steps are taken to develop land-use performance tools which will provide better understanding of the relationship between performance of the individual sector and broadened social and economic development outcomes. Identification of indicators for measuring sustainability of development plan is carried out at two levels. The first involves the identification of ***land-use planning criteria for sustainable development.*** In this respect, the goals of sustainable development are used, i.e. resource conservation, built-environment in harmony with natural environment, environmental quality and social equity. The second involves the identification of ***land-use planning criteria for sustainable community.*** To this end, ***the principles of sustainable community*** have been chosen, i.e. respect and care for community of life and quality of human life, conserve Earth's vitality and diversity, minimize depletion of non-renewable resources, keep development within Earth's carrying capacity and change personal attitudes and practices. Malaysia has also adopted an Integrated Planning and Resource Management approach which manifests the global need for sustainable development and places emphasis upon the integration between environmental and physical planning. This is further strengthened by the need for spiritual development and the availability of easy access to physical planning information. To ensure wide acceptance and full support from the public, Malaysia has been exercising a consultative process at all levels in order to get opinion from the public, based on the moderation approach, on all aspects before any decision is made. The success of realizing sustainable community is largely dependent on the extent of commitment from the public and the local government. Thus, people empowerment and decentralization of power to the local government are the major agendas being addressed in Malaysia.

1 Extracted from "Planning Practices in Malaysia" prepared by Puan Hajjah Norasiah Bte Hj. Yahya, representative of the Federal Department of Town and Country Planning, Peninsular Malaysia for discussion at the Workshop on Guidelines and Manual on Land-use Planning and Practices in Watershed Management and Disaster Reduction, Bangkok, Thailand, 18-21 March 1997.

2. Land-use planning principles at the basin scale

The basin scale of land-use planning offers the most logical and effective approach to integrated resource management and natural disaster reduction. One of the most commonly accepted principles of the river basin approach to development planning and management is that the integrated utilization of land and water resources provides an effective means for the concurrent achievement of development objectives and ecosystem integrity. It does so by recognizing and considering not only physical and biological processes, but also the social context, all at the basin scale. The principles of land-use planning at this scale are governed by the integrity of the basin ecosystem, characterized by various physical and biological processes; the social, economic and environmental context of development in the basin; regional and national level objectives; and advances in planning and management technology. These principles need to be elaborated into development methodologies, strategies and policies and supported by a coordinated programme of data and information collection. Land-use planning at this level is regarded as the central theme of these guidelines, and is elaborated in more detail in Chapter IV.

THE EXPERIENCE OF THE REPUBLIC OF KOREA[1]

In the Republic of Korea, the prediction of future socio-economic changes within the country has been found to be of major importance for watershed management planning. The development of a river basin usually takes several years. In rapidly developing countries like this one, the economic and social structures can change very rapidly and various new demands for watershed development can emerge whilst development projects are being implemented. The Republic of Korea has experienced many such changes including industrial structural change, migration of population from country to urban areas, sky-rocketing increases in labour costs and land value, run-off increases due to urbanization, and water quality degradation, all in a relatively short period. Those changes were too large and too rapid to be predictable at the planning stage or at the commencement of watershed development projects. The socio-economic changes strongly altered the expected impacts of the development projects. New development projects have had to be initiated upon the completion of previously planned projects in order to meet rapidly increasing demands for water resources and land development. Environmental conservation has come to be a more and more important aspect for consideration in the context of watershed management and water resources development in this country. Water quality in the watersheds is becoming degraded through various natural and man-made causes, whilst efforts to protect the watersheds through the application of appropriate practices have lagged behind the pace of development. The effective development and management of watersheds clearly needs to be based upon reasonable expectations of forthcoming socio-economic issues, including changing environmental concerns.

1 Extracted from "The Comprehensive Keum River Basin Projects as a Case Study for Watershed Management and Disaster Reduction in the Republic of Korea" prepared by Huh, Yoo Man for discussion at the Workshop on Guidelines and Manual on Land-use Planning and Practices in Watershed Management and Disaster Reduction, Bangkok, Thailand, 18-21 March 1997.

3. Land-use planning principles at the local scale

At the local scale, successful implementation of land-use management options provides the driving force for integrated watershed management and sustainable development. The principles adopted for land-use planning at this level may include the following components:

(a) Integrated utilization of natural resources;

(b) Sustainable farming systems;

(c) Interactive and pro-active community farming systems;

(d) Community participation;

(e) Conservation measures;

(f) Development of models for sustainable land-use systems.

A sustainable farming system needs to focus on the social conditions, especially poverty alleviation, and may include the following components:

(a) Food component;

(b) Fodder component;

(c) Fuel component;

(d) Income generation component (which is supported by house-hold production systems.)

The interrelationships and interlinkages among the components of the farming system need to be analysed and treated in a holistic manner. These components will be discussed in more detail in subsequent chapters as important elements of sound and integrated watershed management.

THE INDIAN EXPERIENCE

Guidelines for watershed management developed by the Ministry of Rural Development of India stipulated the following purposes of watershed management:

(a) To promote the economic development of the village community which is directly or indirectly dependent on the watershed through: (a) optimum utilization of the watershed's natural resource such as land, water, vegetation, etc. that will mitigate the adverse effects of drought and prevent further ecological degradation, and (b) employment generation and development of the human and other economic resources of the village in order to promote savings and other income-generation activities.

(b) To encourage restoration of ecological balance in the village through (a) sustained community action for the operation and maintenance of assets created and further development of the potential of the natural resources in the watershed, and (b) simple, easy and affordable technological solutions and institutional arrangements that make use of, and build upon, local technical knowledge and available materials.

(c) To place special emphasis on improving the economic and social condition of the resource-poor and disadvantaged sections of the Watershed Community, such as the assetless and the women, through (a) more equitable distribution of the benefits of land and water resources development, and the consequent biomass production, and (b) greater access to income generating opportunities and focus on human resource development.

It was also expected that each Watershed Development Project would achieve the following results by the end of the project period:

(a) The completion, with the active participation and contribution of the user groups, of all the works/activities that are planned for the treatment and development of the drainage lines, arable and non-arable lands in the watershed area.

(b) The taking over by the user groups of the operation and maintenance of the assets created, and the making of suitable administrative and financial arrangements for their maintenance and further development.

(c) All the members of the Watershed Development Committee, and staff such as Watershed Secretary and Volunteers, to have been given orientation and training to improve their knowledge and upgrade technical/management and community organizational skills, to a level appropriate for the successful discharge of their responsibilities on withdrawal of the Watershed Development Team from the Project.

(d) The village community to have been organized into several homogeneous groups for savings and other income generation activities which achieve sufficient commitment from their members and built up sufficient financial resources to be self-sustaining.

II. CATEGORIES OF WATERSHED DEGRADATION

A. The meaning of land degradation

The ecological diversity of the many thousands of watersheds to be found in the ESCAP region ranges across an extremely broad spectrum. Watershed conditions can range from wet tropical rain forest to arid desert and from equatorial heat to alpine cold. The richness of their natural resources of soil, water and vegetation varies enormously, ranging from the rich and fecund to the poor and barren. The past management of these resources, and the degree and nature of their exploitation, along with the stability and robustness of the ecosystems in which they occur, has resulted in a widely varying degree of land, resource and ecosystem degradation. Here again, the level of land degradation to be encountered also ranges over a very wide spectrum, ranging from the pristine to the very severely damaged.

The degradation of land is a multi-faceted phenomenon, which can be manifested in a variety of forms. It is generally accepted to mean deterioration of the land surface, either by the accelerated removal of soil, the progressive alteration of soil properties, or the loss of vegetative cover from soil. Some of the causes of land degradation are natural, being the consequence of disaster events such as floods, bushfires or drought, whilst others are the consequence of human activities, such as overgrazing, deforestation or poor agricultural practices. Land degradation can itself aggravate the damage caused by natural disasters, by such means as increasing flood run-off or increasing the potential for serious soil erosion. Land degradation is therefore the consequence of a multitude of causes and effects which all contribute to the reduction of the value of the land for human and ecological purposes.

In this publication, land degradation is classified into three major categories, each of which has a number of sub-categories, as listed below.

(a) Ecosystem alteration, including changes to vegetative cover and composition and the introduction of plant and animal pests, which can be classified into the following sub-categories:

- (i) Deforestation
- (ii) Land clearing
- (iii) Weed invasion
- (iv) Introduction of animal pests
- (v) Loss of wetlands

(b) Soil erosion and deposition, including processes which transport soil and deposit it elsewhere, which can be classified into the following sub-categories:

- (i) Water erosion
- (ii) Wind erosion
- (iii) Siltation and sedimentation
- (iv) Mass movement of soil
- (v) Coastal erosion

(c) Soil degradation, involving the alteration of soil properties *in situ,* which can be classified into the following sub-categories:

- (i) Soil salinity
- (ii) Degradation of soil structure

(iii) Soil fertility decline

(iv) Soil acidification

(v) Waterlogging

(vi) Soil pollution

Each of the sub-categories of land degradation listed above is to be found at various locations within the ESCAP region. At these locations, each of them is a consequence either of unsound or inappropriate watershed land use or of natural disaster occurrence, the effects of which may have been exaggerated or accelerated by land mismanagement. In particular, in the context of this document, land degradation can occur wherever the natural balances in the landscape are altered by development for agriculture, mining, forestry, industry or urban settlement, or for infrastructure such as roads, railways, dams, power stations, pipelines and transmission lines.

The most immediate and obvious *in situ* consequences of land degradation are evident as major changes to soil, vegetation and fauna populations, along with progressive and sometimes total loss of the productivity of the land itself. Within a watershed, land degradation also has *off site* effects, which will include sedimentation of streams, impaired water quality and increased severity of flooding and drought.

In a few words, degraded land can be defined as land which has lost some or all of its value for human use. This implies acceptance of the concept that land is a resource, requiring careful management if it is to retain its resource values. On the basis of this concept, we can enunciate a basic principle of conservation land use:

"to use the land according to its potential, yet conserve it according to its needs."

B. Ecosystem alteration

1. Deforestation and land clearing

Many forms of watershed degradation are evident as some form of direct damage to the soil. In the case of soil erosion and deposition, for example, the effects of degradation are manifested in the loss or transfer of soil, which has direct consequences in reducing the productivity of the site. In the case of soil degradation, the effects are manifested in a deterioration in the *in situ* properties of the soil, again with direct consequences in terms of reduced productivity. In the case of ecosystem alteration, however, the immediate consequence is a deterioration in the quality of the entire ecosystem which the land unit under threat supports. The effects will be manifested in a loss of vegetative biomass, a reduction in vegetation productivity and species diversity, and an impairment of habitat for native flora and fauna, as well as the secondary consequences of water and wind erosion and other forms of soil degradation that will be an eventual result of the reduced or impoverished vegetative cover.

Deforestation is here taken to mean the large-scale removal or partial removal of trees from forested areas, which may be deliberate or due to natural causes. Deliberate causes of deforestation include commercial logging, firewood production, clearing for agricultural or timber plantation purposes, "slash and burn" techniques of shifting agriculture, and clearing for such purposes as urban development or the development of infrastructure such as dams, road, railways or mining facilities. Natural causes of deforestation include wild fire, predation by a variety of pests and parasites, disease, damage by pest animals or grazing animals and human traffic or occupation.

Forests shield the soil surface from heavy rainfall, reduce the rate of run-off by increasing the rate of infiltration and as a consequence decrease the amount of flooding, mitigate soil erosion and limit the sedimentation of rivers. They can also act to control landslides and other forms of mass movement of the land surface.

On the other hand, deforestation of watersheds, especially around smaller rivers and streams, can increase the severity of flooding, reduce stream flows by lowering the watertable and increase sedimentation of rivers. Accelerated erosion, soil salinization and impairment of water quality are other common adverse consequences of deforestation. These secondary forms of degradation and ways and means for controlling or mitigating them will be discussed in some detail in later sections of this chapter.

The factors contributing to deforestation can all adversely affect land and water resources. The loss of protective tree cover has resulted in erosion, landslides and the silting of rivers and dams, as well as increased flooding downstream. The loss of trees also results in reduced organic matter and the loss of nutrients from the soil by leaching. This leads to further degradation of the quality and extent of forest cover. The destruction of trees on steep slopes and along the banks of rivers and streams can significantly increase erosion and sedimentation problems in the lowland areas of watersheds. In the ESCAP region, the rate of deforestation is a major factor contributing to watershed degradation and the increased severity of water related natural disasters. Until comparatively recently, the rate of deforestation in areas of tropical rainforest has been a cause for much national and international concern. There are also countries where the rate of removal of temperate forest and woodland is a matter for concern. Such concern has been heightened by a widespread community perception of the significance of forests in the mitigation of global Greenhouse effects, as well as increasing international concerns for nature conservation and the widespread adoption of sustainable development principles.

Land clearing is here taken to mean the large-scale removal of vegetation from woodlands, shrublands and grasslands in order to use them for such purposes as grazing, cropping or irrigation development. This form of activity is practised in low to marginal rainfall areas where the climatic and soil conditions are not suitable for forest growth but there is potential for large-scale crop or livestock production. As with deforestation, the removal of vegetation makes the land susceptible to water erosion and wind erosion, the latter in particular being a major potential problem in arid and semi-arid areas. Other associated adverse effects may be various forms of soil degradation as a consequence of cropping or irrigation practices, as well as potential invasion and damage by pest species. As is also the case with deforestation, extensive land clearing involves a loss of ecosystem productivity and diversity and the destruction of habitat for native flora and fauna.

Like the other forms of watershed degradation already discussed, land degradation due to deforestation or land clearing occurs as the direct consequence of poor or inappropriate land-use practices and can be avoided through the application of sound land-use planning and management principles. Good management implies sound overall ecosystem management, a process which requires the striking of a balance between economic objectives for productive land use and ecological objectives for the maintenance of ecosystem quality and diversity. Putting it another way, this kind of approach requires the adoption of an ethic of ecologically sustainable development, which in itself is the essence of the integrated watershed management approach.

2. Loss of wetlands

A wetland is an area of land which is partly or wholly inundated by shallow water for part or all of the time. The water in a wetland is normally slow moving or stationary and may be fresh, brackish or saline. In the context of this manual the concern is with natural wetlands, as distinct from artificial wetlands which have been constructed for a variety of purposes which might include water treatment and water quality management, flood control, fish breeding and production, waterbird breeding and production or the cropping of wetland plant species.

Until about twenty years ago, natural wetlands were often considered waste land of little value, which was frequently drained and "rehabilitated" for use in agricultural production or for urban and industrial development. Throughout the ESCAP region there has been a progressive loss of wetlands to such purposes. More recently, it has begun to be appreciated that natural wetlands possess a wide range of valuable attributes and play a key role in many ecological, biological and environmental processes. Many Governments are now taking positive steps to manage existing wetlands more effectively and preserve and restore degraded wetlands. Application of the integrated watershed management approach involves an appreciation of the role of natural wetlands and the development and implementation of appropriate wetland management policies as an integral part of the overall catchment management programme.

Wetlands are the habitat for a wide and diverse range of animals including waterbirds, frogs, invertebrates and fish species, as well as a variety of water-adapted plants including grasses, rushes and tree species. As the border between aquatic and terrestrial environments, they become strategic refuge areas in times of drought, often providing a haven for endangered species. They provide important breeding and nursery areas for a large range of animals including birds, fish and invertebrates. Estuarine wetlands, including mangrove swamps and salt marshes, form an important link in the productivity of estuarine and offshore fisheries, a majority of coastal fish species spending part of their lives in such areas. Seasonally flooded inland wetlands provide major breeding grounds for water fowl.

Wetlands can have a major effect on water quality downstream, acting as sediment basins, filters and sinks for nutrients that would otherwise cause river and lake eutrophication and trigger algal blooms. Because of their ability to absorb nutrients from water and promote nutrient cycling through plant take-up, wetlands can become highly productive ecosystems, characterized by seasonal changes in plant mix and grazing patterns for a variety of wildlife and domestic animals.

Natural wetlands may have significant effects on the hydrology of a watershed and its river system. They can be effective flood detention storages, reducing flood peaks downstream and attenuating the floodwave pattern. Wetlands may also act as groundwater recharge areas, particularly in upland areas where water is retained in wetland storage for long periods and can gradually percolate into underlying aquifers.

If properly managed, natural wetlands can provide valuable opportunities for agricultural, pastoral and forestry production. In drought periods, wetlands can provide grazing when other areas are depleted. Ephemeral wetlands, often dry for long periods, can provide opportunities for extensive grazing and intermittent crop production. Wetland timbers may provide sawlog and firewood sources. Both inland and estuarine wetlands are extensively used by indigenous peoples as sources of food and water and centres of cultural activity. In urbanized and industrialized regions, natural wetlands provide important sites for a variety of recreational and cultural activities.

The loss or degradation of wetlands may be due to a variety of causes, which may be natural or man-made and direct or indirect. Direct losses are principally the result of deliberate decisions to divert water away from wetlands and drain them so that they can be used for agriculture or for urban and industrial development. Such decisions are driven either by population pressures or by profit motives and stem from a lack of appreciation of the intrinsic ecological and environmental values of wetland ecosystems. In recent years there has been a growing recognition by governments of the importance of wetlands, accompanied by the introduction of regional, national and international policies and agreements requiring the preservation and proper management of natural wetland areas.

Whilst these changes have retarded the rate of loss of wetlands through development pressures, loss and degradation of wetlands still occurs through indirect causes which largely relate to poor management of wetland catchments. Extensive soil erosion on such catchments, as a consequence of the use of inappropriate farming practices, overgrazing or deforestation, causes progressive siltation of wetlands downstream and is a major source of wetland degradation. Both point and non-point pollution sources on wetland catchments, introducing excessive quantities of nutrients or toxic substances, can also be major causes of wetland degradation. On larger river basins, upstream diversion of water for purposes such as domestic or industrial supply, and particularly large-scale irrigation, can also be a major cause of wetland degradation. Regulation of streamflow for such purposes, or the construction and operation of large upstream reservoirs for flood control, can also be highly damaging to wetlands, interfering with the cyclic sequence of flood periods and drought periods on which many wetland ecosystems depend.

Effective protection of wetlands from these indirect forms of degradation or loss requires the adoption of an integrated watershed management approach in which the various beneficial values of wetland systems are recognized and appropriate control measures are developed and implemented. In particular, land-use planning and control and the general adoption by land users of appropriate land-use management techniques are all essential tools for effective wetland preservation and management.

3. Other forms of ecosystem alteration

Other forms of ecosystem alteration which are an indirect consequence of human activity or inappropriate land use include invasion and damage by a variety of pests, which may include diseases, insect predators, weed species or feral animals. These pests, in their turn, may produce secondary effects of soil erosion and deterioration and ecosystem degradation.

An outstanding example of this form of degradation is the case of the rabbit pest in Australia. Introduced in the mid-nineteenth century for sporting purposes, the rabbit bred explosively and soon spread throughout the southern part of Australia and subsequently through arid and semi-arid areas across the continent. It has since caused enormous damage through overgrazing and burrowing, being a major factor in the initiation of water and wind erosion as well as the degradation of grassland ecosystems and the destruction of the habitat of many small native animals. It has been classified as the cause of the most serious and widespread land degradation in Australia and many billions of dollars has been spent on attempts at its control. Despite the partial success of the disease *Myxomatosis,* introduced in the 1950's, and more recently the *Calicivirus* virus, in achieving large-scale biological control, the rabbit remains a major threat and a potential cause of continuing and widespread land and ecosystem degradation.

Throughout the ESCAP region, a variety of other exotic and feral animals, including feral goats, pigs, buffalo, horses and camels, cause problems of overgrazing, vegetation removal, soil disturbance and consequential water and wind erosion. In many areas, a wide variety of weed and pest species of exotic plants cause very substantial ecosystem alteration and impairment and indirectly result in serious land degradation, loss of habitat and significant reduction in agricultural productivity.

This form of land degradation may not necessarily be the result of poor or inappropriate land use; as in the example of the Australian rabbit, it may be a consequence of the accidental introduction of a pest species or even direct introduction for what seem at the time to be perfectly valid reasons. Frequently, however, land-use decisions have led indirectly to the creation of conditions which greatly favour the establishment and flourishing of various pest species and lead subsequently to various severe forms of land degradation and ecosystem impairment. Such decisions would include the adoption of changed land-use practices, such as extensive deforestation or shrubland clearing to permit cropping or grazing activities, which may provide augmented potential for the establishment and spread of pest species. Land-use policy changes therefore need to be made with careful consideration of their likely adverse environmental and economic consequences.

C. Soil erosion and deposition

1. Erosion processes

Erosion is the wearing away of the earth's surface by natural or artificial processes. Under natural conditions it occurs at a spasmodic but slow rate, under the influence of water, wind or gravity. This process is termed "geological erosion" or "natural erosion". Throughout history, human activity has from time to time caused disastrous erosion and consequential land degradation and loss of land productivity, sometimes over very extensive areas. This process is called "accelerated erosion" or simply "soil erosion".

Within the ESCAP region, soil erosion is the most widespread and most serious problem of land degradation. It is particularly extensive in the more arid countries of the region, affecting vast areas of Northern China and Australia. It also occurs at many locations throughout the humid and tropical areas of the region, wherever extensive deforestation, land clearing or agricultural development occurs or where steep land has been cleared for mining or urban development. Its most serious consequence is a reduction in the productivity of agricultural land, potentially a major problem because the population of the region depends upon agricultural production for its food and fibre needs.

2. Water erosion

The most widespread form of soil erosion is water erosion. Water erosion is a complex process involving the detachment of particles from the soil, followed by their transportation and subsequent deposition. The process is an intermittent and episodic one, occurring principally at times of heavy rainfall, overland flow and stream flooding. The rate at which it occurs depends upon many factors, which include climate, weather, soil characteristics, topography, plant cover and land use.

There are several forms of water erosion which include raindrop splash erosion, sheet erosion, rill erosion, gully erosion, tunnel erosion, and streambank erosion. The initiating mechanism for surface erosion is heavy rainfall, during which the impact energy of raindrops breaks up soil aggregates and causes detached particles to move laterally by splash action. On sloping land, there is a net movement of soil particles downhill, which is then further aggravated as overland flow begins and promotes particle transport further downslope. The extent of the erosion is greatly affected by the size and impact energy of the raindrops, the soil structure, the steepness of slope and, particularly, the nature and amount of plant cover available to shelter the soil surface from raindrop impact. Without plant cover to reduce impact energy and assist in binding soil particles together, the rate of erosion will be greatly accelerated.

If heavy rainfall continues, the further detachment and transportation of soil particles downslope will develop through the processes of sheet and rill erosion. Sheet erosion is the comparatively uniform removal of surface soil across a significant area and involves the processes of separation, entrainment and lateral movement both by raindrop splash and by turbulent overland flow. It is usually associated with rill erosion, a process which develops when overland flow becomes concentrated into small channels or rills, as is usually the case except on the very smoothest of surfaces. The term is appropriate when the erosion channels are so small that they can be obliterated by tillage practices; larger erosion channels are called gullies and these are formed by different mechanisms, which are further discussed below.

Rill erosion involves the entrainment and transport of soil particles from the rill channel walls and floor and is caused predominantly by the erosive force of the run-off flowing down the rills. It occurs on comparatively uniform slopes as well as slopes which are uneven and variable in slope and micro-topography. It is usually combined with sheet erosion, the latter occurring on the inter-rill surfaces and transporting detached material into the rill channels, where further transport and additional erosion occurs. Rill erosion is usually the most obvious form of upland surface erosion and the bulk of the downslope movement of eroded soil occurs through transport by rill flow. The factors which determine the rate of rill erosion are complex, but include the rate of surface run-off, the depth of overland flow, the structure and physical characteristics of the eroding soils, and the length and steepness of the eroding slope.

Sheet and rill erosion have the direct effect of removing topsoil and causing the loss of nutrients and organic matter, leaving an unproductive surface which is difficult to cultivate and substantially impairing agricultural productivity potential. These forms of erosion occur most commonly on cropping

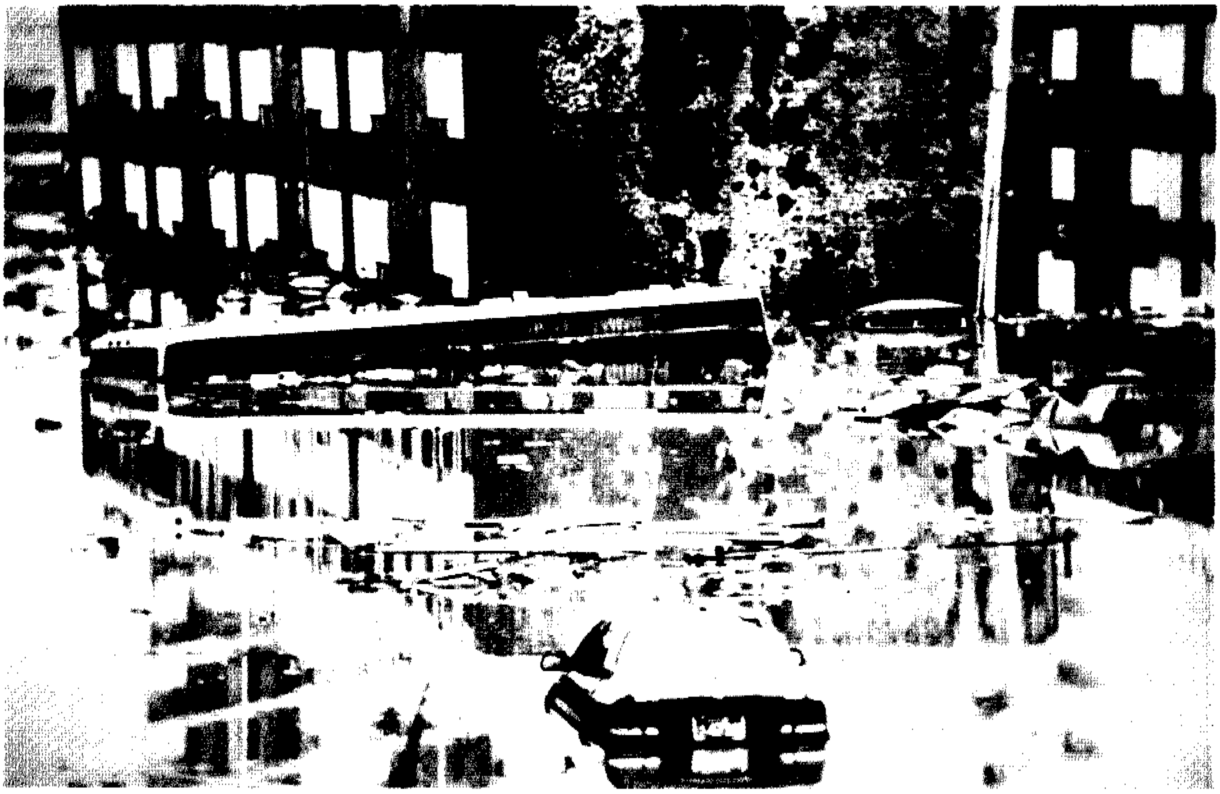


Photo 3: **For intensively developed urban areas and floodplains, land-use planning and control measures have an important role to play in flood mitigation strategy (Moosan City, Kyungkido Province, Republic of Korea)**

Photo 4: **Drought may have devastating social and economic consequences for both local and national communities (Kyungkido Province, Republic of Korea)**

Photo 5: Exposed tree roots: a consequence of wind erosion when cover vegetation is sparse and strong winds blow across sandy or silty soil surfaces

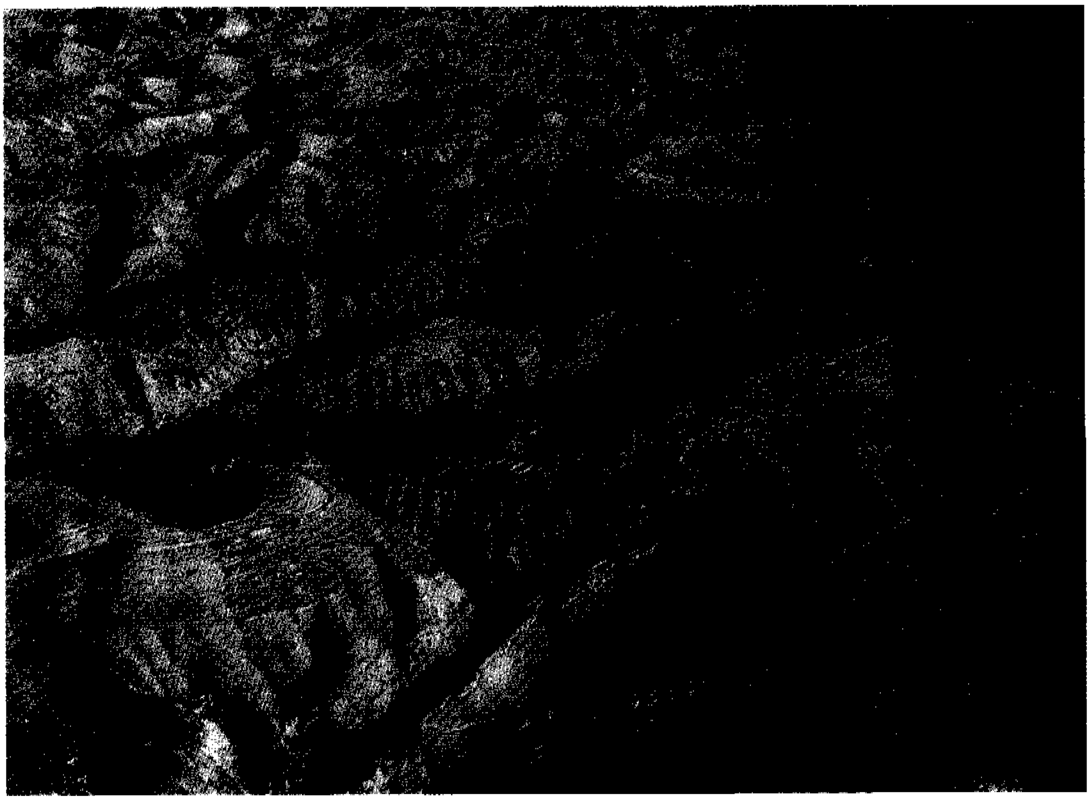


Photo 6: Soil erosion is the most serious and widespread form of land degradation, as exemplified by this gully erosion on the loess hills of central China

lands, particularly where clean tillage and long fallow cultivation methods are employed. They can also occur on grazing land which has been seriously denuded by overgrazing or any land left bare of vegetation by deforestation, clearing or drought conditions.

Further downslope, as rates and volumes of run-off and quantities of transported sediment increase, larger-scale erosion processes begin to occur. Gully erosion is essentially a macro-scale version of rill erosion which results in the form of large, incised erosion channels too big to be filled by normal cultivation practices and too wide and deep to be crossed by farm machinery. The classification of gully erosion is usually applied when the depth of the incised channels exceeds 300 mm, although depths of 10 m and more may be experienced under severe erosion conditions.

Gully erosion involves a number of interacting processes which depend upon climate, soil type, topography and land use. It is initiated in minor drainage lines when normal equilibrium is upset by concentration of water flow or locally decreased resistance of soil to detachment or transport. It develops by two major mechanisms – gully head erosion, which is caused primarily by concentrated flow over the gully head and is the process by which the gully lengthens and moves upslope, and gully side erosion, which can be caused by diffuse over-edge inflow, interflow and groundwater seepage, undercutting, flow along the gully and raindrop erosion, and is the process by which the gully widens and deepens. As a gully extends upslope the catchment area contributing to head erosion reduces, and uphill movement may eventually stabilize. On the other hand, the rate and amount of over-edge inflow and sub-surface inflow may increase concurrently, enhancing the side erosion process and causing deepening or widening of the gully so long as its capacity to transport eroded material downstream is not exceeded.

Gully erosion can result in the loss of considerable areas of productive cropping or grazing land. It causes significant increases in farming costs, because it makes the operation of farm machinery and the management of livestock more difficult. It also produces serious off *site* effects, resulting from the movement and deposition of sediment, as described below.

Because of their size and areal extent, eroded gullies can remove and transport downslope very large quantities of material. If a stream or waterway does not exist downstream to transport this material further down the watershed, a sediment fan will be deposited at its lower end. This can render a substantial area of agricultural land unproductive and may damage farm infrastructure and public facilities such as roads and irrigation or drainage channels. Disturbed flow across the fan deposit may initiate further instability lower down the slope, leading to extended multi-channel or compounded gully development. If the gully discharges into main watershed drainage system, movement of sediment into stream channels will occur, to be eventually deposited further downstream causing river sedimentation or accumulating silt in lakes and artificial reservoirs, with consequential adverse effects on flooding, river and lake productivity and reservoir storage capacity and a general impairment of downstream water quality.

Tunnel erosion is an unusual form of erosion, because it involves the removal of sub-surface soil by water whilst the surface soil layer remains relatively intact. This produces long, tunnel-like cavities below the surface, which enlarge until parts of the surface collapse inwards, leaving holes and depressions which may eventually develop into open gullies.

Tunnel erosion may occur under land systems ranging from equatorial rainforest to semi-arid rangeland. The erosion tunnels may vary in diameter from a few centimetres to several metres, and their formation depends upon the availability of a sub-surface water velocity and flow rate sufficient to produce entrainment and transport of soil particles along the tunnel cavities. Tunnel formation is initiated by soil cracks, discontinuities between soil horizons, rodent burrowing or accelerated interflow and groundwater seepage into gully walls. The erosion process is aggravated by any processes that increase soil permeability within or between soil layers and is particularly serious in dispersive soils which entrain readily and can be transported at very low velocities.

Tunnel erosion reduces agricultural productivity and increases farming costs. It is particularly serious if it develops into gully erosion extending over a large area, when it can be the cause of significant land degradation.

Streambank erosion involves the removal, transport, and deposition of bank material along streams and rivers. It is a episodic process associated with flood events, initiated by bank scouring during high velocity streamflows, perhaps assisted by wind and wave action. Streambank erosion and deposition are part of the normal processes of stream geomorphology, which also include bed scouring, sediment deposition, and sediment re-entrainment and re-deposition. These processes occur naturally without human intervention, although their extent and their effects and consequences may be aggravated and accelerated by a variety of human activities.

Streambank erosion occurs when the stresses applied by streamflow energy exceed the shear resistance of the streambank materials. The mechanism usually involves scouring and removal of the lower sections of the bank face, particularly along its toe, which leads to collapse of the overlying bank material and its subsequent entrainment and transport downstream by the flowing water. Major factors influencing the rate and amount of bank erosion are the velocity, flow rate, flow depth and duration of the flood flow causing the event; the height and slope of the streambank; the properties of the streambank material; the curvature and plan shape of the stream channel, which influences the direction of erosive flow onto the bank; the existence of natural or artificial features which cause localized increases in flow velocity or concentrate flow against the bank; and the nature and extent of vegetative or other protection or armouring of the bank face.

Streambank erosion occurs most extensively on floodplain reaches and its most direct adverse consequence is the total loss of prime agricultural land. Bank erosion may also damage or destroy bridges, roads and other infrastructure, which may have much more serious economic consequences than the loss of agricultural land. The eroded material provides a source of sediment for deposition further downstream, where it may reduce stream capacity and increase flooding damage. Eroded sediment will also provide a source of sediment for silt accumulation in reservoirs and behind weirs and other control structures, as well as producing an impairment in downstream water quality.

The occurrence and severity of streambank erosion can be strongly influenced by land use on the watershed and along the stream banks. Poor land-use practices and inadequate land-use planning and management on the watershed above an erosion site can increase the rates and volumes of flood events. It can also bring down an accumulation of debris or sediment which may aggravate erosion at critical locations. The nature of the land use along the river bank above potential erosion sites, and the nature and amount of vegetative protection along the bank alignment, may also determine the extent of erosion damage and its economic consequences.

The land degradation caused by each of the forms of water erosion discussed above is directly or indirectly a consequence of poor or inappropriate land use. The single most important factor is the existence or otherwise of a suitable vegetative cover, which provides protection against raindrop impact and splash erosion and minimizes the effects of other erosive mechanisms. Land-use practices which involve the destruction or clearing of vegetation and the direct exposure of the soil surface to water erosion processes are particularly likely to result in severe erosion and substantial land degradation.

Watershed land-use planning and the application of appropriate land-use management techniques on the watershed therefore provide a range of important and significant ways and means for the control of water erosion induced land degradation *in situ,* as well as the minimization or mitigation of its off site effects. These tools and techniques are discussed in detail later in this document.

3. Wind erosion

Wind erosion is a process involving the removal of soil particles from the land surface by the action of strong winds. It is a form of land degradation which occurs particularly in semi-arid areas having an annual rainfall of less than 300 mm, and also in more humid areas subject to long rainless periods and seasons of hot dry wind. It can be a serious form of environmental damage in districts where extensive cropping and grazing are practised under marginal climatic conditions, particularly where long drought periods which denude the soil of plant cover are occasionally experienced.

In the ESCAP region, wind erosion is not so serious or widespread a problem as water erosion. There are, however, extensive areas meeting the climatic conditions described above for which wind erosion has been a problem in the past and is a potential problem for the future. In particular, there are extensive areas of Australia and North China where this is the case, along with parts of Pakistan and northern India.

Wind erosion commences on a soil surface when the entrainment and transportation forces exerted by the wind exceed the gravitational and cohesive resistance forces tending to keep soil particles in position. Three distinct types of erosive motion occur, depending principally upon the size of the soil particles. *Suspension* is the movement of very fine particles, generally less than 0.1 mm in diameter, which are lifted by turbulence and can remain aloft for long periods. Suspended material is visible as dust and can be carried to considerable heights (6000 m) and over considerable horizontal distances (8000 km): on several occasions in the past, dust storms from eroded croplands in western New South Wales and South Australia have been blow across the Tasman Sea to be deposited on the Southern Alps of New Zealand.

Saltation is a process by which larger particles, too large to remain suspended in the air flow, are moved along the surface by a bouncing motion. It affects particles ranging in diameter from 0.1 mm to 0.5 mm. The particles do not rise more than about 30 cm but may be transported downwind over distances ranging from tens to hundreds of metres, eventually coming to rest and accumulating against fencelines or other impediments to further movement.

Creep involves the movement of larger particles again, which are not lifted but rolled along the surface of the ground, pushed by the force of the wind and the impact of other particles moving with the wind. Particles which move by creep are usually in the range of 0.5 mm to 2 mm in diameter. Transport distances are rarely more than a few metres.

Of these three modes of movement, saltation is the most important, generally accounting for from 50 per cent to 80 per cent of the total sediment transport. Furthermore, the other forms of movement cannot take place unless saltation is also occurring.

An important consequence of the size-dependent entrainment mechanisms and the size-selective transport modes is that the wind erosion processes change significantly the particle-size distribution of the soil. Wind erosion removes the finer particles, along with organic matter and nutrient material, leaving a coarser and much less fertile material and significantly reducing potential agricultural productivity.

The principal factors affecting the rates and amounts of wind erosion are the physical properties of the soil, the wind velocity and the boundary layer aerodynamics, and the amount and extent of vegetative cover.

The soil types which are most susceptible to wind erosion are sandy or silty soils of low cohesion, particularly when they are dry and the surface is relatively smooth. High soil moisture levels and a well-structured, cloddy surface resist entrainment forces effectively. The wind speed above the surface, and the degree and nature of turbulence in the boundary layer, are important factors in the entrainment process. A high degree of roughness on the soil surface, increasing frictional resistance to the wind and creating a turbulent boundary layer with a comparatively flat velocity gradient over the surface, will limit entrainment forces effectively.

A factor of major importance is the vegetative cover. Indeed, the most effective way of preventing soil erosion is to maintain a suitable vegetative cover. This has two effects – it substantially modifies the surface roughness and the wind velocity distribution in the boundary layer, whilst its physical structure assists in reducing entrainment by suspension and saltation. Either standing vegetation or stubble and crop residue provide effective cover for erosion control.

The various measures used to manage wind erosion depend upon the manipulation of one or other of the factors discussed above. Wind velocity and its above-surface gradient can be managed by increasing surface roughness, maintaining vegetative cover or providing windbreaks. Special farming practices can be used to increase soil moisture, reduce cultivation and maintain as much vegetative cover as possible. Strip cropping, minimum-till or low-till cultivation techniques, stubble retention, or the careful control of over-grazing on pasture lands, are some of the techniques available. These techniques are discussed in further detail in Chapter VI.

It will be obvious from the foregoing that land-use planning and management policies and techniques offer major opportunities for wind erosion control. Land-use planning can be used to zone land uses on lands susceptible to wind erosion and to restrict clearing and farming practices to those which provide effective wind erosion control. As has been briefly discussed above, a variety of specialized farming, grazing and other land management techniques has been developed for wind erosion mitigation and these should be required to be used in districts susceptible to land degradation from wind erosion.

4. Other forms of erosion and deposition

Erosion by water and by wind are the most serious and widespread forms of land degradation occurring in the ESCAP region. There are other forms of degradation by processes involving erosion or deposition which can have serious consequences in specific localities. These include siltation and sedimentation, mass movement, and coastal erosion.

Siltation and sedimentation processes refer to the off-site movement and deposition of the products of soil erosion. The soil entrained by the action of water erosion moves downslope under the influence of the various transport mechanisms in operation and eventually becomes deposited as sediment or silt when the transportation forces, for one reason or another, become ineffective.

In the case of raindrop, sheet and rill erosion, the distance moved by sediment may not be very considerable, perhaps of the order of metres or tens of metres, in the course of any particular erosion event. With the occurrence of another event, re-entrainment, further downslope transport and eventual re-deposition may occur. The process of gradual removal and transport of soil thus becomes an episodic one, with large movements occurring only on sporadic occasions.

In the case of gully erosion, and larger-scale mechanisms such as river bank erosion, the entrained particles may move considerably further before re-deposition. Movement however is essentially local, and confined within small watershed areas, except on very large river basins during major flood events.

An important feature of the transportation and deposition processes is that they are highly particle size selective. The largest particles, of gravel and sand sizes, move only comparatively short distances and will be deposited as sediment within the watershed from which they originated. Very fine particles of silt or clay size, on the other hand, may be transported many kilometres and sometimes tens or hundreds of kilometres downstream, to be deposited eventually as silt on floodplains or in reservoirs, lakes or estuaries.

The rate of soil formation under natural conditions is very slow. Formation rates vary considerably depending upon the nature of the parent materials, the climatic conditions and many other factors, but are likely to be only of the order of millimetres per thousand years. The rate of production of sediment and silt from eroded areas, however, is likely to be several orders of magnitude greater.

Assuming, for purposes of illustration, a surface soil bulk density of 1.4 gm/cm^3, then a soil depth of 1 mm corresponds to a mass of 14 tonnes per hectare and a volume of 1000 cubic metres per square kilometre. Extensive studies of soil losses from soil plots, small watersheds and large catchments throughout Australia provides the following data, which probably can be applied in general terms elsewhere throughout the ESCAP region:

(a) Natural rates of soil formation are generally less than 1 t/ha/yr;

(b) Land-use and management practices have a major effect on soil loss, any practices that reduce the amount of protective ground cover being likely to increase the risk of soil loss;

(c) Soil loss per unit area decreases with catchment size, and care must be taken in the extrapolation of loss figures from soil plot studies to watershed scale;

(d) Mean annual losses tend to be strongly skewed in their distribution and are dominated by major losses in a few years;

(e) Losses from individual storm events can be many times the mean annual loss and can reach values of the order of hundreds of t/ha – reports of high losses during such events can give a biased view of overall conditions;

(f) On forested watersheds, losses are likely to be in the range 0-1 t/ha/yr – accelerated rates of the order of 10-50 t/ha/yr can be experienced after forest fires and before regeneration;

(g) Under pasture cover, mean annual losses are likely to be less than 1 t/ha/yr;

(h) Under cropping, losses are in the range 1-50 t/ha/yr, and can be kept to the lower end of this range with good management;

(i) Under bare fallow conditions in temperate climates, losses are likely to be of the order of 50-100 t/ha/yr;

(j) Under crops such as sugar cane growing in tropical and sub-tropical conditions, losses can be expected to be of the order of 100-500 t/ha/yr.

It is obvious from these figures that substantial quantities of sediment can be expected to be produced as a consequence of erosion processes when poor land management is practised. The coarser sediments will be deposited a comparatively short distance downslope of their place of origin, where they may bury productive agricultural or grazing land or damage roads and other infrastructure. Sediments which reach watercourses may block channel sections and so aggravate the effects of flooding or increase the potential for streambank erosion.

The very fine erosion products of silt or colloidal size may be carried considerable distances downstream of their site of origin by floodwaters, eventually being deposited as siltation when the velocity of flow transporting them becomes so small that the particles can drop out of suspension. Where this occurs as a consequence of overbank flow across a floodplain, the effects may be beneficial, building up arable soil depth and providing additional organic and nutrient matter. Where it occurs in large water bodies such as lakes, reservoirs and estuaries, siltation has a number of adverse effects. These may include the reduction of storage capacity, interference with navigation, damage to fish species and other aquatic fauna, and general impairment of aquatic ecosystems.

As has been explained in previous sections, effective control of sedimentation and siltation can be achieved through land-use control and management, particularly where this involves watershed management practices which aim to minimize land clearing, to maintain vegetative cover on land used for agricultural purposes, and to foster agricultural practices which facilitate water and wind erosion control. These practices and techniques are discussed in detail in Chapter VI.

Mass movement encompasses a variety of erosion processes in which gravity is the primary force acting to dislodge and transport land surface materials: for completeness in the classification system used here, it has been categorized under the heading of soil erosion and deposition. The mechanisms by which these processes occur, along with a discussion of their degradation effects and ways and means of controlling them, are discussed in some detail in Section III.D, "Land Instability".

Coastal erosion refers to forms of land degradation which occur along coastlines under the action of wind and wave induced forces which cause the movement or loss of soil, sand and rock material. It occurs in two principal forms – processes involving the loss of coastline material into the sea, as a consequence of severe wave action, and processes involving the loss of vegetation on coastal sand dunes and the movement of sand inland by wind erosion forces.

Both forms of coastal erosion occur along coastlines within the ESCAP region, particularly in localities subject to tropical cyclone action or the likelihood of storm surge or tsunami effects. Coastal erosion can result in the total loss of coastline land, either valuable for intensive agricultural purposes or, in many locations, intensively developed for high-value urban, commercial or resort use. In some locations, resort areas including resort beaches and lagoons, often of high value to local economies, are particularly susceptible. In less developed regions, coastal communities and fishing villages may be similarly at risk. Wind erosion on coastal sand dunes, causing large volumes of sand to be blown inland, can also result in the burial and loss of land valuable for a variety of purposes and damage to, or destruction of, buildings, industrial sites and public infrastructure.

Erosion processes which result in the loss of material to the sea generally occur sporadically under the same conditions as those which cause coastal flooding. These conditions are discussed in some detail in Section III.C.5, "Coastal Flooding". It should be noted that this form of erosion can sometimes be severely aggravated by the inappropriate construction of devices mistakenly planned to control or mitigate coastline or beach erosion or to develop the coastal zone for navigational or other purposes, such as training walls, breakwaters, groynes, offshore loading jetties, or beachfront retaining walls.

This form of coastal erosion offers considerable potential for mitigation through land-use zoning and the strict control or prevention of either adverse or risk-prone forms of land use. In particular, good management requires the zoning of the immediate coastal strip to prevent commercial, housing or infrastructure development in locations susceptible to land damage and strict building controls over structures which offer potential for the aggravation of wave and wind erosion effects.

Coastal sand dunes are constantly under threat from wind erosion, particularly in areas subject to occasional high winds of tropical cyclone or other storm condition origin. Susceptibility to this form of erosion is vastly increased where vegetative cover is sparse or non-existent, when major sand blows may occur causing the movement of sand a considerable distance inland. The key to the management of this form of land degradation is the establishment and maintenance of a dense vegetative cover, which may require substantial vegetation or regeneration programmes and the careful control or prevention of adverse forms of land use, including grazing, building or road construction, mining, or simply uncontrolled access by humans or vehicles.

D. Soil degradation

1. Soil salinity

Saline soils are soils which contain such a quantity of soluble salts that plant growth is significantly reduced. Soils which have been saline for many thousands of years, as a result of natural landscape-forming processes, are said to exhibit *primary salinity.* Soils which have recently become saline, as a result of rising water tables consequent upon changes to the local hydrology or poor irrigation practices, are said to exhibit *secondary salinity.* In this document, we are primarily concerned with land degradation resulting from secondary salinity, which is capable of being managed through appropriate land-use practices and policies.

Secondary salinity occurs in two principal forms, depending upon whether or not the degraded land has been irrigated, which are generally referred to as *irrigation salinity* and *dryland salinity.* In point of fact, the essential features of the salinity process are the same for both forms, although one is the result of poor irrigation practice and the other the result of unsound land use on non-irrigated agricultural, pastoral or forested lands.

Primary salinity is a world-wide phenomenon. Within the ESCAP region, it occurs in China, Thailand and Australia, the latter alone having nearly 40 per cent of the world's total area. Irrigation salinity is also widespread, occurring in most of the world's established irrigation areas and having been responsible, in ancient times, for the breakdown and collapse of some early civilizations. Within the ESCAP region, it occurs in Australia, China, India, Pakistan and Thailand, principally where major irrigation schemes have been developed in semi-arid lands on the flood plains of major rivers. Dryland salinity is a more recent phenomenon, generally occurring in upland watersheds on land which has been cleared for cropping, grazing or plantation forestry. Within the ESCAP region, it occurs in Australia, China and Thailand and is becoming an increasingly serious problem in most areas where it has developed.

The cations and anions most commonly occurring in saline soils comprise sodium, calcium, magnesium, chloride, sulphate and bicarbonate, of which the dominant ones are usually sodium and chlorine. The salts go into solution in the plant root zone, producing an increase in osmotic pressure and causing increased water stress in growing plants. This may severely inhibit plant growth, reducing crop yields and the extent of plant cover or in severe cases causing plant death and making it impossible to grow plants having low salt tolerance. On upland watersheds, the reduction in plant cover substantially increases the potential for water erosion, leading to further loss in productivity and progressive land degradation.

Irrigation salinity develops when the salt concentration in the root zone of irrigated soils becomes high enough to inhibit plant growth. This may be due to the presence of salts in the soil, the presence of salts in the applied irrigation water, or a combination of both. In poorly drained irrigated soils, the water table progressively rises, bringing dissolved salts from the underlying soil material into the root zone. The processes of transpiration and evaporation remove water from the zone, leaving salts behind and causing an increasing build-up in salinity levels. If saline water drains to the lower water table, and is eventually discharged into a watercourse, a progressive build-up of salinity in the river system downstream will develop. Thus the adverse effects of irrigation salinity may not only occur within the irrigation area, but also have environmental consequences for the entire river basin system of which the irrigation area forms a part. These consequences are particularly evident in terms of impaired water quality, reducing the suitability of river water for further irrigation use or domestic and industrial supply and affecting the function of the riverine ecosystems.

An associated problem with irrigation salinity occurs when water tables rise so high as to come close to or reach the surface, causing waterlogging and loss of productivity or, in extreme cases, total loss of land to agriculture. This problem is aggravated when irrigation is practised on clay soils or shallow soils underlain by impervious material.

There is a range of solutions available for the management of irrigation salinity, involving either changes in irrigation practices, changes in land-use and cropping practices, or the manipulation of site hydrology through improved drainage and other means.

Changes in irrigation practice are aimed either at the more efficient use of irrigation water, so reducing the build-up of shallow water tables, or the movement of accumulated salts out of the root zone into the drainage system. Changes in practice may include the use of an alternative, lower-salinity water source, the improved levelling or grading of flood-irrigated land, or changing from flood or paddy irrigation methods to sprinkler or drip irrigation application systems. In extreme cases of irrigation salinity, the total cessation of irrigation as a land use may be necessary. Where sufficient quantities of low-salinity water are available, and the irrigation fields are adequately drained, the practice of leaching, involving the application of excess irrigation water to flush salts from the root zone downwards to the water table, is a common technique.

Changes in land use involve changing to different crop or pasture types or different farming methods. Most commonly, this involves the selection and introduction of more salt-tolerant plant species.

Manipulation of site hydrology is aimed at facilitating leaching and drainage to remove excess salt concentration from the root zone and prevent the build-up of high water table or waterlogging problems. It normally involves the construction or improvement of sub-surface drainage systems, which may be achievable with simple drainage channels or dykes but might, particularly in very flat land, require the installation of pumping equipment. Improvement of drainage brings an additional problem, in that means must be found for the disposal of saline drainage water. Where drainage water is discharged into the nearest watercourse, potential problems of water quality impairment further downstream are likely. Where drainage water is highly saline, alternative methods of disposal might be necessary. These include discharge to other catchments, into salt lakes, into saline aquifers or into the ocean. In Australia, discharge into evaporation basins, from which salt is eventually harvested commercially, is an increasingly common practice.

Dryland salinity is also a problem associated with rising watertables, which generally develops on hillslopes and the valley floors beneath them as a consequence of upper slope clearing. Under natural conditions, rainwater falling on upper slopes infiltrates through the soil surface and moves into the groundwater zone, from whence it gradually percolates downwards beneath the surface to the valley floor and discharges into the stream bed. The vegetation on the upper slopes, particularly if it includes deep-rooted trees and shrubs, removes water from the groundwater zone by transpiration, establishing and maintaining an hydrological balance whereby the watertable remains at a safe distance below the soil surface and waterlogging or seepage do not become problems.

If the natural vegetation is removed from the upper slope, the amount of water extracted from the groundwater zone by plant roots is substantially diminished. The water table consequently rises, and may come into the root zone or even to the surface on the lower slope and the valley floor. The flowing groundwater dissolves salts from the rock and soil through which it filters, so that its salinity progressively increases. The shallow saline seepage water impairs plant growth, reducing productivity and frequently leading to the replacement of the existing vegetation by more salt-tolerant and generally less productive or less palatable species. Where seepage water comes to the surface, evaporation leaves a characteristic residue of white crystals on the soil and the high concentration of salt may lead to the removal of all vegetation. Under these conditions the surface is particularly susceptible to erosion, and this may be aggravated by the trampling of livestock attracted to the salt. Severe sheet, rill and gully erosion is a likely consequence.

Apart from its localized effects on vegetation and agricultural productivity, dryland salinity has adverse off-site effects which include, apart from the consequences of severe soil erosion, the impairment of both groundwater and surface water quality, which may be evident for a considerable distance downstream.

The development of dryland salinity is a long-term process, which may take several decades to become established. In Australia, for example, extensive areas of dryland salinity are beginning to make their appearance in locations where the clearing of native vegetation was undertaken 70 or 80 years ago.

The solutions available for the management of dryland salinity are similar in principle to those employed for the management of irrigation salinity. They include methods involving changes in land-use and farming practices, as well as methods involving the manipulation of site hydrology.

Methods involving changed farming practices include moving from cropping to grazing, excluding stock or strictly controlling grazing on affected areas, introducing salt-tolerant grasses, shrubs and trees and changing from farming to agro-forestry. Direct manipulation of site hydrology includes the use of mole or pipe drainage to lower the watertable beneath saline areas, pumping groundwater from aquifers below the saline areas, and constructing banks and drainage ditches to divert excess water or improve the drainage of water from saline locations.

A number of interesting and successful methods of treatment combine both these approaches, by using vegetation to manipulate the shallow groundwater hydrology. These are essentially "recharge control" techniques, which seek to lower the watertable by reducing the inflow from the upper slope areas or increasing the rate of water extraction from the same areas. They include the revegetation of the groundwater recharge zone along the upper slope with deep-rooted trees and shrubs; the introduction to the upper slopes of plants or crops which have a much higher water use than the existing vegetation; and improving the management of existing crops and pastures to maximize their water use.

It is evident from the foregoing paragraphs that the adoption and implementation of appropriate land-use practices provides the key to the management and mitigation of those forms of land degradation which result from secondary salinity. Land-use planning, in anticipation of the development of new irrigation areas, will clearly also provide the key to the development of future problems of irrigation salinity, making it possible to avoid the establishment of irrigation schemes on land which is susceptible to this form of degradation for various reasons. In the same way, the development of future problems of dryland salinity on upland watersheds can also be avoided by sound land-use planning and the early introduction of appropriate land-use controls, such as the prevention of vegetation clearing on upper slopes in districts where soils are susceptible to salinization.

2. Degradation of soil structure

Degradation of soil structure relates to a serious reduction in the continuity, distribution and size of the pore spaces in a soil mass. This occurs either as a result of manipulation or trafficking of the soil surface, which may be a consequence of ploughing or other forms of cultivation, the passage of heavy farm machinery, or trampling by livestock, or as a result of the practice of irrigation on susceptible soils.

Degradation caused by trafficking or cultivation has a variety of adverse consequences, which include surface sealing and crusting, sub-surface compaction, and the formation of sub-surface plough pans or hard pans. It results in much reduced infiltration capacity, permeability and aeration, restricted germination, declining plant yield and substantially increased susceptibility to water and wind erosion. It also causes increasing farming costs as more and more energy is required for satisfactory cultivation. This form of degradation is most likely to occur with soils which have a high clay content and high in situ soil moisture levels. Dispersive and sodic soils are particularly likely to be susceptible.

Rehabilitation of soils damaged in this way can be achieved by discontinuing cropping and changing the land use to pasture production. The rehabilitation process is slow and stocking rates have to be carefully managed whilst it is in progress. More rapid but much more expensive improvement of the soil condition can be achieved through mechanical processes such as deep ripping and by the application of a soil ameliorant such as gypsum.

Structural breakdown under irrigation is a consequence of the effects of wetting on clayey soils. It occurs in two principal forms; slaking, which is the mechanical collapse of normally well-structured soil aggregates when wetted, and dispersion, which is a consequence of the chemical behaviour of high-sodium soils when wetted. The type of irrigation and the irrigation techniques employed affect this process, degradation being more severe under flood irrigation. Soil cultivation and crop management techniques, particularly the use of heavy farm machinery when soils are at high moisture levels, may also have an effect on breakdown.

The consequences of this form of degradation are impaired soil structure, reduced soil permeability and deteriorating sub-surface drainage characteristics. Poor germination, severely reduced crop yields and increased farming costs result. A combination of reduced surface infiltration capacity, restricted sub-surface permeability and much poorer drainage capability can lead to severe problems of rising water table, waterlogging and salinization, as well as raising problems with the management of excess tailwater.

Degradation of this kind is most likely to occur when soils are fine-textured and poorly-draining, susceptible to slaking and dispersion, susceptible to sub-surface compaction under farm machinery, underlain by highly saline soils or groundwater, or poorly drained because of flat topography or the presence of underlying soil or rock strata of low permeability.

This form of degradation can be managed, and rehabilitation achieved, through an understanding of the factors which cause it to occur. Modified irrigation practices and improved methods of cultivation and harvesting are necessary and a change in farming practice, involving planned cropping rotations with alternating irrigation and dryland cereal cropping phases, has been shown to be effective in reversing the process. In cases of severe deterioration, and where the high cost warrants it, treatment with an ameliorant such as gypsum may also be necessary.

Within the ESCAP region, degradation of soil structure is an increasing problem in countries where extensive, highly-mechanized cropping is practised. It occurs in India, Pakistan, China, Thailand and is prevalent in Australia, where it is claimed to be a more costly form of land degradation than soil erosion. There is considerable potential for this problem to become increasingly widespread and increasingly serious within the region as populations expand and the demand for greater food production accelerates.

Because this form of degradation is a consequence of the application of unsuitable farming practices and methods on susceptible and readily identifiable soil types and topography, there is very considerable potential for its control, and the limitation of its further spread, through sound land-use policy and the application of appropriate land-use management techniques. Land-use policy must provide for the proper identification and assessment of potential problem areas for future development, through such means as land survey, soil survey and land capability assessment; the zoning of farm lands to restrict development on soils susceptible to this form of degradation; and the control or prohibition of inappropriate forms of land use on farming areas under existing development. Methods of land-use management for the control of this problem have been briefly discussed above and will be further detailed in Chapter VI.

3. Soil fertility decline

Soil fertility decline is a progressive reduction in the productivity of a soil. It is a complex process, evident through a deterioration in organic matter content, nutrient availability and biological activity in agricultural soils. It becomes evident through impaired germination, reduced crop yield and declining crop quality, along with increased farming costs brought about by the need for increasing amounts of chemical fertilizer application.

The extent and severity of this form of degradation is not well documented, largely because its effects may be attributed to a variety of other causes such as climatic variations, changing farming practices, or the consequences of other forms of degradation such as water and wind erosion. It is known to occur in many parts of the ESCAP region. It may occur in tropical areas where rainfall rates are very high and soils are porous, as a result of nutrient leaching. It is particularly likely to occur in cropping lands of low natural fertility, in locations where rainfall is generally variable and marginal. Extensive cropping lands in China, India, Pakistan and Australia are likely to become increasingly affected – in Australia, it already appears to be widespread in cereal cropping regions.

Soil fertility decline will become a problem of serious potential significance in the region as the demand for food and fibre production increases and more extensive cropping of low-fertility marginal lands become necessary. To avoid its development, land-use policy needs to emphasize the need for comprehensive resource data collection, particularly topographic survey, soil and vegetation survey, and land capability assessment. Monitoring of soil fertility conditions to provide warning of potential fertility decline, along with the adoption of land-use practices aimed at the better incorporation of organic matter, the good health of the soil biota, and the maintenance of natural nutrient sources, are all necessary for the effective management of this form of degradation.

4. Soil acidification

Soil acidification is a progressive reduction in the pH of a soil, leading to a gradual increase in soil acidity. It appears to develop when certain farming practices cause modification to the carbon and nitrogen cycle processes within the soil mass. It occurs on naturally acid, light-textured soils in regions of comparatively high rainfall where nutrient leaching is more pronounced. It develops principally on lands used for pasture production which have been subject to a long period of artificial fertilizer application, particularly on leguminous pastures with a long history of superphosphate application.

This form of degradation becomes gradually evident through reduced pasture yield, poor plant establishment and increasing susceptibility to plant disease. The health of stock grazing on the pasture may be affected, and where the condition is severe an erosion hazard may develop. Response to chemical fertilizers is progressively diminished, leading farmers unaware of the cause to increase their fertilizer application rates, which has the effect of compounding the problem as well as increasing farming costs.

The most common and effective method of treating soil acidification is to apply agricultural lime, which raises pH, increases calcium content, improves the availability of trace elements and enhances legume nodulation. Lime is applied by surface spreading or, in some cases, by sub-surface injection at the time of pasture sowing.

Knowledge about the extent and severity of this problem within the ESCAP region is not well established. It is widespread on the grazing lands of the slopes and tablelands of Eastern Australia, and is likely to be a potential problem in other districts within the region where soil types, climatic conditions and farming practices are similar.

As with soil fertility decline, the adoption of good land-use policy is necessary to ensure the early detection of this form of degradation and develop appropriate ways and means for its management.

Monitoring of soil acidity and levels of crop and pasture production, along with the development and dissemination of information about detection, treatment and the appropriate land-use practices, are all necessary requirements for the effective management of this problem.

5. Other forms of *in situ* degradation

Soil waterlogging occurs when the water table rises and comes close to the soil surface. If it comes high enough to enter the root zone, air is driven out of the soil pore space and saturation occurs. Under these conditions, plant growth is severely restricted and crop or pasture yields severely reduced. The existing vegetation may be killed and replaced by far less productive or less palatable species. In extreme cases, the water table may rise to the surface or above it, causing surface saturation or flooding and effectively rendering the land useless for crop or pasture production.

As has already been explained, this form of degradation results from changes in local hydrology and is usually a consequence either of vegetation clearing on upper slopes or of the application of excess irrigation water. It is compounded by a variety of factors which include soil types, soil drainage characteristics, and climatic conditions.

This form of degradation is usually associated with problems of soil salinity, either of irrigation salinity or of dryland salinity, and has already been discussed in association with those problems in Section II.D.1 above.

Soil pollution occurs when soils become contaminated with toxic pollutants. This may have a number of adverse environmental consequences, including reductions in crop and pasture yield, crop and pasture losses, sickness and poisoning of livestock, surface and groundwater pollution, or the rendering of land unsuitable for human settlement or habitation.

This form of degradation is most commonly associated with industrial or mining activity, often being a legacy of abandoned factory or mine workings. In such cases it generally affects a specific and localized area, where it is easily identified and can if necessary be treated, although this may be at considerable cost. Land-use zoning, to prevent or restrict agricultural, urban or village development on or close to such areas, may be an appropriate management technique.

Less severe but more widespread forms of soil toxicity can occur as a result of farming practices. Contamination due to the excessive application of herbicides, pesticides or fumigants is an example. Other forms of soil degradation, such as salinity and soil acidification, may also have secondary toxic effects producing a build-up in concentrations of salts or trace elements. These problems are best controlled through a monitoring of their presence, an understanding of their causes and the application of sound farm management practice to minimize their effects.

E. The regional experience

The majority of the countries within the ESCAP region are now experiencing the adverse effects of land degradation and deforestation. These effects are manifested through such indicators as increased soil erosion, loss of soil fertility, increased sediment discharge and a decline in agricultural productivity. They are also evident through more frequent flash flooding and more active mass movement on upland watersheds.

Bangladesh is a relatively flat country, with less than 5 per cent of its total area classified as hilly. The elevated lands of the Chittagong Hills Tract is well covered by forest and jungle and is not subject to severe erosion or sedimentation problems. Elsewhere, soil erosion due to intense rainfall is not a serious problem. The most serious form of natural disaster affecting Bangladesh is flooding, which predominantly has its origin in the upper catchments of the large rivers beyond the borders of this country. Under flood conditions these rivers carry heavy silt loads, which causes raised river bed levels, creates navigation problems and reduces the hydraulic capacity of the river channels. The high rates of discharge and high velocities associated with flood flows are responsible for land degradation in the form of migration of river channels and the erosion of banks and floodplain surfaces.

Forest cover across Cambodia decreased from 73 per cent of the total land area in 1972 to 63 per cent in 1995. The consequences of this rapid rate of deforestation have included widespread erosion, soil and water degradation, landslides, siltation of watercourses and reservoirs and an increasing frequency of flash floods. The principal reasons for this deforestation have been agricultural expansion, shifting cultivation practices, firewood gathering, commercial logging and forest fires.

Land degradation, in the form of extensive soil erosion, is a serious problem in China, where nearly 40 per cent of the land area is so affected. Of this area, some 48 per cent has been caused by water erosion and the remaining 52 per cent by wind erosion. It has been estimated that the total area of eroded land is increasing at the rate of two per cent per annum. Adverse consequences of this widespread erosion have included the siltation of rivers, lakes and reservoirs and an increased intensity of such disasters as flooding, landslides and mud flows.

The area of degraded land across India represents about 25 per cent of the total land mass. This comprises land which is deteriorating because of inappropriate land-use practices or because of deforestation or a lack of adequate vegetative cover. Degradation is most evident through soil erosion and the loss of agricultural productivity.

As a result of uncontrolled land development and a high demand for agricultural land, forest cover has been progressively removed from the steeper slopes in many parts of Indonesia. This has led to degradation in land and water quality and accelerated soil erosion. Population pressures have compounded the problem by increasing the demand for the utilization of steep slopes for agricultural purposes. Insufficient funding for watershed protection and improvement has not helped to slow the rate of degradation. Over-exploitation of forests, shifting cultivation practices and mining activities have all been instrumental in producing soil erosion and sediment production. High rates of rainfall on unprotected land surfaces have increased the erosion of fertile soils and the incidence of landslips and mud flows. Sedimentation in the lower reaches of major rivers has increased the magnitude and severity of lowland flooding.

The main cause of land degradation in the Lao People's Democratic Republic is deforestation. Removal of vegetation through uncontrolled logging, slash and burn methods of agriculture, and over-utilization of fragile lands have all accelerated the rate of soil loss and increased surface run-off.

In Malaysia, nearly 60 per cent of the land surface has been retained under forest cover. Within the undisturbed forested areas land degradation is not a significant problem. Elsewhere, however, land clearing, shifting cultivation, intensive land use and urbanization have caused land degradation, which is evident in the forms of soil erosion, sedimentation and landslip. This is particularly the case in many of the watersheds of Sabah and Sarawak, and, to a lesser extent, in Peninsular Malaysia.

Deforestation and clearing of natural vegetation have been responsible for significant soil erosion and land degradation in Myanmar. Such activities as commercial logging, shifting cultivation, inappropriate farming practices, uncontrolled grazing, wild fires and poor maintenance of roadways and other earthworks have all contributed to this problem.

In Nepal, the exploitation of forests has resulted in significant deterioration of environmental quality and extensive degradation of watersheds. Massive deforestation has been undertaken over recent decades in order to create more land for cultivation, in an attempt to satisfy the needs of a rapidly-growing population. The removal of vegetation, along with uncontrolled grazing, has severely damaged the fragile slopes of this mountainous country, increasing gully erosion, triggering landslides and mass wasting, accelerating the rate of run-off and causing increased sedimentation in rivers and streams.

Pakistan has developed significant land degradation problems in the forms of soil erosion, landslides and sedimentation. These have been exacerbated by the exploitation and over-development of marginal lands on upland watersheds. Increased cultivation, excessive livestock grazing, deforestation and removal of vegetative cover have all contributed to the process of environmental degradation.

The rate of forest destruction in the Philippines is estimated to have been amongst the highest in the world. In less than ninety years, the area under forest has been reduced by more than 75 per cent. In addition to deliberate clearing, frequent forest fires have been responsible for the destruction of large areas of virgin and plantation forests. The destruction of upland forests has resulted in massive soil erosion, landslips, declining soil productivity, sedimentation of river channels and siltation of reservoirs, and acute water shortages during the dry season. It is estimated that about 75 per cent of the total uplands area of the Philippines is now vulnerable to soil erosion.

Encroachment onto forest reservations by squatters, deforestation from both illegal and commercial logging, clearing for rubber plantations and mining activities have all contributed to the degradation of upland watersheds in Sri Lanka. Poor soil conservation techniques and frequent landslides have resulted in the widespread loss of topsoils, evident in heavy siltation of the lower reaches of the island's rivers.

Significant deforestation over recent decades has denuded much of the landscape of Thailand. Increased soil erosion on unstable slopes, a consequence of the excessive removal of the native vegetative cover, has led to significant land degradation, sedimentation, landslip, and the more frequent occurrence of flash floods on the smaller watersheds.

The practices of shifting cultivation, overlogging and land clearing, along with the effects of forest fires, have reduced Viet Nam's forested area by 16 per cent over the past fifty years. As a consequence, flooding has intensified and the areas of land inundated during major flood events has increased dramatically. In contrast, the altered hydrologic regime has also increased the intensity of droughts. The removal of forest cover has resulted in severe land degradation, which takes the forms of soil erosion, loss of soil fertility and increased downstream sedimentation.

III. CATEGORIES OF WATER-RELATED NATURAL DISASTERS

A. Introduction

The occurrence of water related natural disasters is common in the ESCAP region and their impact is becoming more devastating. Increasing populations and the denser occupation of hazard-prone areas contribute to the growing costs of damage and disruption resulting from such disasters. Unwise land-use is a significant factor in these escalating costs.

A collation and description of the major categories of water-related natural disasters which afflict the region is presented in the following sections.

B. Tropical cyclones

Tropical cyclones are intense low-pressure rotating wind systems, which develop over warm oceans in low-latitudes and move onto adjacent land masses, where they may have tremendous destructive potential. In the ESCAP region, such phenomena are called "typhoons" in the north-west Pacific and the South China Sea, or "tropical cyclones" in the Indian Ocean, the Arabian Sea, the Bay of Bengal, the northern coasts of Australia and the South Pacific. In North and Central America and the Caribbean they are called "hurricanes". All these terms are taken to be synonymous in this document.

A major tropical cyclone may affect an extensive area for a period from a few days to a week or more. Its passage is associated with extremely heavy rainfalls and extremely high velocity winds which can lead to major and extensive flooding, enormous property damage, human injury and heavy loss of life. During its life it may vary in intensity and destructive power and move along a variable path, affecting a number of countries.

The tropical cyclone cell is a circulatory wind system having an intense low pressure core. Wind circulation around the cell is clockwise in the Southern Hemisphere and anti-clockwise in the Northern Hemisphere. The diameter of a mature tropical cyclone varies from as little as 100 - 200 km to as much as 1000 km in a large system. Wind velocities around its centre may exceed 200 km/h.

A tropical cyclone forms over the open sea where the surface temperature is 26.5° C or more and the latitude about 5° to 20°. Its movement is generally along a curved westerly and polewards track. Once over land its power dissipates as a consequence of the lack of moisture supply and the friction due to the land's roughness, and it eventually deteriorates into a tropical rain depression. The time from its detection to its disappearance is commonly around 5-6 days.

Tropical cyclones are classified according to their intensity. The World Meteorological Organization (WMO) provides the following classification table:

CLASSIFICATION		MAXIMUM SUSTAINED WINDS		
		mps	knots	kph
(a)	Tropical depression	up to 17.2	up to 34	up to 62
(b)	Tropical storm	17.2 - 24.4	34 - 47	62 - 88
(c)	Severe tropical storm	24.5 - 32.6	48 - 63	89 - 117
(d)	Typhoon / tropical cyclone	32.7 or more	64 or more	118 or more

(*Source:* WMO Guide to Marine Meteorological Sciences (WMO-No 471) and WMO Manual on Marine Meteorological Services (WMO-No 558))

Tropical cyclones occur more frequently in Asia, and particularly in the Northwest Pacific, than in any other part of the world. In the ESCAP region, the most frequent source for the formation of tropical cyclones is just east of the Philippines, where the main tropical cyclone season extends from July to October and the frequency of occurrence in those months is about five cyclones per month.

Tropical cyclones spawned in this region generally track westward and may later turn north-west, first affecting the Philippines and then moving on to the Asia mainland or recurving north-eastward towards Japan.

Those tropical cyclones which move westward across Indochina tend to lose their intensity after crossing the coastline. They may redevelop, however, over the Bay of Bengal and continue to move westwards over India or recurve northwards towards Bangladesh or Myanmar.

In the Bay of Bengal, in addition to those cyclones originating in the Northwest Pacific, tropical cyclones commonly develop over the southern section of the Bay and move in either a westerly or northerly direction to affect India, Bangladesh or Myanmar. These cyclones are more likely to occur before April/May or after October/November and may be accompanied by storm surges.

Some tropical disturbances track across India or develop over the Arabian Sea and more towards Pakistan, the eastern part of the Islamic Republic of Iran or the Sultanate of Oman. The occurrence of damaging tropical cyclones which affect these countries is infrequent.

Tropical cyclones originating within the Southern Hemisphere zone of the ESCAP region have an extensive spawning area which includes the Indian Ocean, the Timor Sea, the Arafura Sea, the Gulf of Carpentaria, the Coral Sea and the South Pacific. Within this region, the frequency of occurrence of tropical cyclones is about half that which is experienced to the north of the Equator and the tropical cyclone season is restricted to the period December to April. These Southern Hemisphere disturbances tend to have more erratic tracks and slower travel speeds that those formed in the Northern Hemisphere, although their destructive effects may be just as severe.

C. Floods

1. The nature of flooding

A flood can be defined as an excess flowing or overflowing of water, especially over land which is not normally submerged. The source of the flow of water which produces disastrous flooding can have various origins, which include intense and prolonged rainfall, snowmelt, the downstream blocking of river channels by landslides or avalanches, the upstream failure of dams or river blockages, storm surges, abnormally high tides, and tidal waves.

Within the ESCAP region, the extent and cost of disastrous flooding has been intensifying as a consequence of increasing populations, denser occupancy of floodplains and other flood-prone areas, and the expansion of adverse forms of watershed land use. Within this region, floods are the most frequently occurring and the most destructive of all the forms of natural disaster which affect the area, although tropical cyclones have caused heavier loss of life. The most serious flooding experienced in the region comes from intense rainstorms associated with tropical cyclones or widespread and prolonged heavy rainfall associated with monsoonal depressions. Cyclonic storms may occasionally produce more than 1000 mm of rainfall per day and monsoonal flood rains may persist for many days. The resulting floods may produce inundation over periods lasting from a few hours to three weeks or more, depending upon the size of the catchment and the characteristics of the river channel and its floodplain.

Flooding is a natural phenomenon which occurs inevitably from time to time in a river or drainage basin and cannot be prevented. The problems associated with disastrous flooding arise because of man's deliberate occupancy of flood-prone areas, undertaken for a variety of good reasons. These include the suitability of flood plains and river banks for agriculture and other forms of primary production, for convenience for transport and navigation, for appropriate topography for towns and cities, and for proximity to domestic, industrial and irrigation water supply. The very existence of the flood plain is, however, clear evidence that floods will occur and flooding cannot be avoided. There can be no such thing as flood prevention: the best that can be expected is flood damage mitigation, which can be achieved only to the extent that the community is prepared to meet the costs incurred.

The important characteristics of floods, which determine the magnitude and cost of their disastrous effects, comprise the following:

(a) The peak depth of inundation, which determines the extent and cost of damage to buildings and crops and the cost and feasibility of mitigation measures;

(b) The areal extent of inundation, which determines similar factors;

(c) The duration of flooding, which is an important factor in determining the degree of damage and inconvenience caused;

(d) The rate of rise of the flood event, which determines the effectiveness of flood warning and evacuation procedures;

(e) The velocity of flood flow, which determines the cost of flood damage and the feasibility and design of levees and floodproofing structures;

(f) The frequency of flooding, which expresses the statistical characteristics of flood events of a given magnitude and determines the long-term average costs and benefits of flooding and flood mitigation;

(g) The seasonability of flooding, which determines the cost of flood damages, particularly when agricultural areas are inundated.

To understand the nature of flooding, and to provide a basis for assessing the likely effects of different forms of land use on flood behaviour, it is necessary to consider briefly the mechanics of the run-off process. This is a complex hydrological process in which many variable factors and influences may be at work. Its complexity increases with the size of the catchment under consideration, so that the flood behaviour of a small upland watershed may be entirely different from that of a large river basin of which it is a part, even though they are both subject to the same flood-producing storm rainfall conditions.

When heavy storm rainfall occurs, the precipitation will initially be intercepted on vegetation or infiltrated into the soil, where it will build up soil moisture levels and reduce infiltration capacity. When this capacity is exceeded, overland flow will commence and a build-up of surface run-off, flowing towards the nearest watercourse, will commence. Once this run-off reaches a watercourse, the rate of streamflow will commence to increase and, if the supply of run-off continues, to cause the stream to rise and perhaps overflow its banks. At the same time, precipitation which has infiltrated into the soil may move laterally as interflow or, at a deeper level, as groundwater flow, and eventually enter the watercourse and supplement the flood streamflow.

In a large valley, this process will be repeated on many sub-catchments, all of which may contribute surface and groundwater run-off to channel flow. A combined flood wave of increasing magnitude will move downstream through tributaries to the main river channel, where it may eventually exceed the capacity of the river channel and overflow its banks to inundate the flood plain.

A significant and fundamental aspect of this process is that at every stage and in every component of it, there are various forms of temporary storage through which the water must pass as it moves through the catchment. Examples of such storage include interception storage, soil moisture storage, groundwater and interflow storage, surface depression and detention storage, channel storage and floodplain storage. As it fills and subsequently empties, the effect of each component of the catchment storage is to delay and attenuate the flow of flood water, so that the peak of the flood hydrograph occurs some time after the peak rate of the storm rainfall which produced the flood flow. On very small watersheds, this delay may be a matter of minutes or at worst a few hours; on large river basins it may be several weeks and in extreme examples, as on very long, low-gradient inland rivers in some parts of the region, several months.

As a flood moves down a large valley, storage effects in the river channel system become increasingly dominant in the determination of the magnitude and time distribution of the flood wave. As the contributing catchment area increases, the peak rate of flow may be expected to increase but the rate of run-off per unit of contributing catchment area can be expected to decrease. The shape of the flood hydrograph will become increasingly attenuated as the flood wave moves down-catchment and the effects of variations in such contributing factors as the intensity and time-distribution of the storm rainfall, the nature of the vegetative cover and land use on the upper catchment, or the extent and effectiveness of upstream flood control measures such as soil conservation works or small detention reservoirs will become increasingly less significant. This is primarily because the channel storage effects become increasingly more significant and eventually, as the catchment size and the storage capacity of the channel system increase, become totally dominant in determining the shape of the flood hydrograph.

The importance of the relative storage effects to the mechanics of the run-off process is such that it is possible to classify catchments according to the level of their significance. Small watersheds are highly sensitive to changes in rainfall intensity and duration, the effects of changes in land use and the effects of other factors which determine overland flow characteristics. As the size of the watershed increases, the effects of channel flow and basin storage become increasingly dominant and sensitivities to variations in rainfall, interception or infiltration become increasingly suppressed. Thus it is possible to classify a "hydrologically small" watershed as one so small that its sensitivities to short-term variations in rainfall intensity and changes in land use are not suppressed by its channel storage characteristics. A "hydrologically large" watershed can be classified as one in which the channel storage effects are dominant in determining flood behaviour and the sensitivities to rainfall and land use are largely suppressed. In terms of actual area, the upper limit for an "hydrologically small" watershed may vary considerably according to a variety of catchment characteristics, but is likely to be in the range of hundreds of hectares to a hundred or more square kilometres.

If the run-off behaviour of a watershed is such as to bring it within the hydrologically small category as defined above, the application of appropriate forms of land use can be expected to be a particularly effective method of flood mitigation. On the other hand, if a catchment falls clearly into the hydrologically large category, there will be substantial limitations upon the effectiveness of such measures for major flood disaster reduction, at least over the lower reaches of the river basin and particularly on the flood plain.

This is not to suggest, however, that land-use management on the upper watershed should not be undertaken. First of all, such management is of substantial value for direct flood mitigation in upper watershed locations. Further downstream, whilst it might not substantially reduce major flood peaks, it may be of significant value in reducing catchment and streambank erosion and reducing the transport of sediment downstream. Watershed management on the upper catchment may be seen to have a range of other advantages, which include maintaining the integrity and productivity of the catchment soils, maintaining the productivity and sustainability of forestry and agriculture, preserving the integrity of natural vegetation and wildlife habitat, maintaining the quality of the catchment ecosystem and the catchment environment, and improving the quality of life of the catchment community. Furthermore, upper watershed land-use control and management may have very significant effects in terms of the maintenance or improvement of water quality throughout the entire river system, and may be desirable for this purpose alone.

2. Riverine flooding

Riverine flooding occurs when the flow in a river channel exceeds its bankfull capacity, overflowing the normal banks and inundating the adjacent floodplain. It is a phenomenon associated with hydrologically large catchments and its most significant effect is the widespread, comparatively shallow inundation of large expanses of flat terrain.

The most important factors determining the magnitude and severity of riverine flooding are the total depth of the excess rainfall producing the flood in question, the total area of the contributing catchment, and the lag or delay time between the occurrence of the storm peak and the passage of the flood hydrograph peak. The factors will particularly affect the depth and areal extent of flooding, matters which will also be determined by the topography of the inundated areas and particularly the lateral slope and width of the floodplain. The duration of the flood-producing rainfall, as well as the catchment lag characteristics, will also affect the duration and time distribution of the flood event.

Within the ESCAP region, riverine flooding is a common occurrence which involves substantial average annual flood damage costs. In this region, a very high proportion of the community in many countries occupies floodplain sites which experience frequent and devastating flooding. The most common cause of disastrous riverine flooding is prolonged intense rainfall, although is some parts of the region, in the Himalayas or at higher latitudes, snowmelt may be a contributing factor.

The most severe flooding experienced in the region is caused by very intense rainfall associated with major tropical cyclones, particularly where the influence of the cyclone extends over a considerable area. Intense long-duration rainfall associated with monsoonal depressions is also an important cause of serious riverine flooding.

In the large river basins of the region, such as the Ganges, the Mekong and the Yangtze, flooding is usually seasonal and may last for many weeks. These basins are subject to continual rainfall during the wet season and exhibit a long high water period, with a comparatively slow rise and fall, during this season. Major flooding can result if intense storm rainfall occurs during such conditions. On smaller drainage basins, on rivers such as those of north China, Japan and the Republic of Korea which are subject to occasional tropical cyclones and intense convective storm activity, basin lag times are shorter and marked fluctuations of river level can occur during wet season conditions.

There is a variety of techniques which can be used to mitigate the damage caused by riverine flooding, and these are discussed in Chapter VI. Because this kind of flooding is a feature of river basins which are hydrologically large, there are limitations upon the extent to which the use of land-use practices and land-use control measures on the upper watershed can reduce the magnitude of disastrous riverine flooding. Within the floodplain areas subject to inundation, however, land-use management practices, and specifically land-use control by zoning, may be an important aspect of flood mitigation and a key component of the overall integrated watershed management programme for the river basin concerned.

3. Flash flooding

Flash flooding is a phenomenon principally associated with watersheds which are hydrologically small. It is commonly caused by intense convective storms of comparatively short duration but producing highly intense rates of rainfall. The severity of flooding is increased if the watershed is steep and its surface has low infiltration capacity. The duration of the flooding is short but the depth of flooding can be considerable and very extensive damage may result. Because they occur very rapidly and with little warning, flash floods can cause substantial injury and loss of life.

In the ESCAP region, flash flooding can be experienced wherever high intensity thunderstorms are common during the summer months or wherever intense thunderstorm activity associated with the passage of strong monsoonal depressions can be expected. It is most damaging in mountainous areas on small, steeply sloping catchments which have been cleared of protective vegetation. This type of flooding appears to be becoming more prevalent and more costly in terms of life and property because of increasing population density in districts subject to deforestation.

Because flash flooding is a phenomenon which is principally associated with watersheds which are hydrologically small, changes in land-use practices and the use of land-use controls can be effective means of flood mitigation. Such land-use practices as forest revegetation or the use of farming techniques such as terracing or strip cropping can substantially reduce flood damage and corresponding land degradation.

Land-use controls, such as the zoning of flash flood prone lands to prohibit village occupancy, can also be most effective.

4. Urban flooding

Urban flooding can be experienced in watersheds of all sizes, wherever the community has occupied locations which are susceptible to inundation by floodwater. In watersheds which are hydrologically small, it results from cyclonic or storm rainfalls falling on local areas, within or adjacent to urban settlements, where the process of urban development itself has dramatically altered the run-off-producing characteristics of the catchment. In watersheds which are hydrologically large, it is essentially an aspect of riverine flooding, which occurs because of overbank flow from major rivers onto floodplains which have been intensely developed for urban settlement.

When a catchment becomes wholly or partially occupied by urban development, this development can increase the volumes and rates of run-off from storm rainfall dramatically, partly because of the extent to which it decreases surface infiltration capacity and partly because of the extent to which it reduces times of concentration. In a dense urban environment, as compared with a natural rural environment, the enormous increase in impervious roofing surfaces and sealed pavement surfaces such as roads and parking areas results in much reduced infiltration of rainwater and a much greater volume of run-off.

The increase in paved ground surfaces, together with the installation of a more efficient drainage system, greatly reduces surface depression and detention storage, reduces the time of concentration and delivers run-off to the nearest watercourse in a fraction of the time that this would have taken prior to urbanization. The result is a much sharper rise in the rate of flood run-off, which greatly increases the peak discharge rate from the catchment and substantially increases the subsequent depth and severity of flooding. For these reasons, urbanization can significantly increase the peak discharges in smaller, comparatively frequent storms. Even in larger, rarer storms the peak discharges can be double those of an equivalent rural catchment.

For urban development on upland areas away from the floodplain, where the urbanized catchment behaves as an hydrologically small watershed, the extent to which land-use planning and management can be utilized to assist in flood mitigation is limited. Zoning of the urban area to provide adequate flood disposal waterways, to provide flood run-off detention storage sites and to prohibit residential development in highly flood-prone areas are some of the measures commonly adopted.

For intensely developed urban areas on floodplains, where there is a high risk of disastrous flooding, land-use planning and control measures have an important role to play in any flood mitigation strategy. In particular, land-use zoning to restrict or prevent housing development in areas subject to deep or high-velocity flooding is a widely-used technique under such conditions.

5. Coastal flooding

Coastal flooding can be caused by a number of factors. In the ESCAP region, the most serious forms of coastal flooding may be due to storm surge, storm tides or tidal waves (tsunami).

Storm surge flooding occurs when a tropical cyclone approaches a coastline. The low atmospheric pressure at the centre of a tropical depression causes the water surface below it to become elevated above the level of the surrounding ocean. As the cyclone approaches the coast, strong winds may pile up the already high sea waters against the shoreline, thus aggravating the rise in water level. The combined effect can produce serious flooding in low-level coastal areas.

A storm surge can be expected to be accompanied by high winds, wave action, intense rainfall and major flooding. Although its effects are restricted to a relatively narrow strip of coastline, it has the potential to cause substantial loss of life and property damage, particularly in coastal regions which are heavily populated.

When the landfall of a tropical cyclone coincides with a high tide, the depth of the storm surge is augmented by the tidal rise and the rise in sea level may exceed several metres above normal. The combined effect is termed a "storm tide". This phenomenon can be particularly devastating.

A tsunami is a different form of coastal flooding, generated by a submarine earthquake which causes a travelling ocean wave. As this wave approaches the coast its height increases rapidly and it can become very destructive as it inundates the shoreline zone.

Within the ESCAP region, many of the most severe disasters associated with tropical cyclones have involved storm surges. These phenomena are most severe in coastal regions within the tropical cyclone belt, although coastal flooding can also occur in extra-tropical and temperate regions. Countries or areas which are particularly susceptible to storm surge disaster include Australia; Bangladesh; China; the Philippines; Hong Kong, China; the Republic of Korea; Thailand; and the Pacific island countries. The northern sector of the Bay of Bengal, where the coast geometry exacerbates the phenomenon, is reported to be particularly at risk.

Because the disasters resulting from coastal flooding are location-specific, land-use planning and management offers significant potential mitigation potential. In particular, zoning to limit or prohibit high-risk development in areas highly susceptible to storm surge flooding, if acceptable, is a highly effective mechanism.

D. Land instability

The term "land instability" is used here to apply to those kinds of disaster which involve the sudden movement of masses of earth and rock material down slopes and hillsides, principally as a consequence of heavy and prolonged rainfall. Such disasters include landslides, earth slips, mud flows, talus slides and detritus flows and in the context of this manual they are assumed to be associated with abnormal meteorological phenomena such as tropical cyclones, heavy thunderstorms, or intense and prolonged storm rainfall events associated with monsoonal fronts and extra-tropical cyclones. Land instability can also be initiated by earthquake action, which in some cases may aggravate the effects of rainfall saturation and gravity sliding.

The stability of a hillside or a man-made slope depends upon the weight of the overlying material, the steepness of the slope and the strength of the underlying layer or foundation. If the gravitational forces tending to cause sliding exceed the shearing strength of the underlying material along any potential failure surface, failure by slipping or sliding will occur.

When such instability does occur, the soil or rock material moves downwards and outwards – the upper part of the slide area, or *root,* subsides and the lower part, or *tongue,* bulges and extends outwards from the foot of the slope. In some types of slide, where the moving material is very soft and unstable or temporarily in a liquified condition, the tongue may move outwards for some hundreds of metres from the toe of the slope and completely block the valley floor.

The area encompassed by an individual landslide is usually comparatively small and self-contained, although it may extend across many hectares. Even on relatively uniform slopes of great length and approximately uniform height, all subject to the same extreme weather conditions, slides usually occur only at a comparatively small number of isolated places, separated by considerable distances.

If the land surface overlying the slide area, or the land in the locality below the tongue of the slide, has been developed for forestry or agriculture or more seriously, is occupied by domestic or industrial development, the result of a major land instability event may be disastrous, causing serious loss of production and land productivity, dramatic damage to buildings and property, and potentially extensive injury and loss of life.

Disastrous land instability is generally a consequence of the presence of excess water in the sliding material and the underlying foundation. The source of this water may be infiltration, interflow or shallow groundwater consequent upon heavy or prolonged rainfall, and the condition is aggravated by poor drainage. The presence of excess water greatly reduces the stability of the slope for several reasons: it increases the weight of the overlying material; it increases the pore pressure in the underlying material; it lubricates the underlying failure surface; and it seriously reduces the shear strength of the material along the failure surface. In extreme cases, the presence of water may cause the complete liquefaction of the material on the slope, leading to the phenomena known as mud slides or flow slides.

The susceptibility of a given hillside or mountainside to sliding is dependent upon the nature of the overlying material and the geology of the underlying strata. The most common types of troublesome material include layers of weathered schists or shales, very loose water-bearing sands, homogeneous soft clay, stiff fissured clay, clay with sand or silt partings, and bodies of cohesive soil containing pockets or layers of water-bearing sand or silt. An underlying geological structure with slip or fissure planes lying approximately parallel to the slope offers particular problems. On natural slopes, the propensity to sliding may be aggravated by poor drainage conditions, works or land treatment measures which encourage the infiltration of surface water into the unstable material or its foundation, or the removal of vegetation, particularly large tree species which have extensive root systems capable of providing resistance to sliding forces. In developed regions, the existence of large engineering works such as quarries or road and railway cuttings is particularly likely to increase the risk of disastrous land instability unless appropriate and adequate engineering precautions are taken.

The term "landslide" is generally applied to the sudden movement of a large mass of soil and/ or rock material down a steep slope, with the damage extending over a comparatively large area. "Landslips" are much smaller phenomena, although in country susceptible to landslip failure a great many individual slips may occur over a significant area in a short period of time. "Landcreep" failures, on the other hand, occur very slowly, allowing time for the taking of ameliorative or corrective measures.

"Mud flows" and "flow slides" occur when the overlying material is thoroughly saturated and, as a consequence of various initiating forces, becomes suddenly liquified. Failure occurs rapidly and the moving material travels a considerable distance outwards from the toe of the slope, causing extensive damage and devastation.

"River blockages" are a consequence of land instability, occurring when the outwards movement of material from the toe of a large landslide or flow slide completely blocks a river valley, forming a high dam behind which flood water accumulates to form a large reservoir. Such a dam is naturally unstable and extremely likely to fail suddenly, either by overtopping or by slumping, allowing the sudden release of a large volume of water and causing a flood wave to surge downstream. This may result in substantial injury and loss of life, serious property damage, damage to the river channel because of severe bank erosion and the destruction of any infrastructure, such as bridges, roads, or railways, which lies in the path of the wave.

In the ESCAP region, water-based disasters due to land instability are of widespread occurrence and periodically lead to significant damage and loss of life. They are particularly prevalent within the tropical cyclone belt, on steep hillside and mountain country which has been cleared of native vegetation and developed intensively for agriculture or rural village settlement. In more temperate regions, land instability can also be a serious problem in mountainous areas where intense and prolonged rainfall events can occur. For example, landslides are a common occurrence in the Himalayas, whilst extensive land slip disasters are occasionally experienced in other countries, such as Thailand.

Because the susceptibility of specific localities to land instability can usually be predicted and is generally well-known, land-use planning and management tools and techniques offer considerable potential for disaster mitigation. Where it is feasible, land-use zoning can be employed to prohibit or restrict human settlement or agricultural development in high-risk areas. Where the occupation of such areas is unavoidable, there is a variety of land-use control techniques, such as the restriction of logging or overgrazing or the application of precautionary land management practices, which can be utilized to assist in disaster prevention or mitigation.

E. Drought

Drought is a quite different form of water-based natural disaster from those previously described, because it is consequent upon a severe deficiency of water, not an excess of it. It can, however, be equally devastating in its effect, bringing severe economic and social consequences and resulting in serious loss of rural productivity and wide-spread and long-lasting degradation of land and other natural resources.

Drought might be briefly defined as a serious water shortage. This implies some specification of the amount of water required and the purpose for which it is to be used, both of which will determine whether a drought condition exists. What constitutes a drought for a given use in a given location may not be considered a drought elsewhere. By way of example, in Bali a drought is defined as a period of six days without rain, whereas in Central Australia an annual rainfall total of less than 200 mm might be considered normal and a severe drought may have a duration of several years.

It is generally accepted that there are at least three types of drought:

A "meteorological drought", which can be defined as a significant decrease in the normally expected seasonal rainfall, extending over a substantial area – the parameters used to measure and express its effect are the total rainfall depth and the duration of the drought period.

An "agricultural drought", which can be defined as a period during which the amount of rainfall and soil moisture content are inadequate for crop and pasture growth and animal production – the parameters used to express its severity are rainfall depth and soil moisture content.

An "hydrological drought", which can be defined as a period of below average water content in rivers, reservoirs, lakes, groundwater aquifers and soils – the parameters used to indicate its magnitude are given in terms of water storage volumes and available flow rates.

The adverse consequences of drought may be both short-term and long-term. Droughts produce immediate and relatively short-term disastrous effects upon a wide range of economic activities from crop and livestock production to water navigation and hydro-electric power production. In the longer term, droughts may result in significant loss in agricultural productivity, a forced move to less economic forms of land use, progressive land degradation or desertification, land abandonment, depopulation and the failure of communications.

A further consequence of prolonged drought, not normally expected, can be the severe increases in flooding and soil erosion which may occur if heavy storm rainfall occurs at the end of a drought, when protective vegetative cover has been lost and run-off rates may be substantially increased.

Because the nature and severity of a drought event is determined by weather conditions, it is difficult to predict its onset, its intensity or its likely duration. In the ESCAP region, this is particularly the case in higher latitude, continental regions which are outside the Tropics and away from monsoonal, trade wind or other seasonal rain pattern influences. There is increasing evidence, however, that in those parts of the region lying around the western Pacific rim, the occurrence of severe drought is associated with the El Niño phenomenon.

Drought is an intermittent problem in all the countries of the ESCAP region, even including the Philippines, Indonesia and the islands of the South Pacific. 1Major drought disasters are experienced from time to time in Australia, India and northern China, where the consequences of a drought event may be of very considerable significance to the national economy over a long period. Heavy loss of livestock, human disease and starvation, loss of wildlife and natural vegetation, and extensive and long-lasting land degradation, are all likely outcomes of drought disaster.

Land-use planning and management can provide a range of tools and techniques to assist in the mitigation of drought disaster. These include a wide range of special agricultural practices aimed both at improving preparedness for drought and managing drought conditions more effectively. Conservation farming practices are designed to increase the intake and storage of soil moisture, to reduce the rate of usage of soil moisture, and to mitigate the in-drought and post-drought effects of wind and water erosion. The conservation and storage of food, fodder and water and a variety of livestock management techniques are also employed both as drought survival tools and as safeguards against drought-induced land degradation.

Water conservation and the careful management of surface and underground water resources are key elements in any drought mitigation strategy. In drought-prone areas, the provision of adequate water storage and distribution systems and facilities for water supply and irrigation is essential, along with the careful and conservative development and husbandry of groundwater resources. Watershed management practices aimed at increasing and stabilizing the long-term supply of surface and groundwater and recharging groundwater aquifers have an important part to play in drought management practice.

F. The regional experience

Water-related natural disasters in the form of tropical cyclones, floods, landslides and mud flows are periodical occurrences in the majority of the countries of the ESCAP region. In many places land degradation, the consequence of poor land management, has served to aggravate the seriousness of such disasters. The available data indicate that, whilst not all the ESCAP countries are affected by tropical cyclones, very few of them are free from damaging flood events. These data also indicate that whilst tropical cyclones and associated storm surges are likely to cause the highest numbers of fatalities, floods are the most frequently occurring disaster events and the ones which cause the greatest total amount of damage. Tsunamis are also the cause of substantial destruction in coastal regions. Elsewhere, landslides and mud flows following very heavy rainfalls may cause considerable damage in both urban and rural communities. Droughts are a frequently occurring natural disaster in many countries, impacting particularly upon rural communities. Land degradation may exacerbate and prolong the adverse consequences of such events.

Cyclones, floods and drought are the worst forms of natural disaster to affect Bangladesh, although droughts occur only comparatively rarely. Tropical cyclones originating in the Bay of Bengal are usually associated with heavy rainfalls, strong winds and storm surges. Tidal waves often accompany cyclonic storm events. Tidal wave and storm surge conditions have from time to time been responsible for very heavy loss of life and extensive property damage. Severe flooding occurs along the main rivers in Bangladesh and smaller tributary streams may also experience serious flooding as a result of intense local rainstorms. Because Bangladesh has only a small area of hilly country, flash flooding or mass movement are not significant problems.

In Cambodia, major flooding can be caused by the Mekong River, as a consequence of heavy monsoon rainfalls over its upper catchment. Flash flooding is also common on smaller high-level watersheds across the country. Landslides caused by heavy rainfalls are also a common occurrence on upland watersheds.

Tropical cyclones can occur along the entire Chinese coast and the inland areas adjacent to it. The eastern and southern coastal regions are particularly vulnerable but all inland areas, with the exception of the north-western region, are within the range of cyclone damage. Most of the tropical cyclones affecting China approach from the China Sea. They may cause heavy damage along both large and small rivers, as well as along the coastline. Flooding may also be caused by heavy rainstorms, ice jams or landslides. Apart from these effects, landslides and mud flows can be problems across substantial areas of China. Many areas are also affected by droughts, often occurring sequentially, which result in severe impacts upon agricultural production and the overall national economy.

India has a long coastline which is exposed to tropical cyclones originating in the Bay of Bengal and the Arabian Sea. These cyclones are usually associated with high winds, torrential rains, flooding and storm surges. Elsewhere in India, flooding occurs during the monsoon season and is a consequence of heavy rainfalls associated with cyclone events, the monsoons, or intense tropical storms. Flash flooding is a problem on steep watersheds. Landslides are also a common and frequent form of natural disaster in India, a consequence of heavy rainfalls and land and soil degradation resulting from inappropriate human activities on steep country. The highest incidence of landslide disasters is to be found in the Himalayan region. Many parts of India are also subject to severe drought events, a consequence of the erratic occurrence and behaviour of local rainfall conditions. It is estimated that 70 per cent of the agrarian districts of India are drought-prone.

Climatic conditions in Indonesia are dominated by the tropical monsoon which extends from December to May each year. Flooding is the most frequently occurring natural disaster phenomenon, but tidal waves, landslide and droughts may have severe effects on local populations. The occurrence and severity of such events varies widely across the many island regions of which Indonesia is composed. Generally speaking, the upper watersheds of most large rivers are characterized by very steep slopes which are occasionally subject to very high intensity rainfall. Under such conditions, flash flooding and landslides are common occurrences. On the coastal plains, extensive and protracted flooding occurs from time to time.

The major forms of water-based natural disaster to affect the Lao People's Democratic Republic are droughts and floods. Whilst tropical cyclones are not a direct threat, they can produce very heavy rainfalls leading to devastating flooding on the many smaller tributaries throughout the country. Flooding along the Mekong River results from heavy monsoon rainfalls during the period of August to September. Droughts may be experienced between May and July, before the arrival of the monsoon season.

On the east coast of Peninsular Malaysia, and along the coastline of Sabah and Sarawak, flooding is commonly associated with the north-east monsoon during the months of November to February. Intense, localized and short-duration thunderstorms are often the cause of flash flooding on the small but steep watersheds along the west coast of Peninsular Malaysia. In urban areas of Malaysia, intensive convective thunderstorms during the monsoon season are often the cause of flash flooding, particularly in Kuala Lumpur. Landslips or mudflows are an occasional consequence of heavy localized rainfall. Generally speaking, however, Malaysia is relatively free from massive flooding caused by severe tropical cyclones.

Along the coast of Myanmar, widespread damage can result when tropical cyclones coincide with storm surge conditions. Cyclones occur during the months of June to December. Severe tropical storms are also experienced during April, May, October and December. Flooding during the south-west monsoon may severely affect the lower reaches of the Ayeyawaddy River. Flash flooding is also experienced over upstream tributaries and smaller watersheds as a consequence of heavy rainfall. Damages from landslides, mudflows or droughts are essentially negligible by comparison with the severe damages that results from cyclone and flood events.

The climate of Nepal is largely controlled by the monsoon cycle. The principal flood season coincides with the period of maximum monsoonal rainfall, which usually occurs in August. High altitude watersheds are subject to major flooding from snowmelt. Flash flooding may also occur in the higher watersheds as a result of heavy rainfall. Glacial outburst floods may occur as a result of the sudden release of ponded glacial lakes and landsliding is also a common occurrence in high watersheds.

Pakistan does not suffer from the damaging effects of tropical cyclones, but is subject to devastating floods originating from monsoon rainfalls and snowmelt. The most widespread flooding occurs on the floodplains of the larger river systems, but upstream flooding resulting from landslides or the blocking of tributaries by glacial dams is also a common problem. Drought is a common feature of climatic conditions in the arid regions of Southern Pakistan and may have severe adverse effects, not only in economic and social terms but also in its land degradation consequences.

Water-related natural disasters are of common occurrence in the Philippines, where they may produce massive devastation. They include cyclones, floods, mass movement and drought. The severity of the impact from such disasters varies from region to region according to geographical location and topographical features. This country lies within the tropical cyclone belt and is affected by cyclones associated with the south-west monsoon during May-September and the north-east monsoon during November-February. Flooding is the most commonly occurring form of natural disaster and includes both riverine flooding and coastal flooding. Coastal areas are particularly susceptible to flooding from tsunamis, which may be aggravated at high tide periods. Floods often cause tremendous damage to prime agricultural lands and to government infrastructure such as roads, bridges, irrigation dykes and flood-control structures. Landslides are the most commonly-occurring form of mass movement disaster in the Philippines, and may affect pristine, disturbed or developed land areas.

The Republic of Korea is located in the temperate monsoon region. About two-thirds of the annual rainfall is received during the monsoon period from June to August. During these months, tropical cyclones and intense depressions bring heavy rainfall which often results in major flooding. Prior to the monsoon season, occasional droughts affect the agricultural and industrial sectors and impact upon rural communities. Tsunamis and landslides produce less frequent and less harmful natural disaster events.

Sri Lanka may be subject to a variety of natural disaster events, which include tropical cyclones, floods, droughts, landslides and coastal erosion. Heavy rainfalls occur during both the north-east monsoon period, from October to February, and the south-west monsoon period, from May to September. Tropical cyclones occur only rarely, but they can cause severe destruction and heavy loss of life. Floods are a common occurrence and they are often associated with landslips. Flash flooding is experienced on the high watersheds of the central mountain range and its slopes. Drought is also a common occurrence in the northern and eastern districts.

In Thailand, major natural disasters are mainly the consequence of flooding caused by heavy rainfalls associated with tropical cyclones. Landslides may also cause severe problems, whilst droughts are a common occurrence in the months preceding the rainy season. Tropical cyclones and deep tropical depressions may extend across Thailand between May and October. These are associated with very heavy rainfalls which can produce major and protracted flooding along the larger rivers and their flood plains. Destructive flash flooding is also a common occurrence on the smaller watersheds scattered throughout the country.

In Viet Nam, the northern and central regions are often affected by tropical cyclones during the rainy season, which occurs between July and October. Storm surges may also be a problem along the coastline. Flash flooding occurs on the many small, steep watersheds in the central region, whilst extensive and protracted flooding can be experienced in the Red River Delta region to the north. Although tropical cyclone damage is rare in southern Viet Nam, the Mekong Delta region commonly experiences major flooding as a result of heavy rainfall on the upper catchment.

IV. INTEGRATED WATERSHED MANAGEMENT

A. Watershed management and natural disaster management

Most countries in the ESCAP region are rapidly coming to the recognition that land degradation is reaching serious proportions, causing damage to the national economy and lowering living standards. The consequences of inappropriate cultivation practices and other exploitative forms of land use are becoming manifest in the form of deep erosion gullies, bare and eroded grazing lands, over-clearing of vegetation, rising water tables, salinized soils and the movement and accumulation of sediment and erosion debris in streams and river channels.

The effects of land degradation are cumulative and far-reaching. Not only do they affect rural communities, but they also affect urban populations. Reduced agricultural productivity is often accompanied by an increase in the impact of water-related natural disasters which devastate rural and urban and communities alike.

Land degradation control is essential if future rural production is to be maintained and improved. Land restoration measures, involving soil erosion control, enhanced vegetative cover and water run-off management will help to preserve the remaining soil and vegetation resources and assist in mitigating the severity of natural disasters. However, much of the land degradation is already irreparable and no amount of effort can overcome the existing damage. Any productive soil which is already lost through erosion has already permanently left the system.

If land degradation is to be checked, there is a need for careful planning in the approach to the development and use of the land. In many countries, the need for planning is urgent because the effects of inappropriate practices of land utilization and its over-exploitation are already irreversible or rapidly approaching that state. Many practices used in the past have contributed to the present degraded state of the environment and should be discontinued if the land is to contribute to the continued prosperity of the individual countries. Any delay in implementing a comprehensive and coordinated system of land management will further exacerbate the situation.

Land management strategies should aim to achieve sustainability of natural resources – land, water, vegetation and fauna – by balancing development and the use of these resources with conservation. To be effective however, land-use management should not be restricted to isolated areas but should be applied to total watersheds. This approach is called "integrated watershed management" and is based on the concept that the components of natural resource systems, such as watersheds, are inter-connected so that changes to one part of the system will influence other parts.

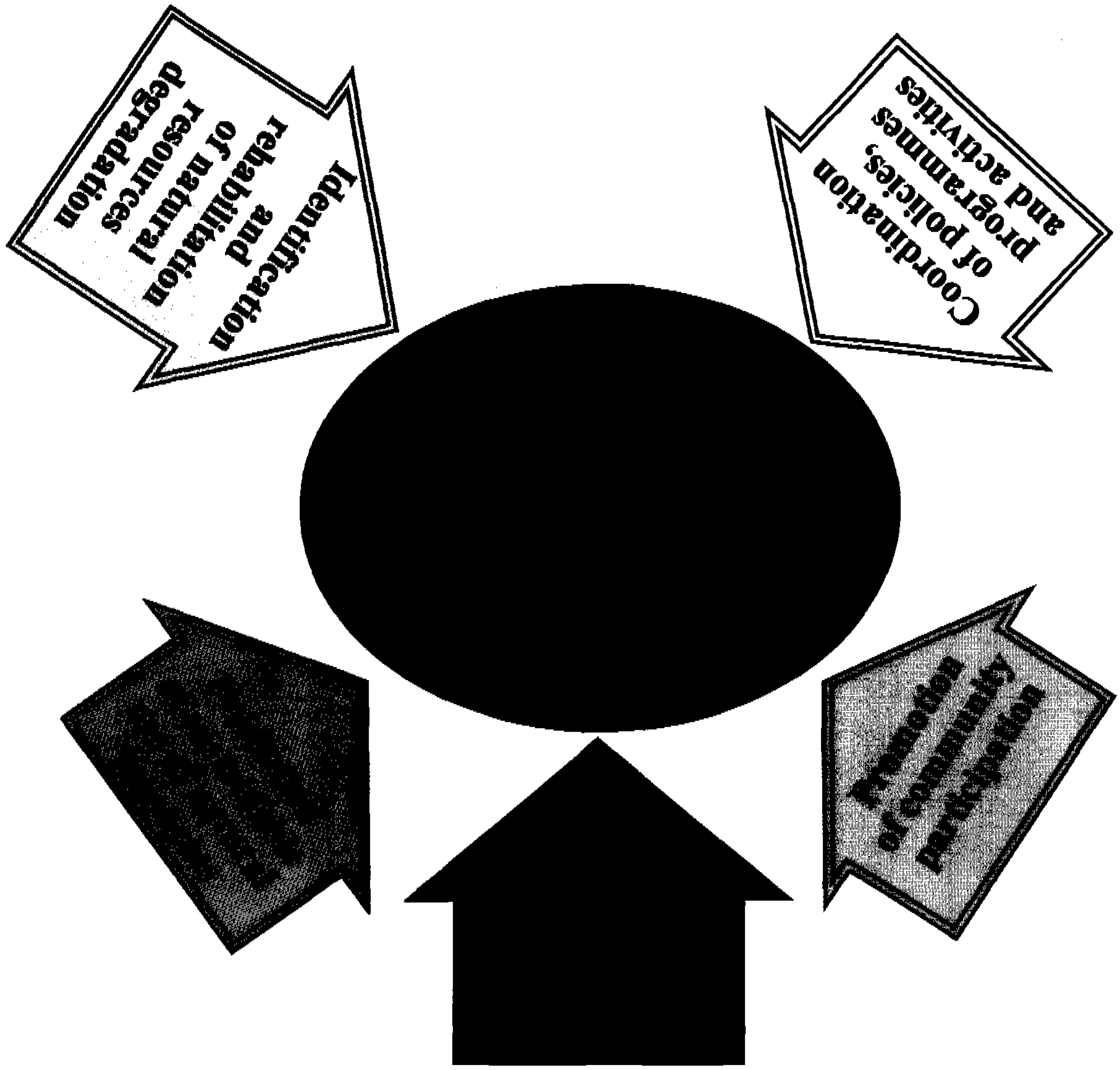
Integrated watershed management should be based on a plan which sets the direction and provides a framework for the planning and development of individual catchments. These plans should ensure that there is a structural approach to the management and exploitation of natural resources, such as land, water and forests, and that these resources are managed in a sustainable fashion. They should address the issues and consider the activities which culminate in land degradation. Strategies which overcome land degradation and which mitigate the effects of natural disasters should also form an integral part of the management package.

Those strategies which are essential to the achievement of the objectives of integrated watershed management, as illustrated in figure 2, comprise:

(a) Coordination of policies, programmes and activities as they relate to integrated watershed management;

(b) Promotion of community participation in integrated watershed management;

FIGURE 2. STRATEGIES TOWARDS INTEGRATED WATERSHED MANAGEMENT OBJECTIVES



(c) Identification and rehabilitation of natural resource degradation;

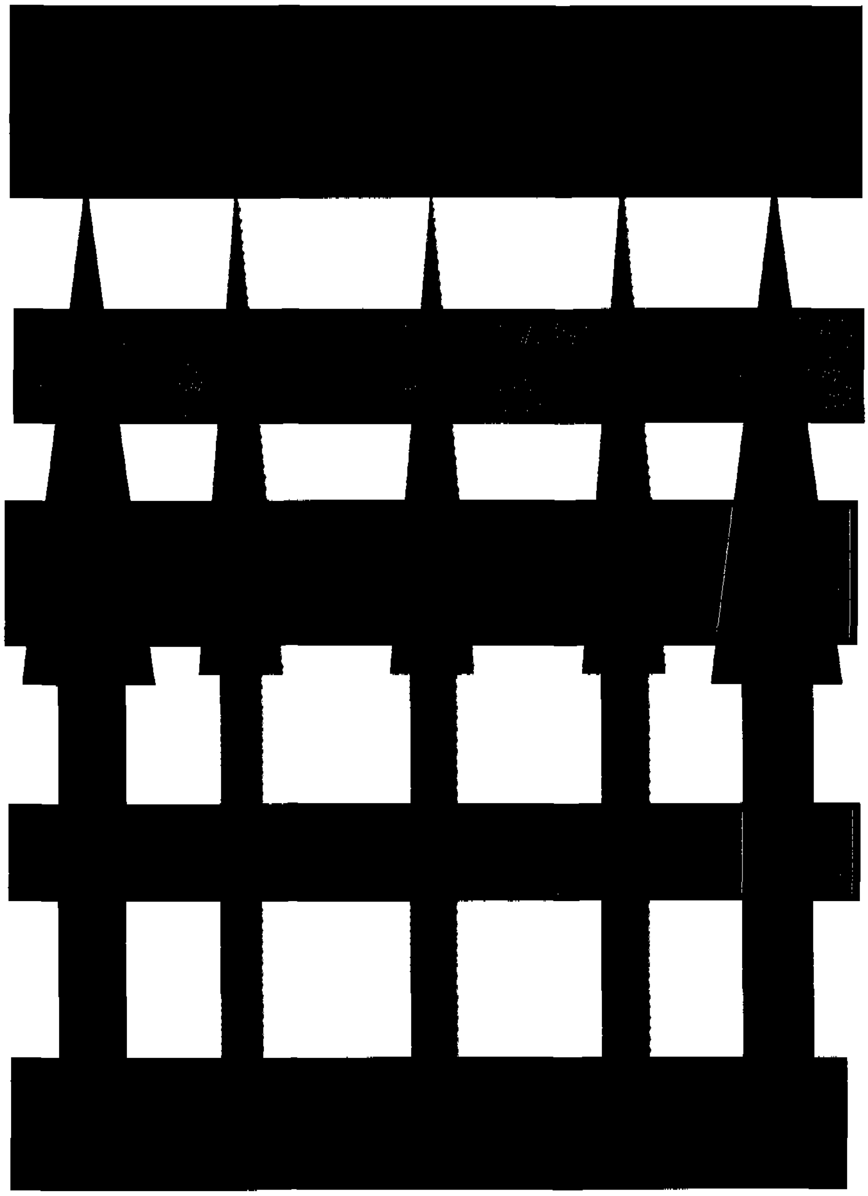
(d) Promotion of the sustainable use of natural resources;

(e) Provision of stable and productive soils, high quality water, and protective vegetative cover within individual watersheds.

These broad-based strategies recognize that problems with water, soil, vegetation and natural resources in urban and rural areas do not happen in isolation but are often inter-related. For example, many activities in a watershed may have only limited impact when carried out in isolation but their combined impact may be significant and require the adoption of strategies which

- prevent further land degradation
- restore degraded natural resources
- ensure that natural resources are used within their capability
- minimize the impacts arising from the use of natural resources

FIGURE 3. A STRATEGIC APPROACH TO INTEGRATED WATERSHED MANAGEMENT



- ensure that native flora and fauna are protected
- promote appropriate planning and management
- preserve items and places having cultural heritage values

Integrated watershed management can be the most effective approach in mitigating the effects of natural disasters by adopting the best management practices to balance the competing and compatible uses of a watershed's natural resources to meet social, economic, environmental and other community goals. It should be stressed that when the risk of natural resources disasters is not fully appreciated the loss of life and damage to property can be dramatically increased.

B. A strategic approach

Land-use planning and management are important government functions. When governments fail to exercise effective controls in this and related fields, the natural environment, the community and the national economy may all become casualties. On the other hand, when good planning and management practices are adopted, many existing or potential problems are automatically overcome or avoided. A strategic approach, including effective governmental arrangements which address resource management and environmental protection issues and utilize enlightened watershed management principles, is considered to be the key to achieving an efficient and acceptable administrative system (see figure 3).

Appropriate legislative and institutional arrangements are also necessary to ensure a satisfactory level of environmental protection, social well-being and sustainable resource development.

In some countries, governmental approaches to land-use planning, environmental protection and natural resource management are under ongoing development. In the past, resource management, planning and environmental law has tended to evolve in a somewhat *ad hoc* and reactive fashion. Throughout the ESCAP region, however, much of the existing legislation is currently being redrafted or refined, with the objectives of reducing complexity, overcoming delays and eliminating conflicts and confusion in relation to resource and environmental management. Some of the existing deficiencies, expected to be remedied through recent and current legislative and institutional developments, include:

(a) Adverse trends in natural resource degradation and depletion;

(b) A low level of strategic and policy commitment to natural resource management, with inadequate financial, legislative or operational support;

(c) Uncoordinated and conflicting approaches from various government agencies;

(d) Lack of uniformity or consistency in policies, legislation and strategies amongst different tiers of government;

(e) Inappropriate and inconsistent administrative structures and boundaries;

(f) Low levels of policing and enforcement of controls, conditions and regulations;

(g) Low levels of community involvement in resource management activities.

The requirements of an improved administrative system capable of meeting the challenges of protecting the environment, integrating economic and land-use planning and management and encouraging sustainable resource management include the following needs:

(a) A comprehensive and strongly coordinated legal and administrative system which addresses planning, environmental protection and resource management in an integrated fashion;

(b) Consolidated legislation based on the principles of sustainable resource management, protection of the environment and the maintenance of vital ecosystem processes;

(c) A land and resource management system based on watershed or river basin units and utilizing standardized regional planning policies and processes;

(d) Clearly defined responsibilities for each tier of government;

(e) Consolidation of existing legislation into a manageable number of concise but comprehensive Acts.

In some countries, recent developments in this respect have led to the consolidation of several government agencies into a single, comprehensive agency and the consolidation of existing legislation into a single omnibus Act. Within the ESCAP region, New Zealand provides an outstanding example of this approach, which is worthy of investigation. In larger and more diverse countries, particularly in large Federations where several states have resource and environmental management responsibilities, this might not be an appropriate solution. The important emphasis should be on coordination and cooperation between agencies, integration of management activity and responsibility, and the taking of a holistic view of resource and environmental management issues, rather than upon amalgamation and unification.

If the needs listed above can all be met, a basic framework is provided for the planning and implementation of new and existing plans, policies and strategies for the efficient and effective management of land and water resources. Such a management system focuses upon the effects and consequences of development, rather than upon development itself. To be effective, this management system must provide for the meaningful involvement of the watershed community, as well as, and in strong coordination with, all tiers of government.

C. Development of a management system

Watersheds are naturally occurring units of the landscape, containing a complex array of inter-linked and inter-dependent resources and activities which are not determined by political boundaries. They form a dynamic and integrated bio-physical, economic, social, environmental and political system containing people, agriculture, industry, communications, services and recreational facilities. The land resources of soil, water and vegetation cannot be managed in isolation from each other. The natural balance of resources in a watershed can be easily disrupted by changes in land use, by mismanagement or through bad planning.

Integrated watershed management recognizes that the natural resources and the environment of a watershed can only be successfully preserved and protected by integrating and managing the available natural resources. The broad objective is to develop policies which promote the sustainable use of natural resources and take into consideration the economic, social and environmental issues of the watershed.

Successful implementation of the integrated watershed management (IWM) concept requires coordinated action by the various government authorities that are involved in land and water management. This is because no single authority can have the experience, expertise and legislative powers to be solely responsible for the overall management of natural resources. In addition, it is essential that the community and individual landholders play a major role in IWM because their actions and farming practices will, to a large extent, influence the outcome of the approach.

IWM strategies should address the use and management of land within the watershed so that degradation of the land, and of the environment in general, is avoided. This form of planning is directed towards coordinating and controlling land-use change and development in order to minimize impacts which may be harmful to the environment. At the same time, it should aim to maximize the benefits of development to individuals and the community. The desirable objectives of this management system (see figure 4) can be summed up as follows:

(a) Encouraging proper management of the country's resources, which include natural areas, forests, minerals, agricultural and urban lands, water and other resources;

(b) Promoting the social and economic welfare of the community;

(c) Sharing the responsibility for environmental planning between all levels of government; and

(d) Providing opportunities for community involvement in planning.

If adverse environmental effects are to be minimized, the system should allow for:

(a) Environmental factors to be considered before a decision on development is made;

FIGURE 4. OBJECTIVES OF AN INTEGRATED WATERSHED MANAGEMENT SYSTEM

- Encourage proper management of the country's resources, which include natural areas, forests, minerals, agricultural and urban lands, water and other resources
- Promote the social and economic welfare of the community
- Share the responsibility for environmental planning between all levels of government
- Provide opportunities for community involvement in planning

(b) Public participation in the planning process, so that members of the community can have an input to planning decisions.

The management system is concerned with providing conditions or guidelines in those areas where there are potential impacts on the land resources, in order to minimize these impacts and maintain the long-term integrity and productivity of the resources. The concept of IWM may be incorporated into a series of land-use plans. These plans should detail the physical resources of a catchment and the environmental impacts, such as loss of productivity, degradation of land, reduction of water quality, etc. should uncontrolled development proceed. These plans may contain conditions on policies to be applied to developments to ensure that adverse impacts are minimized.

The preparation of IWM strategies may involve two principal elements: an inventory of physical resources and a series of interpretive maps of combinations of resources. These strategies will provide a basis for planning purposes and environmental evaluations. In particular, the IWM strategies will provide (see figure 5):

(a) Land resource data;

(b) Conditions to be attached to the use of land;

(c) Proposed strategies and priorities for development;

(d) Coordination between organizations which have responsibilities for land management in a particular area.

FIGURE 5. CORE FUNCTIONS OF AN INTEGRATED WATERSHED MANAGEMENT SYSTEM

- Inventory of land resource data
- Determination of specification for the establishment of conditions attached to the use of the land
- Development of strategies and priorities
- Coordination between organizations

These strategies should incorporate the basic components detailed below.

1. Land resource data

The resource inventory and interpretive maps should identify

(a) Locations and descriptions of land features, e.g. topography, soils etc;

(b) Specific constrains to land use e.g. flooding, unstable land etc;

(c) Specific resource features e.g. water supply catchments, prime agricultural lands, open-cut mines, etc;

(d) Areas of land degradation, e.g. erosion, mass movement, salinity, soil acidity etc;

(e) Land-use capability and/or suitability classifications;

(f) Cumulative impacts of development on land and water characteristics;

(g) Recommended levels of optimum use of land to maintain long-term productivity and stability;

(h) Areas requiring special land rehabilitation land management techniques to minimize damage to the environment and maintain productivity within the watershed.

2. Conditions attached to the use of the land

IWM strategies can be used to determine conditions for the use of land. These conditions may be in one of two forms:

- specifications for the maximum intensity of the use of land
- specifications for development standards should land be used for different purposes

The first set of conditions is designed to ensure that the intensity of land use does not exceed specified levels because of harmful effects on the environment. For example, tree-clearing densities may be recommended for lands with potential instability to prevent mass movement by slump or earthflow failure. Agricultural industries such as piggeries, which may cause pollution by effluent disposal, may need to be regulated in number to ensure that water quality levels do not fall below acceptable standards.

Under the second set of conditions, development standards would be recommended for land-use proposals to ensure that environmental standards were maintained. This might include the development of standards for the control of soil erosion or polluted run-off.

3. Development of strategies and priorities

IWM strategies provide an overview of the watershed. This overview, in the form of a land resource inventory and a series of interpretive maps, is a basis for land-use planning. These strategies take an holistic view of the natural environment. Their use to assess the quantity and availability of a particular resource, or to determine the cumulative impacts of different types of development, or to identify the extent of some problem, enables strategies and priorities to be set by land users as part of their planning. They can be used to develop preferred strategies for the allocation or use of a resource or the resolution of a problem. Options can be developed from the available information to achieve an acceptable mix of land uses, while achieving social and economic objectives.

4. Coordination between organizations

The formulation of any strategies is a time-consuming task which involves the coordination of Government agencies to ensure that their activities and advice are complementary and work towards the achievement of the aims of the strategy. Individual agencies are usually responsible only for a single aspect of a resource in a watershed. When decisions are made in an *ad hoc* manner, what may be beneficial to the areas of responsibility of the agency can sometimes conflict with the interests of another agency.

IWM strategies can be an effective means of reducing the impact of some natural disasters. In this regard land-use planning and management form some of the non-structural measures to mitigate such disasters.

Land which is prone to such hazards as flooding, landslide, landslip etc. can be withdrawn from use or limited to those purposes which are least threatening. For example, floodplains can be used for flood-compatible purposes or slopes which are prone to landslide can be left undeveloped.

Land-use planning and the adoption and employment of building codes are among the most effective measures for minimizing damages when natural disasters occur.

One strategy for mitigating small floods is to retard run-off in upland areas. This can be accomplished in as number of ways. In rural areas, the measures usually adopted are associated with such conservation practices as terracing, contouring, strip cropping, planting cover crops or using farm ponds. In urban areas, run-off can be retarded by on-site detention facilities. The implementation of such strategies requires the cooperative involvement of land management agencies, departments of agriculture, and rural or urban local government authorities.

In many parts of the ESCAP region land degradation can be attributed, at least indirectly, to the inadequacy of various forms of land ownership and land tenure. In particular, insecurity of land tenure often leads to over-exploitation of the land, encouraging its use at an intensity beyond its physical capacity and leading to productivity decline, soil erosion or various other forms of soil degradation.

In many of the member countries of the region, the average size of land holdings can be as small as two hectares. Rapidly growing populations, increasing demands for food production and the scarcity of additional virgin lands all combine to exert increasing pressure upon these small farming plots.

Forms of land tenure which can lead to the encouragement of land exploitation and degradation include communal ownership, short-term cultivation rights, share-cropping, shifting cultivation and absentee ownership.

The existence of such forms of ownership or tenure may pose serious problems for the successful implementation of watershed management strategies aimed at controlling land degradation and promoting sustainable land use. Unless landholders are provided with permanent land ownership rights, and perceive the long-term stability and productivity of the land they utilize to be in their own long-term interest, they will find it difficult to accept a commitment to watershed management or restoration programmes.

Careful evaluation of existing land tenure provisions, and the development where appropriate of more effective land ownership arrangements, must therefore be recognized as an important component of any new approaches to land-use policy and practice, particularly where this is to be implemented in an integrated watershed management context.

D. Funding arrangements

Under the concept of integrated watershed management, the different tiers of government can formulate national and regional policies in relation to the control of land and water use, the destruction of natural vegetation, environmental degradation, and similar aspects of land resource management activity. Appropriate legislation can be enacted to delineate the powers and responsibilities through which governments can promote the sustainable management of natural resources. This involvement may include direct management, management oversight, monitoring, the setting of standards, the setting of policy, the imposition of penalties, the prohibition of adverse management practices, and the enforcement of powers of intervention. It also empowers governments to take action to mitigate, prevent or require the rehabilitation of land and water resource degradation.

In additional to the regulatory devices outlined above, there are many ways in which governments can utilize economic tools to achieve their resource and environmental management objectives. These tools work by providing economic assistance and economic incentives for improved resource management activity, rather than by imposing regulatory controls and penalties. The instruments available for this purpose include:

(a) Tax policies which allow the deductibility of expenses incurred in the rehabilitation of land degradation, such as soil erosion, decline of soil fertility and structure, loss of natural vegetation, salinization or silt and debris accumulation;

(b) Low-interest loans offered to encourage the restoration of degraded land and the protection of production potential through the implementation of soil conservation measures, salinity control measures, tree planting etc.;

(c) Direct government grants to organizations involved in the restoration of degraded land and water resources, which might include State, regional and local government agencies, landholder groups, conservation organizations etc. Different kinds of cost-sharing arrangement might be used, depending upon the nature of the project, which could range from full funding to cost supplementation and equivalent in-kind contributions.

The availability of appropriate funding is usually the principal constraint to the achievement of a satisfactory level of watershed rehabilitation.

With few exceptions, the different tiers of government in the ESCAP countries provide funds for rehabilitation, made in the form of grants, to support the implementation of integrated watershed management programmes. These grants are made for such purposes as re-forestation, soil conservation, water conservation and pasture improvement.

Funds allocated for these activities may be obtained by central governments from a variety of sources. These include:

(a) Income derived from normal budgetary functions, such as taxes, tariff, etc;

(b) Grants from donor countries or international organizations, made for the support of specific integrated watershed management projects;

(c) Loans from international funding institutions.

Depending upon the area of responsibility each tier of government occupies with respect to natural resources management, such funds may be allocated directly to the central government agencies or channelled through the appropriate State or provincial government for allocation to its agencies. In some countries, rural communities participating in watershed management projects may also contribute funds towards the maintenance of works associated with these projects.

In some cases, limited funding has been forthcoming from the private sector for the support of individual projects, particularly where these have involved sustainable forest plantation activities.

Where funding is limited, as is usually the case, and alternative projects have to be considered for possible support, economic efficiency criteria based on conventional benefit/cost analysis procedures are generally applied to determine whether a given project is economically justifiable. Such analysis might also be used to establish the need for the project, to provide guidance for project formulation, to assess the relative economic merits of alternative measures for meeting the project objectives, or to choose between competing projects.

Where the rehabilitation of degraded land is involved, benefits can be assessed either by estimating the loss in agricultural production income incurred by the degradation, estimating the potential increase in such income if the project were to be undertaken, or estimating the improvement in property value to be expected once the restoration project has been undertaken. The net benefit can be assessed as the difference between the estimated benefit and the estimated cost of the rehabilitation project. Alternatively, the benefit/cost ratio might be calculated. Where alternative methods of rehabilitation are being examined, or where several alternative projects are to be funded from a limited total pool of funds, the alternatives or projects showing the highest net benefit or the highest benefit/cost ratio should be supported. It should be noted, however, that in cases of severe land degradation it might become government policy to provide financial assistance for projects which are not economically efficient, showing negative net benefits or a benefit/cost ratio less than unity.

E. Institutional and legal requirements

The effectiveness of land-use planning and management in the ESCAP countries depends, to some extent, on the system of government and the strength of existing legislation available to each country to control environmental degradation. Those countries which operate under a system of a strong national government usually are more efficient in controlling land-use planning and management than those which operate under a dual system of national and State/provincial governments. In the latter case where the State/provincial governments assume responsibility under the constitution, there is a tendency for the legislative and institutional arrangements for land-use planning and management to be disparate and fragmented among the various states/provinces. Such fragmentation can culminate in a diverse set of legislative provisions. This situation is unlikely to promote the most efficient system for land, water and vegetation conservation. Even in those countries where the constitutional power for land use is vested in the national government the existing legislation is often ineffective in controlling watershed degradation problems. To be fully effective it is necessary to invest the central government with the powers and responsibility for land management which are enshrined in comprehensive legislation. This legislation should encompass the following objectives:

(a) The adoption of a single and comprehensive legal and administrative system which adequately addresses land-use planning and management from the viewpoint of sustainable development;

(b) The empowerment of the central government to direct the development and management of land resources, formulate national policy, set standards, monitor progress, use economic instruments and intervene in land management matters to ensure that the land resources are being managed efficiently;

(c) The promotion of a system of land management which is based on the principle of watershed boundaries.

In association with the enactment of suitable legislation, an integrated approach to institutional arrangements and administration needs to be adopted. The fragmentation and lack of clarity in responsibilities of the various government agencies involved in land management leads to ineffectual land-use practices. In many cases there is uncertainty in the role of agencies, their responsibilities and ability to treat problems in a comprehensive manner. An integrated approach would best be achieved by conferring the responsibility for the overall coordination of legal, administrative and financial matters in one leading authority. This authority should review the operating philosophies, roles and functions of the agencies involved in land management and coordinate their activities into a system of effective watershed management.

Legislation in the form of land-use regulation and codes can control the disturbance of forest cover by prohibiting the erection of buildings, clearing, cultivation and burning. Land-use regulations have proved to be successful in preventing flood damages through land-use zoning which directs development away from hazardous areas.

F. Public involvement

The loss of agricultural productivity through land degradation is an issue of major concern in the ESCAP region. Because most of the highly productive arable land of the region is effectively utilized, agricultural expansion has moved into marginal lands. If this land resource is to be utilized in a sustainable fashion, agricultural practices must be accompanied by appropriate soil conservation measures. However, many of the current cultivation practices are unsustainable and are responsible for valuable agricultural land going out of production. Consequently, land owners need to be educated in the practice of sustainable management.

It needs to be stressed that land degradation is not solely an environmental issue and any measures which address it purely as an environmental issue are doomed to failure. This has been the cause of many expensive failures in erosion control and watershed management the world over.

Land degradation is often merely the symptom of underlying socio-political problems. The nature of land tenure, lack of services and agricultural extension all contribute to the land degradation problem.

The primary responsibility for soil degradation should be vested in a government agency which has defined management responsibility for soil conservation. This organization should be in a position to foster the implementation of the most technically appropriate methods to arrest land degradation.

It is the government structure which bears primary responsibility for addressing these concerns, either directly through policies and programmes or indirectly by guiding and facilitating the work of other agencies. Government will need to assume a positive role as a facilitator, coordinator and integrator of local initiative and involvement rather than acting as a prescriber and controller.

It is widely appreciated that many subsistence farmers will overwork and exploit the soil resource for short-term gain. If land degradation is to be averted then it is necessary to establish an atmosphere of cooperation and requires the endorsement of government, community organizations and individual land users. To develop mechanisms to minimize adverse landscape impact it is necessary to develop sets of guidelines for the implementation of IWM strategies. This can be achieved through the establishment of a committee with representatives from the major land-use and planning arms of government and representatives from the community. The role of this committee should be to develop IWM strategies for the relevant watersheds. These strategies would form the basis of a comprehensive plan which would lay the foundation for solving watershed land degradation problems and minimizing adverse impacts on the watershed environment.

IWM has the capability to encourage cooperation and liaison between all tiers of government and the landholders of an individual catchment. It should reduce the threat of conflicts in land-use practice, pave the way for ensuring sustainable resource development and minimize environmental damage.

Community responsibility involves all those people, organizations and authorities who have an interest in using the resources of an area of land, including individual farmers. Improvement of the landscape in the long term must involve an integration of agricultural land use with other land uses. This in turn can only be achieved by detailed planning, based on an assessment of the land's capability to support various activities, including agriculture, and a cooperative approach to land management. Under this process, dialogue is encouraged between all the parties who have a stake in watershed management and who can contribute to gaining a common understanding of how the resource should best be managed within the bounds of the principles of sustainable resource management.

G. Human resource development

Because rural populations rely very heavily for their daily living needs upon the natural resources of the watersheds in which they live – such as water, soil, forests and pastures – it is necessary to manage both the natural resources and the human resources which depend upon them in a coordinated way, in order to ensure that the people utilize their land resources in a sustainable manner.

Land degradation occurs on many of the watersheds within the ESCAP region. This has largely been the consequence of mismanagement or exploitative utilization of the watershed resources, which has included such activities as deforestation of steep slopes, cultivation of land without taking appropriate measures for soil and water conservation, or the destruction of vegetative cover through overgrazing.

In many parts of the region this degradation is accelerating, a problem which is aggravated by the already degraded condition of many watersheds, the limited scope for expansion of the available areas of arable land, and the restricted opportunities for further development of irrigated agriculture. Because of this, there is a pressing need for the development and application of improved technology for the stabilization and improvement of the productivity of degraded watersheds. This requires that traditional farming practices be assessed and upgraded where necessary to ensure that watersheds are managed in a sustainable manner.

Scientific research is therefore necessary, particularly at the watershed scale, to develop ways and means for overcoming the many adverse effects associated with many traditional farming practices, which are aggravated by a lack of data about land capability, soil productivity, soil and water conservation techniques and sustainable farming practices. Such research should be directed particularly towards the enhancement of the sustainability and productivity of the land and water resources of the watershed. This will require the development of programmes to assess the best combinations of cropping patterns, crop varieties, soil conservation measures and fertilizer application needed to obtain optimal productivity on a sustained, long-term basis, in such a way as to maintain soil fertility and soil loss or degradation within acceptable limits. Related research topics might include techniques for re-forestation and techniques for increasing stock carrying capacities through such means as increased fodder production and improved methods of fodder storage. It is vitally important that the results of such research be easily communicable, socially acceptable and economically feasible to the watershed community. It is also important that the application of such research yields visible and measurable improvements in watershed productivity and rehabilitation within a reasonable time span.

The education and training of farmers and other resource users are essential components of the application of the integrated watershed management approach. If there is inadequate or incomplete participation by the watershed landholders in any management programme, the effectiveness of that programme will be significantly diminished. It is important that the entire watershed community be fully involved in the programme.

There are various ways in which the education and training of land users can be accomplished. Demonstration farms can be established within the watershed to show landholders how to accomplish rehabilitation and increase productivity and income without further degrading the land or damaging the watershed environment. Specific training in watershed management and conservation farming techniques can be achieved through the provision of adequate extension services, which should be available as appropriate in relation to agriculture, soil and water conservation, forestry and revegetation, animal husbandry and ecosystem care. In addition, general education of the farming community with regard to soil and water conservation techniques and land care can be assisted through such means as the dissemination of information via pamphlets, handbooks, and audio-visual outlets such as radio and television.

H. Policy development and implementation

The broad objective of ecologically sustainable development recognizes the need for the improved management of natural resources, in order that they can support responsible development and economic and social uses on a sustained, long-term basis. To achieve this objective, it is necessary to devise and implement policies which are based on the underlying principle that the various tiers of government, landholders, resource users and the general community must all share the responsibility for resource management.

As has been explained in Section IV.A, the integrated watershed management framework has been specifically developed for this purpose. IWM forms the basis for the development of integrated natural resources management policies, particularly in relation to soils, vegetation, surface water and groundwater.

It is the primary responsibility of government to ensure that policies and policy instruments support the management of land and water resources in an ecologically sustainable manner. To fulfill this responsibility, governments should take the following actions:

(a) Develop integrated goal-setting and policy formulation at the national, regional and local levels, taking proper account of environmental, social and economic issues;

(b) Develop policies that encourage sustainable land use and sustainable management of soil, water, vegetation and fauna resources, having proper regard for the interests and requirements of the national, regional and local communities;

(c) Review the regulatory framework, including laws, regulations and enforcement procedures, so that an efficient and effective system is available for the official management of natural resources;

(d) Implement economic incentives to assist in the rehabilitation of degraded land and encourage the use of best practices for the sustainable development of natural resources;

(e) Encourage the active participation of the local community in planning and implementing programmes of natural resource management.

Under the integrated watershed management framework, component national, state and/or regional policies should be developed for the integrated management of each of the major categories of natural resources. These should include a land-use policy, a soils policy, a vegetation policy, a surface water policy and a groundwater policy.

1. Objectives of land-use policies

The national/state land-use policy should have the following broad objectives:

(a) To achieve greater coordination and integration in the management of land, through appropriate legislative, institutional and policy arrangements and the effective involvement and participation of the whole community;

(b) To ensure that land is always used within its capability, and for its optimal suitability;

(c) To ensure the continued stability and productivity of the land on a sustainable, long-term basis;

(d) To manage land and land resources on an integrated, watershed system basis;

(e) To identify land degradation and rectify this degradation through coordinated land use and management.

2. Objectives of surface-water management policies

The national/state surface water policy should have the following broad objectives:

(a) To manage surface water resources in such as way as to sustain catchment yields and maintain the supply of appropriate and equitable quantities of water to all legitimate water users;

(b) To manage surface water resources in such a way as to maintain and where appropriate improve water quality;

(c) To ensure that river flows are of adequate quantity and quality to maintain aquatic and wetland habitats and ecosystems and ensure the quality of the riverine environment;

(d) To manage surface water resources in conjunction with groundwater resources in a planned and coordinated fashion;

(e) To manage surface water resources on a whole-watershed basis and to integrate water management with the management of related soil, vegetation and other land resources.

3. Objectives of groundwater management policies

The national/state groundwater policy should have the following broad objectives;

(a) To maintain the productivity of groundwater resources and to ensure the long-term sustainability of both the quantity and the quality of these resources;

(b) To ensure that the needs of environmental systems dependent upon groundwater resources are met;

(c) To integrate the conjunctive management of surface and groundwater resources on a whole-catchment basis;

(d) To integrate groundwater management with the wider environmental and resource management framework.

4. Objectives of soil-management policies

The state/national soils policy should have the following broad objectives:

(a) To manage soils in such a way as to avoid their loss or degradation and ensure their continued utility, stability and productivity;

(b) To prevent, mitigate and rectify soil erosion and degradation;

(c) To undertake programmes of soil survey, land capability and land suitability evaluation in order to ensure that soils are used within their capability and for their optimal suitability;

(d) To manage soils in an integrated fashion, in association with the management of vegetation, water and other land resources.

5. Objectives of vegetation-management policies

The state/national vegetation policy should have the following broad objectives;

(a) To ensure that the national/regional coverage of trees and other vegetation is conserved, maintained and where appropriate enhanced in order to conserve soil and water resources and maintain environmental quality;

(b) To maintain and improve silvicultural and agricultural productivity on a sustained, long-term basis;

(c) To conserve native flora and fauna and their habitats;

(d) To conserve the scenic and aesthetic qualities of the environment.

Under each of these broad resource management policy headings, a range of related and more detailed component policies might be developed. Under the umbrella of a surface water policy, for example, there might be more detailed component policies including a water quality policy, a wetlands policy, an estuarine management policy, a flood management policy, a drought management policy, a riparian zone policy and so on.

Implementation of the principles and strategies of integrated watershed management, in order both to maintain and improve the sustainability of watershed-based natural resources and to mitigate the severity of water-related natural disasters, requires close co-ordination between the government and the community and the active participation of landholders and other users of land resources. This requires the adoption of a management system which provides for representation of all the stakeholders in the cooperative management and rehabilitation of the catchment resource system.

There are several mechanisms by which this can be achieved. At the most basic level, it has been shown to be highly effective if governments encourage – and facilitate by financial incentives and the provision of technical aid and advisory services – the formation of locally-based community action groups.

Landcare groups, rivercare groups, and other kinds of watershed-based groups have been shown in some countries to be very effective in achieving direct landholder participation in rehabilitation and conservation activities and giving community members a sense of ownership of resource management problems and their solution. At the larger-scale, catchment or river basin level, various approaches to the involvement of the community and the coordination of community and government activity have been adopted.

In some countries, governments have established catchment or river basin management authorities of various kinds to plan and coordinate land and water resource management activity. To be effective, such organizations required to be adequately funded, either by government allocation or through an ability to levy rates or taxes on landholders and industry within their area of responsibility. They require a small number of their own professional staff and the ability to engage consultants and contractors or to utilize the assistance of state or local government agencies for investigation, design, planning, construction and maintenance activity. The management board of such an organization should have an adequate representation of locally-based community representatives and should preferably also be advised by a community advisory committee or council, widely representative of community interests within the watershed or catchment area. The board membership should also include appropriate representation from the various government resource management agencies responsible for land and water resource management in the area, as well as representatives of the local government agencies responsible for land management and development control in the area.

In other countries, governments have chosen to make land and water resources management at the watershed or river basin scale the responsibility of their own agencies. Under those circumstances, it is highly desirable to ensure community involvement and participation through the establishment of watershed-based coordinating committees or management committees. This approach has been adopted, for example, in some states of Australia. These committees, called catchment management committees, have the function of developing watershed or catchment management plans and coordinating the implementation of these plans. The membership of such a committee must include significant community, landholder and industry representation and representation of the relevant state and local government agencies responsible for land resource management. To be effective, they require strong financial and professional support from the responsible government agencies, including the secondment of appropriately qualified coordinating staff. It also is highly desirable that there be some statutory mechanism to ensure that the catchment management plans developed by such committees have legal standing and are capable of being imposed by the appropriate state or local government authority.

Whatever institutional arrangement is provided for achieving watershed management coordination, the following functions need to be fulfilled by the coordinating organization:

(a) The provision of a coordinated approach to land and water resource management;

(b) The establishment of effective coordination between government, land users, industry and the community at large;

(c) The provision of a forum for the resolution of resource and environmental management conflicts;

(d) The identification of watershed management issues and the development of strategies for addressing these issues;

(e) The recognition of the relationships that exist between the components of the watershed system and identification of the impacts that resource development activities may have on all the components of the system;

(f) The coordination and prioritization of appeals for government funding and the allocation of government funds to assist in the implementation of planned integrated watershed management strategies.

I. The regional experience

Because Bangladesh is a country consisting principally of alluvial floodplain lands, the management of water-related natural disasters has almost exclusively been directed towards the mitigation of floods and storm surges. Land degradation, soil erosion, loss of soil fertility and similar forms of environmental degradation are also matters of concern. The need for improved coordination of the activities of the agencies involved in the management of land, soil and water resources is currently being addressed. At the same time, active community participation in planning, development and management activities related to natural resources management is being encouraged. The preparation of a national water management plan, which incorporates a comprehensive land-use policy and is based on an integrated watershed management approach, is currently being addressed.

The Government of Cambodia has recently enacted legislation relating to environmental protection and the management of natural resources. The purposes of this legislation are to enhance environmental quality through the control and reduction of pollution and to ensure that the conservation, management, development and utilization of natural resources are undertaken on a sustainable basis. The new legislation also makes provision for public participation in the watershed management process. In addition, a Royal Decree on watershed demarcation and management was drafted, with objectives aimed at the management of soil erosion, landslides and sedimentation, the maintenance of biodiversity and water quality and improved management of the natural environment. A national committee to supplement the Government's forest policy has been established under the chairmanship of the Prime Ministers and with membership including representation from the various ministries involved. The long-term objective of this committee is to manage forests effectively and efficiently and on a sustainable basis.

In 1986, the State Council of China established the State Bureau of Land Management as the principal authority responsible for the unification of land management throughout the country. Corresponding organizations were set up in the provinces, autonomous regions, municipalities, prefectures, cities and counties. The task of the Bureau is to guide and coordinate the protection, rehabilitation and development of land resources, activities which are undertaken by several agencies including the agriculture, forestry and water resources departments. The watershed has been adopted as the basic land-use planning unit. Also in 1986, the Government promulgated the Law of Land Management, which is the fundamental act governing the overall planning and management of land resources. In addition, a series of related laws pertaining to agriculture, forestry, grasslands, water and soil conservation and other natural resource management issues was enacted to unify the land management process. Public participation is also a fundamental requirement in China's approach to watershed management.

The prevention of land degradation and the regeneration of natural resources are major areas of concern for the Government of India. Based on the experience gained through the implementation of a number of model watershed development projects undertaken by various research organizations and universities, the development of the micro-watershed concept has become an integral component of the strategy for sustainable development in rural areas. Micro-watershed management practices involve the use of land treatment measures and farming systems which can be adapted by farmers to diversify their rainfed agricultural activities on small, intensively-farmed watersheds. This approach is employed to make the most effective use of rainfall and soil moisture and provide a measure of insurance against crop failure in low-rainfall districts. In addition, it seeks to reduce or control land degradation, being based on the premise that improvements in rainwater conservation will also yield improvements in soil conservation. This approach is employed on what are referred to as "micro-watersheds", which usually range in size from 500 to 5000 hectares. Watersheds as small as 50 hectares have however been also treated in this way.

Key features of the micro-watershed approach are that project preparation is undertaken in close consultation with the watershed community, is based on local farming experience, and is directed towards the solution of the basic problems faced by local farmers. Indeed, the success of such a project is gauged by the extent of participation by the local farmers involved in the scheme. Whilst schemes of this type rely largely upon improved rainwater conservation, achieved through means such as the improvement of drainage lines and the adoption of farming systems and cultivation techniques which increase rainfall interception and infiltration and are ecologically sustainable, other elements many be incorporated into the overall watershed management system. These might include, for example, improved animal husbandry, agro-forestry, horticulture, fish farming and sericulture. To ensure the successful implementation of such a scheme, it is essential that the participating farmers be adequately trained in techniques of low-cost, appropriate technology and the application of sustainable farming methods. This programme is implemented by the Ministry of Agriculture and Cooperation and the Ministry of Rural Areas and Employment. Guidelines have been separately formulated by both Ministries. They provide for public participation, a pattern of funding, institutional arrangements and the involvement of NGOs.

In Indonesia, emphasis has been placed on the development of a watershed conservation programme. The objectives of this programme are to conserve natural resources and improve the productivity of the land. Four key activities have been identified; these involve soil and water conservation, land management, development of appropriate farming systems, and the development of the necessary physical and social infrastructure. These activities have contributed significantly to the improved sustainability of natural resources and a reduction in the frequency and intensity of natural disasters. Many Government agencies and other institutions are involved in watershed management and disaster reduction in Indonesia. This fragmentation of responsibilities amongst sectoral and line agencies needs to be rationalized to improve the efficiency of integrated watershed management. Involvement of the people living in catchment areas is seen to be the key to the successful achievement of watershed protection. Public awareness campaigns and encouragement in the form of subsidies and rewards, as well as penalties, are used to motivate community participation in integrated watershed management.

The Lao People's Democratic Republic has formulated a range of laws, decrees and regulations, which have recently been proclaimed, in order to establish a new framework for the improved management of natural resources. These include new legislation for water, forest and land management. Ongoing efforts relating to natural resources management include the reformation of the land resources management system, the redistribution of land resources, and the strengthening of community participation in resource management, together with the zoning and demarcation of different land-use types according to national development goals and policies. A legal system and administrative framework has been established which provides for close coordination and awareness of responsibilities amongst the concerned agencies. This system will be supervised by a central coordinating council. In addition, it was proposed to create a national information centre for land and natural resources management.

Under the Federal Constitution of Malaysia, the management of land, water, soils and forests is a State responsibility. Federal legislation touching upon such matters cannot be enforced unless it is endorsed by State Governments. In order to achieve uniformity in such matters as land, water and forest management or environmental control, the Federal Government has established, or will be establishing, a series of national councils to deal with natural resources issues. Such a council would, with appropriate State participation, formulate and implement a National Master Action Plan in respect of each major natural resources management area, to be implemented in a comprehensive manner and on a watershed management basis. At the national level, Malaysia has adopted an integrated planning and resource management approach which recognizes the global need for sustainable development and recognizes the need to coordinate environmental and physical planning. To ensure wide acceptance and support from the public, Malaysia has developed a consultative programme which involves all levels of the community in the decision-making process.

Land-use objectives, policy measures, strategies and plans have been enunciated by the Government of Myanmar in its 1995 Forest Policy. The land-use management objectives have been designed to develop a system of balanced and complementary land uses. Under this system, land will only be used for purposes which optimize production and minimize degradation. It is proposed to phase out those practices which are incompatible with sound land-use management and cause environmental degradation. Shifting cultivation practices are to be discouraged and replaced by improved farming methods which improve productivity and increase the economic return to farmers. The Government intends to formulate a land-use plan, specifying permissible land uses, in order to guarantee catchment protection and nature conservation. This plan will ensure that appropriate land-use practices are employed and avoid irreparable environmental damage. To achieve these objectives and facilitate better coordination, a National Land-use Advisory Board will be established. Community participation is considered to be an essential element of the overall land-use management programme.

To ensure that the principles of sustainable development are put into effect, the Government of Nepal has placed emphasis on new policies, legislation and institutional arrangements. These are designed to avoid deterioration of the environment and degradation of watersheds, and seek to reduce the incidence of natural disasters. Although there are a number of existing laws and regulations relating to land and environmental management, these are primarily oriented towards administrative formalities and procedures. The development of a comprehensive legal framework, and the coordination of the activities of the agencies concerned with environmental management, are issues yet to be addressed. It is the Government's objective to ensure the wise and effective use of available resources, to encourage community participation and to conduct a public education programme in order to achieve an efficient and effective land-use management system.

Although the Philippines has a comprehensive and well-prepared suite of legislation relating to watershed protection and preservation, the consequences of improper management, inadequate technical knowledge and other factors have been a failure to use the existing laws to full effect. The achievement of effective watershed management and rehabilitation has been a major thrust of the Government of the Philippines. The principal agencies involved in watershed rehabilitation are the Forest Management Bureau and the National Irrigation Administration. The activities of these agencies are supported by a number of NGOs. Community involvement in the management of watersheds is encouraged and coordinated through the Department of Environment and Natural Resources. The priority concerns of Government are the implementation of plans and programmes for the sustainable development of watersheds, with emphasis on the maintenance of biodiversity, the development of resources and the mitigation of water-related natural disasters.

In the Republic of Korea, national land development plans are prepared to comply with the National Economic Development plans. They are concerned with land resources development, water resources development and agricultural development. Development proposals put forward in these documents are planned and implemented by the relevant ministries and other levels of Government. Similar plans are also prepared by regional governments. The national regional development plans include targets for the reduction of natural disasters for river basins and water districts. In the Republic of Korea, integrated watershed management is an activity which is spread amongst a number of Ministries and their action agencies. The Central Civil Defence Committee has the responsibility at national level for the prevention of natural disasters, including water-related natural disasters. The Ministry of Agriculture is charged with the responsibility for organizing and coordinating the disaster management activities of the Government departments involved in disaster prevention in rural areas. This Ministry is also responsible for the development of agricultural land, whilst the Ministry of Construction and Traffic has the responsibility for urban land development.

The Government of the Republic of Korea has enacted a strong environmental law for the management of watersheds, including the control of water pollution. Community participation is given a strong role and receives considerable encouragement from Government in relation to integrated watershed development and management activities. Community involvement is particularly directed towards sound watershed development, improved production and cooperative activities in rural villages.

In Sri Lanka, at the present time there is no lead agency responsible for watershed management; the task is fragmented and management activities are spread amongst several agencies. The need for comprehensive planning of land use and development activities has been identified and is now being acted upon. A land-use Policy Planning Division has been established for the purpose of developing a national land-use policy and preparing sub-national level land-use plans. A national conservation strategy and forestry master plans are also being developed, along with a national water policy.

In Thailand, the responsibilities for land-use planning and watershed management are spread across several ministries. To achieve the goal of integrated watershed management, the Government has established the Office of the National Water Resources Committee. This organization will act as the central agency in policy making and the formulation of master plans for integrated natural resources management in each river basin.

The Government of Viet Nam has passed a number of laws relating to environmental protection, the development and protection of forests, and the development and management of land. A comprehensive law concerning water resources management is still in the drafting stages. The purpose of these laws is to achieve appropriate control and management of the natural resources of watersheds, in order to ensure that these resources are utilized on a sustainable basis. In this way, living standards can be upgraded and poverty can be alleviated. Community participation is encouraged in the protection and management of watersheds, as part of the process of ensuring that natural resources including land, water and vegetation are not degraded.

PART TWO

THE MANUAL

List of acronyms

AEAM	Adaptive environmental assessment and management
ANSWERS	Areal nonpoint source watershed environment response simulator
APS	Adaptive policy simulation.
ARC/INFO	Proprietary name – commercial GIS plotting package
ARS	Agricultural research service (USDA)
CAD	Computer aided design
CE-QUAL	a series of river water quality simulation models (US Corps of Engineers)
CREAMS	Chemical, run-off, and erosion from agricultural management systems
CRSM	Colorado river simulation model (US Bureau of Reclamation)
DSS	Decision support system
DSS-SLM	Decision support system for the sustainable management of sloping lands in Asia
DTM	Digital terrain model
EPIC	A soil loss prediction model
ESCAP	Economic and Social Commission for Asia and the Pacific
EXIS	A commercial expert systems shell program
GenaMap	A commercial GIS plotting package
GIS	Geographical information system
GLEAMS	Groundwater loading effects of agricultural management systems
GMS	A marine observation satellite system (Japan)
GPS	Global positioning system
HEC-series	A set of simulation models developed at the Hydrologic Engineering Centre, US Corps of Engineers
HSPF	Hydrologic simulation package (FORTRAN)
IBSRAM	International Board for Soil Research and Management
IRS	Indian remote sensing
IWM	Integrated watershed management
MIKE 11	A Danish river water quality model
MSS	Multi-spectral scanner
MOS	Marine observation satellite (Japan)
MOUSE	Modelling of urban sewers (Danish model)
NGO	Non-governmental organization
PC	Personal computer
QUAL Series	A set of water quality simulation models (US Corps of Engineers)
SALMON-Q	A river water quality model (Wallingford, UK)
SOILOSS	An erosion prediction model (NSW Soil Conservation Service).
SPANS	Spatial analysis system (commercial GIS package).
SPOT	Système probatoire d'observation de la terre
SSAR	Streamflow synthesis and reservoir management model
SWMM	Storm water management model
SWRRB	Simulator for water resources in rural basins

SYMPTOX 3	Simplified method program – variable complex stream toxins model
TERRA	TVA environment and river resource aid
TNT mips	Map and image processing system; a commercial GIS package
TR series	USDA run-off prediction models
USBR	US Bureau of Reclamation
USDA	US Department of Agriculture
USLE	Universal soil loss equation
WASP 5	Water quality analysis simulation program
WEPP	Water erosion prediction project (USDA)
WMO	World Meteorological Organization
WSC	Watershed classification

V. DATA COLLECTION AND EVALUATION FOR WATERSHED MANAGEMENT AND NATURAL HAZARD ASSESSMENT

A. Information needs for watershed management and disaster reduction

The occurrence of water-related natural disasters in the ESCAP region is increasing as burgeoning populations make it more and more necessary to occupy locations subject to high hazard. Such disasters are usually accompanied by massive destruction of life, property and infrastructure. The economic costs associated with them can amount to a significant proportion of the national economy for many developing countries. Economic losses of such magnitude can have the effect of preventing advances in living standards and retarding overall economic development.

Natural hazards which can culminate in disasters have been discussed in Chapter III and include cyclones, floods, landslides and droughts. Areas which are at risk of experiencing such disasters can be identified and mapped. The potential impact of these hazards can be increased by watershed degradation, including deforestation, overstocking and soil erosion. Fortunately, the susceptibility of an area to natural hazards can be reduced by the introduction of appropriate land-use planning and practices, which modify land use and promote the implementation of control measures.

The incidence of watershed degradation can be substantially reduced by the adoption of practices which involve the concept of integrated watershed management. Before these principles can be implemented, it is first essential to prepare an inventory of the watershed's natural resources and a survey of its environmental characteristics. This information provides a basis from which to define the potential impact of likely hazards and identify hazard-prone areas. The assessment and mapping of hazards is an essential element in disaster prevention and mitigation. All of these tasks rely upon the availability of basic data about the topography, climate, soils, geological, environmental and land-use characteristics of the watershed. It is the purpose of this chapter to indicate the nature of such data and outline the procedures and techniques employed for hazard assessment, resource and environmental inventory and the effective implementation of the integrated watershed management approach.

B. Data for watershed management

1. Resource information requirements

Integrated watershed management involves the coordinated management of the land resources of a watershed or river basin, undertaken in such a way as to optimize the long-term productivity of these resources whilst at the same time maintaining or enhancing the quality of the watershed environment.

In this context, land resources can be defined as including all the elements of the physical environment which influence the potential for land use. They therefore refer not only to the soil or earth mantle but also to relevant features of geology, geomorphology, landforms, climate, hydrology, vegetation and fauna.

To manage such resources in an integrated and effective manner, it is clearly essential that detailed information regarding the nature, quantity and quality of these resources be available. The collection and presentation of such information is the purpose of natural resources survey or resource inventory activities. For effective management of these resources it is essential also to have information about the uses to which the land is put, requiring the collection of data in the form of a land-use survey. The effects of past human activity in the watershed, such as vegetation clearing or accelerated erosion, form an important component of such a survey, because they impact strongly on the quality of the available land resources.

The integrated watershed management approach requires an assessment of the appropriateness of existing forms of land use and, if considered desirable or necessary, the introduction of improved or more beneficial forms of land use. In this context, land uses include productive uses, such as cropping, livestock production or forestry, along with uses that provide services or other benefits, such as use for water catchment purposes, recreation, tourism, wildlife conservation, or the improvement of environmental quality.

Watershed management decision-making must therefore depend upon an assessment of the potential of the land resources for alternative kinds of use and where appropriate, the introduction of modified or improved forms of land use. The assessment of the potential of the land is what is called land evaluation. Its basic feature is a comparison of the requirements of land use with the resources offered by the land. Its fundamental purpose is to predict the consequences of land-use change, as a basis for the planning of such change.

Land evaluation depends upon basic information from three major sources: land resources, land use and economics. In making integrated watershed management planning decisions, which should be based upon agreed multiple objectives, additional information is needed from other sources, which should include environmental, social and political considerations.

Resource inventory requires the collection, analysis and presentation of data relating to all the land resources of the watershed, which can be expected to include the following components:

- Topography and landform
- Geology and geomorphology
- Soils
- Climate, including data relating to rainfall, temperature, evaporation, wind, insolation etc.
- Hydrology, including the quantity and quality of available surface and sub-surface water resources
- Vegetation cover, vegetation associations
- Native fauna, including habitat survey

The collection of resource data can be greatly facilitated through the use of aerial photography and other forms of remote sensing. These techniques are discussed in further detail in Section V.C.3 below. The analysis and presentation of such data can be greatly facilitated through the use of geographical information systems technology, which provides for the computer storage and manipulation of large quantities of data and the presentation of these data in a variety of formats which include comprehensive transparent overlay mapping. These techniques are also discussed in further detail in Section V.B.3 below. Finally, the availability of such data in computer-compatible form allows the development of computer models of watersheds, in which a variety of hypothetical land-use changes and policy initiatives can be explored and assessed through the medium of computer simulation. These techniques are discussed in further detail in Section V.F below.

The mapping of land resources for land evaluation purposes can be greatly facilitated by organizing the survey programme on the basis of land mapping units. These are areas of land which exhibit a substantial degree of homogeneity in terms of their physical characteristics, the scope of which has been defined as a preliminary to the mapping programme. Typical land mapping units might include soil associations, soil series or phases, geomorphological units of various kinds, soil-landform associations, or vegetation communities. The most effective approach for watershed management purposes is to map on the basis of land systems. A land system is an area of land showing a recurring pattern of topography, soils and vegetation and subject to comparatively uniform climatic conditions. Within each land system unit there may be a number of land facets, which are smaller areas having essentially uniform environmental characteristics. Land systems and land facets can be recognized as distinctive patterns on aerial photographs, so that mapping according to land systems depends heavily upon remote sensing techniques. The land systems approach is discussed in further detail in Section V.B.2 which follows.

2. The land systems approach

From the point of view of integrated watershed management, the key feature of the land systems approach is that it is itself an integrated survey approach, allowing all the significant factors of the physical environment of the watershed to be mapped simultaneously. Normally these factors will include topography, landform, soils, geology, hydrology, climate, vegetation and land use. The approach has the advantage that, being based on the interpretation of remotely sensed resource information, it can be undertaken rapidly and cheaply over a large land area. Further, it is readily amenable to computer representation, so that geographical information systems and watershed simulation models can readily be based upon it. Originally devised as a technique for rapid resource appraisal and land evaluation over large areas of empty or sparsely-settled country in undeveloped nations, it offers very considerable potential as a basic mapping tool for integrated watershed management purposes.

As indicated above, a land system is an area of land having a recurring pattern of topography, soils and vegetation and a comparatively uniform climate. These areas are first identified from aerial photography, viewed stereoscopically, and their boundaries are sketched directly onto the photographic prints. For broad-scale, reconnaissance-level survey black and white photography at scales of 1:40,000-1:50,000 is normally used as the basis for mapping at 1:250,000 and 1:100,000 scales. For integrated watershed management purposes, mapping at larger scales, e.g. 1:50,000 or larger, might be desirable. Limited field survey, generally based on vehicular traverses along selected transect lines, is used to verify the airphoto interpretation.

Each land system is given a distinctive name, generally based on the geography of the locality. Within each land system unit, a number of land facets will be identified. Land facets are areas having essentially uniform characteristics and represent the smallest areas that can be recognized and delineated on standard-scale aerial photographs. The land facets are usually geomorphological features that are causally related to the broader features of the land system of which they form a part. They will be given names which are descriptive of their landform character. By way of example, within an upper watershed land system which is composed of steep sided hills and ridges with incised river valleys between them, the land facets may include ridge crests, side slopes, cliffs and crags, footslope terraces, valley bottoms, floodplains and main river channel sections.

The results of a land system survey are presented in an integrated set of documents which will usually comprise:

(a) A map showing the land systems, with an extended legend detailing the principal environmental and climatic features of the area surveyed;

(b) A description of each land system, including details of the principal features of each of the land facets identified within the system;

(c) A textual account of each of the key factors of the environment surveyed, including geomorphology, climate, hydrology, soils and vegetation;

(d) If appropriate, an evaluation or interpretation of the system in terms of its development potential or management possibilities.

As has already been indicated, the nature of the data relevant to this approach is such that it is readily amenable to preparation and presentation in a computer-based, geographical information systems format. This facilitates the cartographic process of transferring system and facet boundaries from airphotos to the base map, using graphical digitizing equipment, and permits the preparation of comprehensive land system base maps using a range of overlay techniques to display topographic, environmental and climatic features. It also greatly facilitates the collation and display of the land system description information, which is usually presented in several components, graphic and tabular, including a schematic diagram of the system and its facets, a listing of the key characteristics of the system amplifying the legend of the base land systems map, and a detailed tabular description of the individual land facets of the system. The latter mighty be accompanied by sketches of typical facet cross-sections and/or small maps illustrating facet features.

The detailed account of the key environmental factors of the system is presented in a document comprising several chapters giving systematic accounts of the geomorphology, climate, hydrology, soils and vegetation of the system. This should be accompanied by a set of related maps presented at smaller scales than the system base map, which might include special maps presenting such features as arable soils, vegetation associations, areas of erosion or slope stability hazard, etc.

The detail presented in the final section of the survey report, the evaluation section, will depend upon the purposes for which the survey was undertaken and the extent to which it will itself form the basis for a much more comprehensive land evaluation, land capability or land suitability study. Normally, a land systems survey report will include at least one chapter presenting an evaluation or interpretation of the system under study for specific uses or management needs, which might for example be an evaluation of potential for cropping, livestock production or forestry production; an assessment of engineering factors relevant to water resources development, road construction, railway construction or urban development; an assessment of natural hazard risk from flooding, cyclone or land instability; or an assessment of watershed management constraints and opportunities.

For integrated watershed management purposes, however, the land systems survey is best treated as an essential preliminary to further and more detailed studies aimed at specific land capability and land suitability classification for a variety of catchment land uses. The techniques used for the undertaking of such assessment are discussed in further detail in Section V.C below.

3. Remote sensing and geographical information systems

Remote sensing techniques have become an essential feature of data collection systems for integrated watershed management over the past decade. These techniques are invaluable for the rapid collection of data and for the study of extensive areas, particularly in developing countries for which conventional resource mapping sources are limited. They are particularly suited for reconnaissance studies associated with large-scale soil and vegetation mapping programmes.

The most useful forms of remote sensing involve the collection of images generated by the reflection of radiation emitted from the earth's surface. The various kinds of imagery detected by sensors carried aloft by aircraft or satellites are all referred to under the general term "remote sensing". Each form of remote sensing relates to a specific band of wavelengths on the electromagnetic spectrum. In passive systems which rely on the detection of reflected energy, the sensors used are capable of recording the range of wavelengths from visible through to thermal radiation. Active remote sensing systems generate their own form of energy, which is transmitted from an aircraft or spacecraft and detected as a signal reflected from the earth's surface. This type of system is categorized as radar.

The different types of imagery available possess certain special attributes, depending upon the nature of the image, which fit them for different applications in resource surveys. Black and white photography, standard panchromatic photography, near infra-red monochrome photography, true colour photography and false colour photography all involve the collection of light rays focused onto a sensitive base, usually film. Other types of remote sensing system, such as multi-spectral scanners (MSS), thermal scanners and radar, record reflected radiation as an electronic signal which is subsequently converted into quasi-photographic images.

Each of these techniques is best suited for specific tasks, some of which are useful for watershed management applications such as soil, terrain and vegetation surveys. The utility of a specific technique will depend upon the level of clarity and accuracy with which natural features such as landforms, vegetation types, land use, the existence and extent of water bodies and so on can be distinguished.

Normal aerial photography has so far proven to be the most useful technique for watershed management purposes, because of the high degree of resolution obtainable and the ability of this technique to show the spatial distribution of ground characteristics. The ability to view adjacent pairs of photographs stereoscopically very significantly enhances their utility for the discrimination of ground features. Large areas can be accurately mapped by assembling mosaics from individual photographs. The amount of detail discernible depends upon the map scale employed.

By comparison with conventional aerial photography, satellite imagery has the major advantage of low cost, enabling a much larger area to be covered by a small number of prints. Unfortunately, the ground resolution capability of this form of imagery is much lower than that achievable with aerial photography, which limits the scope of its application to reconnaissance-level mapping.

The most widely used category of remote sensing for water resources management and hazard assessment purposes is black and white or panchromatic vertical aerial photography. Prints are normally available in 23-cm^2 format, flown in parallel strips with stereoscopic overlap to facilitate stereoscopic viewing and permit the making of photogrammetric measurements in three dimensions. Enlargements to various scales are readily obtainable, as well as mosaics and orthophotographs, all of which are widely used as map substitutes for survey and reconnaissance purposes.

The photography scales used in resource assessment and watershed management commonly range from 1:5,000 to 1:50,000. Large-scale prints at 1:5,000 and 1:10,000 are particularly suitable for detailed soil and vegetation surveys as well as base maps for such purposes as the planning and design of erosion control schemes and flood plain zoning. Scales of 1:20,000 or 1:25,000 are particularly useful for soil and vegetation surveys or land capability and terrain evaluation surveys. A scale of about 1:40,000 is most suitable for reconnaissance surveys of large areas.

As an indication of the scope of the various scales suggested above, it mighty be noted that with a large-scale photograph at 1:5,000 the area covered by a single picture is 1.3 km^2 and resolution to less than 1 m on the ground is possible. At a scale of 1:40,000 the area covered by a single picture is 84 km^2 and resolution to about 10 m is possible.

The most widely used MSS satellite imagery is obtained from the Landsat Series (USA) and the SPOT system (France). Countries within the ESCAP region which operate remote sensing satellite systems include Japan (MOS, GMS), India (IRS) and China. Images are available from these sources as computer-compatible tapes or disks, waveband-specific quasi-photographs in black-and-white or false colour, or false colour composites. By comparison with aerial photographs, satellite images cover a large area and are available principally in small-scale formats. Landsat images, for example, cover a ground area of 185 km x 185 km, or 34,000 km^2 and offer nominal ground resolution of about 80 m. More detailed information is obtainable from the SPOT satellite images, which have a swath width of 80 km and offer 10 m resolution. Scales available from MSS sources range from 1:200,000 to 1:1,000,000, the commonest for large surveys being 1:1,000,000. The SPOT system uses adjacent pairs of images from which stereoscopic viewing is possible.

Compared with aerial photography, satellite imagery has two advantages; firstly, its ready availability and relative cheapness, and secondly, its ability to provide coverage of a large area of land on a small number of prints. On the other hand, it has the disadvantages of poor ground resolution and limited stereoscopic capability. Satellite imagery has been widely used, however, for rapid, large-area reconnaissance-level surveys of extensive land areas and in some cases, of whole countries. It also serves as a valuable preliminary to more detailed larger-scale, airphoto-based surveys. Another advantage of satellite imagery, from both a resource monitoring viewpoint and a disaster monitoring and management viewpoint, is the frequency with which imagery is repeated. The Landsat satellites, for example, are in continuous polar orbit with a return period of 16 days, allowing the progression of a major flood or the passage of a major drought event to be closely monitored.

It needs to be appreciated that, regardless of the category of remote sensing employed, field verification or "ground truthing" of the imagery is essential for the effective application of these techniques in watershed management. During the past five years this activity has been greatly facilitated by the readily availability of low-cost satellite-based navigational or "Global Positioning System" (GPS) equipment. For less than $1,000 US anybody can now purchase a hand-held GPS instrument which utilizes signals from five of a set of twenty-four navigational satellites to give an instantaneous reading of latitude, longitude and height above sea level to a degree of resolution of better than 100 m. With more sophisticated equipment, particularly where differential transmitter stations have been established or where the agency undertaking the survey can obtain access to military-quality signals, resolution to a level of 1 m is obtainable. With such equipment, the location of any sampling site and a wide range of distance, area and height measurements can be made rapidly and accurately, greatly reducing the cost and time-requirements of field survey and ground truthing activities.

Over the past twenty years, the enormously increased amount of resource evaluation and assessment data available from the various types of remote sensing system, much of it available directly in computer-accessible format, and the increasingly widespread availability of low-cost computer equipment, has greatly encouraged the development of techniques for the archiving, analysis, mapping and presentation of such data. Where these techniques relate to the collection, analysis and presentation of geographical data and information, they are called geographical information systems (GIS).

Geographical information systems utilize geographical data and information with respect to three components: spatial data, which pertain to the locational aspects of geographical features, along with their spatial dimensions; attribute data, which pertain to the description, measurement and classification of geographical features; and time, which is particularly important in natural hazard assessment because of the rapidity with which geographical features may alter during the occurrence of disaster events. As has been indicated above, the collection of such data has been greatly facilitated by the availability of various kinds of remote sensing systems. Its incorporation into a computer-compatible format, and its ability to be manipulated within the computer for rapid data analysis, classification and presentation, has been further facilitated by the ready availability of digital mapping devices and software programmes, which allow the ready transformation of analogue data from maps or remote sensing images into computer-usable format.

A GIS has four functional components, which comprise:

(a) A data input subsystem, which collects and processes spatial data from sources such as existing maps and remote-sensing imagery;

(b) A data storage and retrieval sub-system, which organizes data in a structured form and allows it to be retrieved in various forms for subsequent manipulation, analysis or display;

(c) A data manipulation and analysis sub-system allowing the modification or reorganization of data according to given rules and providing a basis for the preparation and manipulation of models of the geographic area;

(d) A data-reporting sub-system capable of displaying all or selected parts of the data base in chosen tabular or cartographic formats.

A key advantage of the GIS approach is that it permits the integration of a wide range of categories of data and the merging or overlaying of various groupings of data, which greatly facilitates the use of the data for design, planning or policy-implementation purposes. By way of example, plans of urban and industrial development can be superimposed on topographic maps and plans of communication systems and the whole overlain by maps of major flood level contours to provide a basis for floodplain zoning rules. A further key advantage is that the GIS system permits the aggregation of spatial and attribute data into models of the land or resource system under study and provides a basis for the simulated operation of such models according to a variety of scenarios as a basis for planning and design problem-solving. In integrated catchment management, the data-integrating and model-forming capabilities of GIS packages are of very substantial potential value for management purposes, particularly as a basis for optimizing models, decision support systems and expert systems. The use of such models and decision-support systems is discussed in further detail in Sections V.F and V.G below.

A wide range of commercial software packages and systems for GIS is now readily available, usually in association with related Remote Sensing (RS) packages. Some of the proven commercial systems now in wide use include GenaMap, TNTmips, SPANS and ARC/INFO, all of which are available from organizations located within the ESCAP region. The use of GIS technology is now widespread throughout the region, and has been strongly fostered by World Bank and United Nations agencies for use in developing countries. ESCAP has been very active in the promotion of GIS as a key tool for natural resources development and planning throughout Asia and the Pacific and should be contacted for further information in this regard.

C. Land resource evaluation

1. Land evaluation

Land evaluation is the process of assessing the potential of land for various alternative uses. These may include productive uses, such as arable farming, livestock production or forestry, and uses that provide services or other kinds of benefits, such as water supply catchment, wildlife conservation, recreation or tourism.

Land evaluation is a key process in land-use planning and an essential feature of integrated watershed management practice. Effective land-use planning can best be undertaken on the basis of a detailed assessment of the qualities of the land, a systematic evaluation of its potential for alternative uses and a rational set of decisions regarding the best uses for it. Such planning is essential for effective watershed management, which is concerned with the prediction of the environmental effects of various forms of land use, the application of management practices to control the effects of adverse uses, and planning for the introduction of beneficial changes in land use.

Land evaluation is essentially concerned with a comparison between the available resource qualities of the land and the requirements of different kinds of land use. Such evaluation requires information inputs from three sources: the land itself, the needs and effects of land uses, and economics. A comprehensive resource inventory is necessary to establish the qualities of the existing land resources. Information about the requirements of possible land uses, including their adverse effects, comes from a variety of technical, ecological and environmental sources. In order to determine the best uses, or to rank alternative land uses as a basis for decision-making, economic data relating to the costs and benefits associated with alternative uses and their consequences are also required.

The resource inventory requires an integrated collection of data relating to topography and landform, geology and geomorphology, soil types and associations, climate, hydrology, vegetation, wildlife, and existing land uses. A soils survey is of central importance to land evaluation, because almost all forms of land utilization depend upon the soil as a medium for plant growth or as an engineering material. Whilst a soil survey might provide the basis for more detailed and comprehensive resource inventory, the resource survey needs to be undertaken on a comprehensive, "land systems" basis using some form of land mapping unit as its key structural feature. Where the survey is undertaken for integrated watershed management purposes, as distinct from evaluation for more specific production purposes such as agriculture or forestry, the land systems approach described in Section VI.B.2 above should certainly be employed. Application of the remote sensing and GIS techniques described in Section V.B.3 will greatly facilitate the undertaking of such an inventory and also facilitate the making of the evaluation itself and the presentation of its results.

Information about the resource requirements of various forms of land use, as well as their environmental consequences, adverse and otherwise, can be obtained from a variety of technological and scientific sources. Soil science, agronomy, forestry, ecology, civil and agricultural engineering and related disciplines are the basic sources of such information. Economic data are required for land evaluation to permit an assessment of the costs and benefits associated with alternative forms of land use and allow them to be ranked on a quantitative, dollar basis for purposes of comparison and decision-making. Whilst the disciplines associated with such assessment and ranking are principally those of economics, agricultural economics and resource economics, much detailed information about the costs and benefits associated with specific land uses is held by the technological and scientific disciplines previously mentioned. Comprehensive land evaluation requires not only the consideration of direct monetary costs and benefits from specific land-use practices, but also the assessment of shadow costs and direct and intangible benefits. This must also involve the determination of environmental and social costs and benefits; whilst these might not easily be expressible in terms of monetary values, there are now many techniques available for doing so.

The results of a land evaluation need not necessarily be expressed in dollar terms; evaluation may be qualitative, quantitative in physical terms, or quantitative in monetary terms. A qualitative evaluation is one in which the suitability of land for various alternative purposes is expressed in a qualitative way, using such terms as "highly suitable", "marginally suitable", "not suitable", etc. This may be an appropriate approach for broad-scale, reconnaissance surveys, particularly in the evaluation of undeveloped or sparsely settled areas, or as a preliminary to a more detailed survey. A particular advantage of this approach, which can be offset against its lack of precision, is that it permits the ready expression and comparison of a wide range of costs and benefits, encompassing environmental and social aspects as well as economic aspects. It is also appropriate where decision-makers, such as planners and politicians, have limited economic and technological expertise.

A quantitative physical evaluation is one which provides numerical estimates of the quantities of inputs and outputs associated with various land-use alternatives. Inputs may include resources, labour and capital; outputs will largely comprise quantitative expressions of land-use products, such as tonnes of wheat or rice, quantities of logs produced, volumes of water yielded or recreational and tourist visitor numbers. Such an approach is particularly useful for the expression of the environmental costs and benefits associated with land-use alternatives, as well as the social costs and benefits. Environmental costs and benefits, in particular, are most readily expressed in such terms as water and air quality parameters, tonnes of soil lost by erosion or areas of vegetation cleared. Economic costs and benefits can also be expressed in physical terms in such units as numbers of jobs lost or created. Whilst this approach is particularly useful from the point of view of environmental and social factors, it has the major disadvantage that different alternatives are very difficult to rank and compare on the basis of physical quantities alone; for example, what is the relative value of a tonne of rice as against a busload of tourists? A quantitative physical evaluation is therefore usually undertaken as the preliminary phase to a detailed economic evaluation. It may also be a very useful supplement to an economic evaluation, particularly when broadly similar land-use alternatives, such as various types of agricultural land use, have significant environmental and/or social consequences.

A full economic evaluation requires a detailed analysis of all the costs and benefits associated with existing or potential forms of land use and their expression in common and readily comparable monetary terms. The particular advantage of this approach is that the use of dollar values provides a universal and readily understandable yardstick for the objective comparison and ranking of entirely different categories of land use. To consider an example used in the preceding paragraph, it is the only really effective basis by which a tonne of rice *can* be compared with a busload of tourists.

A full economic evaluation requires the determination or estimation of all the costs and benefits associated with each alternative, expressed on a dollar basis. For comparison and ranking purposes, it is preferable to use the present worth of the net benefits associated with each alternative as the principal measurement unit. Acceptable alternatives, which are sometimes better understood by decision-makers and the community at large, are annual net benefits, capitalized net benefits, or benefit/cost ratios. As has already been indicated, there is a substantial toolbox of economic analysis techniques now available for the estimation of the equivalent costs and benefits associated with inputs and outputs which are not directly measurable in dollar terms. Where market values are not readily available, for example, opportunity costs and shadow prices may provide an appropriate substitute. Again, the environmental benefits associated with the adoption of conservation farming practices might be assessable in terms of the improvement in property values that results from such a change. In other circumstances, the concept of "willingness to pay", widely used in the assessment of water resources development projects, might be applied to obtain dollar values for many non-productive forms of land use such as nature conservation or recreation.

It is essential in a detailed economic evaluation to take proper account of the time-value of money by using appropriate discounting procedures. This requires very careful selection of the discount rates and project lives to be used in the assessment. The choice of an appropriate and rational social discount rate, relevant to the economic circumstances of the country or region in which the evaluation is being undertaken, is of particular importance, because the discount rate alone can significantly influence the ranking of alternatives and control the choice of the best alternative.

The purposes for which land evaluation surveys are undertaken, and the techniques used for this purpose, vary widely according to country requirements. In developing countries, and in sparsely-settled expanses of more developed countries, many broad-scale land evaluation surveys, encompassing whole regions or in some cases the entire country, have been undertaken on a reconnaissance basis. At a regional scale, extensive land evaluation surveys are often undertaken as a basis for major land-use change, such as the introduction of large-scale crop production or the development of a new irrigation scheme. In developed countries or regions, land evaluation studies may be undertaken for the purposes of planning for closer settlement or urbanization.

At the farm level, the particular technique known as land capability classification is very widely used to plan improvements in farm management, particularly for the purposes of sustainable agriculture and soil conservation. A modification of this technique has also been applied to the evaluation of land for the purposes of urban development. These techniques are readily applicable to integrated catchment management purposes.

An alternative approach has been developed for the assessment not merely of the *capability* of land for various land-use purposes, but more importantly of the *suitability* of land for specific land-use purposes. This approach, known as land suitability assessment, has now been extensively used, particularly in developing countries and at a regional scale, to assess the suitability of land for new forms of land development and choose preferred changes in land use. This approach is also appropriate for watershed management application. Both the techniques introduced above, viz., land capability classification and land suitability assessment, are discussed in further detail in the following sections of this report.

2. Land capability classification

Land capability classification is a form of land evaluation which attempts to assess the potential of land for specified uses. Originally developed by the United States Department of Agriculture (USDA) for farm planning purposes, particularly in areas prone to soil erosion, it has been applied in many countries, often in a modified form and extended to such activities as regional planning and urban land evaluation. It is a useful tool for integrated watershed management, particularly for the introduction and promotion of sound conservation farming practices but also for broader scale catchment land management planning, especially at the sub-catchment level.

The results of a land capability classification are usually presented in the form of a land capability map, which divides the land into capability classes. In the original and most commonly used form of the classification, there are eight major capability classes, ranking land-use potential on a "best" to "worst" basis for specified categories of agricultural uses. Within these classes, sub-categories indicating the nature of land-use constraints or conservation farming requirements may be included. The ranking of the classes is based on four major types of land use, which, listed in descending order of assumed desirability comprise:

(a) Land suitable for regular cultivation;

(b) Land suitable for grazing and occasional cultivation;

(c) Land suitable for grazing only;

(d) Land not suitable for agricultural production, but used for woodland production or reserved for uses such as nature conservation, water catchment or outdoor recreation.

The capability classes are presented as a hierarchy of "desirable" land uses, land which is allocated to a particular class having the potential not only for the use specified in that class but also for any of the classes listed below it. The classes used in the original USDA system, and generally used in other countries, are as follows:

(a) Class I: land suitable for regular cultivation where no special conservation measures are necessary;

(b) Class II: land suitable for regular cultivation but requiring simple (non-structural) soil conservation measures;

(c) Class III: land suitable for regular cultivation but requiring intensive soil conservation measures, such as graded banks and waterways;

(d) Class IV: land suitable for grazing and occasional cultivation; requires some non-structural erosion control measures;

(e) Class V: land suitable for grazing and occasional cultivation but requiring intensive (structural) soil conservation works;

(f) Class VI: land suitable for grazing only. Non-structural soil conservation measures required;

(g) Class VII: land which is steep, infertile, erosion prone or has shallow soils. Recommended use is green timber cover, some logging or grazing possible with good management controls;

(h) Class VIII: land which should not be cultivated, grazed or logged but set aside for such non-productive purposes as nature conservation, recreation etc.

Within each of these classes, sub-classes may be used to indicate the nature of the land-use constraints. In the original USDA system, the following sub-class categories were used:

e = erosion hazard

w = excess water problems

s = soil root zone limitations, such as shallowness, stoniness etc.

c = climatic constraints

Thus Class II land might be classified as IIe if it was erosion-prone, or Class V land as Vs if it had a soil depth limitation, and so on. Other sub-classes and other symbols might be used, depending on the region and the purpose for which the classification is being undertaken. The eight major classes might also be identified by other symbols than the Roman numerals used in the USDA system, depending upon local needs and preferences.

The individual capability classes categorize the land principally in terms of its limitations. Limitations are land characteristics which have an adverse effect upon, or otherwise restrict, the potential of the land for given uses. To determine its capability, land is classified first on the basis of its biophysical characteristics, the extent to which these characteristics will limit a particular type of land use and the current technology available for the management of land. The classification also incorporates the assessment of the soil erosion hazards which considers the appropriate level of land use, while avoiding environmental problems caused by soil erosion and sedimentation. The classification also outlines the types of land use appropriate for a particular area of land and the types of land management practices needed to prevent soil erosion and maintain the productivity of the land.

Land capability maps are determined from a consideration of climate, soils, geology, geomorphology, soil erosion, site and soil drainage characteristics, and current land-use data.

(a) For the farm management versions of the system, the determining climatic data are those which relate to plant growth and production, such as temperatures, the likelihood of the season being long enough for productive growth, and the availability of sufficient moisture.

(b) Soil types are assessed on their erodibility, the presence of any adverse soil physical or chemical characteristics, and the land management practices needed to maintain soil productivity and control soil erosion.

(c) Geomorphological data consider the slope gradient, slope length and shape, and terrain type. The terrain type and the shape of the slope, combined with a knowledge of the geology, can be used to infer particular soil types, or when combined with soils information, to define the boundaries of different soil types, such as the boundary of an alluvial flood plain. Slope gradient, slope length and existing soil erosion data are combined to assess the types of soil conservation practices necessary to prevent or to control soil erosion under differing land uses.

(d) Site drainage limitations determine the likelihood of flooding or prolonged inundation of an area. Soil drainage characteristics describe soil drainage conditions, soil permeability, and the nature of the groundwater behaviour. Site characteristics, such as the presence of various forms of soil erosion, rock outcrops and saline patches are also considered to determine the land capability of an area.

Land capability maps are presented at scales which vary according to their purpose. For farm planning applications, scales of 1:5,000 or 1:10,000 are generally used, depending upon the size of the farming property. Such maps are most conveniently prepared by plotting directly onto enlarged aerial photographs. More extensive mapping for regional planning purposes, such as has in some countries been undertaken for large rural regions or entire river basins, smaller-scale mapping at 1:100,000 is usual. For catchment management purposes, where mapping units are based on sub-catchments, intermediate scales of 1:40,000 or 1:50,000, probably airphoto-based, would be more appropriate.

The land capability approach described in this section, if appropriately modified to suit local farming practices and site conditions, provides a convenient way of assessing the potential of land for specified uses. It appears to be most valuable when it is used for its original purpose, *viz.*, farm planning, particularly where soil conservation is a primary objective. It is therefore of value for application to watershed management practice, where a focus on conservation objectives is essential. For use in the watershed management field it is probably still most appropriately applied at the farm planning level, although broader-scale mapping at the sub-catchment level is clearly desirable for the gaining of an overall, integrated picture of sub-catchment management issues and solutions.

In its original form, and the variants that have been applied in developed countries, there is a considerable focus on arable farming. In many catchment management situations this may not be an appropriate focus at all: there may be a requirement to focus on land uses such as forestry, nature conservation and wildlife preservation, water supply catchment reservation or outdoor recreational activity. In many parts of the ESCAP region very considerable modification of the classification categories might be necessary both for farm planning and for catchment management; in Java, for example, intensive rice paddy and tea production is to be found on steep country which in the original USDA system would be classified as Class VII or Class VIII.

A major shortcoming of the land capability classification approach, whatever modifications might be made to render it applicable to local conditions and practices, is that it is designed to indicate the *potential* uses of land, not the *most suitable* or *most preferable* uses of land. It is based essentially on an assessment of the limitations to the use of land, and it takes a negative approach in that it emphasizes which land uses are *not* appropriate on specific parcels of land.

An improved approach, which focuses on land uses and attempts to indicate the degree of suitability that a given parcel of land has for specified uses, is the technique known as land suitability assessment. This technique is the topic of the next section.

3. Land suitability assessment

Land suitability assessment is a process for assessing the relative *suitability* of indicated areas of land for specified land uses. The uses assessed may be any uses which are considered to be appropriate for the region under investigation; the system is by no means restricted to productive arable or grazing uses as in the land capability classification system. Originally developed by FAO in the 1970s for land evaluation purposes in developing countries, it offers considerable potential as a land-use planning and management tool for integrated watershed management purposes.

The results of a land suitability assessment are presented as a comprehensive set of documents, having three components comprising

(a) Detailed descriptions of each of the land uses evaluated in the assessment;

(b) A set of land suitability maps, indicating the relative suitabilities of the land mapping units on which the assessment is based for each of the land uses,so detailed;

(c) A comprehensive statement of the beneficial and detrimental effects and consequences of applying each of the selected land uses to each of the areas of land mapped, including quantitative information about products and yields, input requirements, environmental and social consequences, and economic costs and benefits.

This amount of information provides a strong basis for rational decision-making regarding the best land uses for the area under investigation. For integrated watershed management purposes, this enables land management control and future land-use policy to be planned on sound environmental, social and economic grounds.

The original FAO classification system has four categories or levels of classification, in order of significance: land suitability orders, classes, subclasses and units. Land suitability orders provide a simple classification of land into two classes; "suitable", designated by the letter S, and "not suitable", designated by the letter N. The suitability classes break these categories down into three levels of suitability; "highly", designated by the numeral 1, "moderately", designated by the numeral 2, and "marginally", designated by the numeral 3. These levels are further broken down into suitability subclasses, which indicate the nature of any limitations that restrict the use of the land for the designated purpose. The subclasses are designated by lower case letters, such as "m" for moisture deficiency, "e" for erosion hazard, "d" for drainage limitations or "n" for soil nutrient deficiency. The lowest order, "suitability units", are further divisions of the subclasses which provide for differentiation on the basis of production characteristics or management requirements. These are designated by a dash followed by a numeral, e.g. "-2". Using this system, a land unit may be designated, by way of example, as S2e-2, indicating that it is moderately suitable for the indicated land use, but there is an erosion hazard which can be managed by farming techniques such as strip cropping. Detailed information regarding the required management techniques would be amplified in the descriptive material accompanying the land suitability maps.

For integrated watershed management applications, variations on this system of designation might of course be adopted to suit local conditions and appropriate forms of land use. In particular, a system which focuses on non-productive and protective land uses such as re-vegetation and destocking, water catchment reservation or nature conservation might require special emphasis in land evaluation for watershed management.

The broad procedures for undertaking a land suitability assessment are similar to those described generally in Section V.C.1, "Land evaluation", and Section V.C.2, "Land capability classification". The required field work and associated office investigations involves two parallel sets of activities: a detailed survey of the available resources of the land, and a detailed study of the relevant and appropriate forms of land use.

The resource inventory or natural resources survey should be land systems based and requires the collection of data relating to topography, landform, geomorphology, geology, soils, climate, hydrology, vegetation, fauna, existing land use, existing land degradation and land degradation hazard potential. The basis of such surveys has already been discussed elsewhere in this document, particularly in Sections V.B.1, V.B.2, V.B.3, V.C.1 and V.C.2. It should be re-emphasized that the specific objectives of any such resource survey need to be clearly identified and strongly articulated before any field work is undertaken.

The land-use study requires a detailed study of existing and potential land uses. This must involve a survey of existing land uses and their land requirements, as well as the consideration of possible future alternative land uses. This may require extensive consultation with existing landholders, with appropriate Government agency personnel and, if they are available, with agricultural and forestry consultants and other commercial advisers. A carefully planned and implemented programme of community involvement is an essential part of this process. A willingness to listen to all points of view and a large measure of imagination and lateral thinking are also essential if an appropriate range of alternative land uses is to be identified.

Once these land uses have been identified and described, it is necessary to establish in some detail the land-use requirements and limitations associated with them. These comprise such factors as climate, slope, orientation and exposure, soil types, soil moisture, drainage, nutrient needs and so on. Land-use requirements can be considered under two categories: land characteristics, which are attributes of land that can be measured or estimated in quantitative terms such as mean annual rainfall, slope, soil depth etc., and land qualities, which are attributes of land which act in a distinctive manner to influence its suitability for a specific land use, such as temperature regime, nutrient supply, drainage characteristics or erosion hazard. Land qualities depend upon the interaction of several land characteristics, which need to be identified as a basis for establishing the limits on land use.

Once the appropriate set of land characteristics and qualities for each of the land uses under investigation has been decided upon, these limits can be determined. Specifically, this requires the establishment of boundaries, using quantitative parameters as much as possible, between the suitability classes and subclasses adopted for the land capability assessment; i.e., the boundaries between S1 and S2, N1 and N2 and so on. Where this is done quantitatively the subsequent suitability evaluation mapping process can be greatly facilitated, particularly if the land resource survey mapping has been undertaken in terms of the same characteristics, e.g., slope, annual rainfall, effective soil depth etc.

The next stage in the suitability assessment process is to bring together the two strands of activity – resource survey and land-use study – to make the comparison between land uses and land which is the essential purpose of the assessment. The first step involves a detailed comparison and matching of the established requirements and limitations of the various kinds of land use under examination with the available qualities of the land, initially undertaken on a bio-physical basis. This must be followed by an economic and social analysis and a study of environmental impact. It needs to be supplemented by field checking, in which the provisional suitability classification is reviewed in the field by the landholders, agency personnel, consultants and others who were consulted during the initial stages of the land-use study.

It is important to emphasize that the process described above should be an iterative one, involving successive refinement and frequent feedback. Close contact should be maintained between the resource survey and the land-use study, and the specifications of land uses and their requirements progressively modified in the light of increasing or improving survey information. The iteration process might also involve progressive modification of the resource survey programme in the light of changing concepts of appropriate land uses and possibly, a modification of the original objectives of the evaluation project as needs and opportunities become clearer.

At the end of this process, the land suitability classification can be finalized and the presentation of the results undertaken. As indicated earlier, this generally involves three components: definitions and detailed descriptions of each of the land-use types examined in the assessment; a set of maps and accompanying legends showing the results of the land resource inventory and the land suitability classifications; and an assessment report detailing the suitabilities of each of the land-use types for each of the kinds of land available.

For regional or river basin scale assessments, an appropriate scale for the base land resource map or maps, detailing the basic land system units identified in the resource survey, is 1:50,000. For smaller upland watersheds and sub-catchments a larger scale, 1:25,000 or 1:20,000, might be more useful. The accompanying land suitability maps, showing the suitability classifications for each land-use type, can be prepared at the same scale, although where there is a considerable variety of land units and a large number of land-use types presentation at a smaller scale than the base map might be convenient. Each of the maps should be accompanied by a comprehensive legend summarizing basic biophysical data for each land unit and summary information for each land-use type.

Land suitability assessment, as described in this section, is considered to be far superior to land capability classification as a land-use planning and management tool for integrated watershed management purposes. This is because it provides detailed information about a range of feasible land-use management alternatives, appropriate to watershed management purposes, and presents the consequences of such changes in a concise but comprehensive manner, including their bio-physical, economic, social and environmental consequences. It thus provides, in a convenient form, a sound basis for land-use planning, policy, management and investment decision-making. In the context of integrated watershed management for the ESCAP region, it has the added advantage that it was developed for, and has now been widely applied and proven in, developing countries in tropical and sub-tropical locations. Its adaptation to integrated watershed management applications across the ESCAP region therefore appears to be entirely appropriate.

An interesting regional application of this approach, which has been developed specifically for integrated watershed management purposes, is the Watershed Classification system used by the Mekong River Commission. This system, developed for the Commission by the University of Berne in Switzerland, was originally prepared for the purpose of watershed classification mapping for the watersheds of the Mekong River basin within Thailand. It utilizes a vector-based GIS mapping procedure, producing a series of three-dimensional topographical maps called Digital Terrain Models (DTM). Watersheds are classified and mapped in overlay form on this model according to five categories of recommended land use (i.e., land suitability), which are as follows:

- protection forest
- commercial forest
- fruit tree plantation and agro-forestry
- upland farming
- lowland farming

The watershed category for a given parcel of land is calculated from an empirical formula which depends on five topographic or geological parameters, each of which can be mapped by the GIS model and shown on a coloured three-dimensional map model. The basic parameters used for this purpose are as follows:

- slope
- elevation
- landform
- soils
- geology

It should be noted, however, that in the original mapping undertaken for the Lower Mekong watersheds in Thailand, where soils and geological data were limited, the calculation of WSC was based on three parameters only, *viz.*, slope, landform and elevation.

The watershed classification classes can be shown in colour on the three-dimensional Digital Terrain Model or plotted in colour on conventional two-dimensional topographical maps called "WSC Maps". These maps usually prepared at a scale of 1:250,000. In addition to the WSC classifications, they also show elevation contours and river lines. They are therefore most suitable for macro-scale planning purposes at national, regional or large river basin level. The technique could however be easily adapted for smaller-scale mapping at the upland watershed level, provided that sufficient topographical and geological data were available.

This watershed classification system can be utilized for a variety of land-use planning and watershed management purposes, and appears to offer considerable potential for application to such purposes within the ESCAP region. Further information about mapping procedures and the application of these maps for planning and management will be found in the Mekong River Commission publication listed in the bibliography at the end of this document.

D. Data for hazard assessment

1. Data requirements for hazard evaluation

The data requirements for hazard assessment in connection with the identification of potential water-based natural disasters include the need for reliable and accurate data about such meteorological phenomena as rainfall and other forms of precipitation, wind, barometric pressure, temperature and humidity, along with hydrological data about run-off and streamflow, particularly in relation to flood events, and information about groundwater aquifer characteristics. Geological and geomechanical data, particularly in relation to the likelihood of landslide or other forms of mass movement, as well as detailed information about soil types and soil properties, are also necessary.

Within the ESCAP region, most nations now have reasonably well-established meteorological and hydrological data collection networks, although it is probable that in most cases these networks are not as comprehensive as they need to be for accurate forecasting of major water-based disaster events. Full implementation of the WMO World Weather Watch and Operational Hydrology Programmes will lead to the satisfactory provision of essential data requirements. The establishment and operation of these networks is an expensive, labour-intensive and on-going process that must be maintained into the future if the data collected are to be of continuing value; the longer data recording continues, the more valuable the recorded data become. These data are required for three purposes: firstly, as a record of past conditions, to provide a basis for the design of structures, devices or policies for disaster prevention or mitigation; secondly, to monitor existing conditions, as a basis for the forecasting of likely future conditions and particularly providing advance warning of oncoming disaster events; and thirdly, during the actual occurrence of disaster conditions, for accurate short-term forecasting of the likely time, magnitude and location of developing disaster events. Effective real-time warning systems, particularly cyclone and flood warning systems, may be as useful as high-cost physical structures and devices in reducing disaster damage costs and minimizing injury and loss of life during disaster events.

It is therefore of substantial importance that governments provide adequate funding for the establishment, operation and maintenance of comprehensive and effective data systems in relation to natural disaster phenomena. It is fortunate that the same data are necessary for a variety of other purposes, which in the context of this manual relate particularly to the requirements of data for integrated watershed management, land-use planning and management, natural resources development and management, and the maintenance of environmental quality.

2. Meteorological data

Meteorological data for hazard assessment need to be based on a comprehensive, nation-wide system of meteorological recording stations. It is highly desirable that such a system be funded and operated by the national government and not delegated to provincial or regional agencies. It is also essential that it be closely associated with, and compatible with, the national meteorological recording systems operated by neighbouring nations. WMO, with its 186 member countries, has laid down appropriate requirements in its programmes for meeting these needs.

The main categories of meteorological data needed for effective water-based natural disaster identification and assessment are briefly discussed below.

(a) *Precipitation data*

The precipitation data collection network should be based on a comprehensive system of daily rainfall measuring sites using standard raingauges. In an appropriate set of representative locations, and also on the catchments of critical flood-prone areas, the daily gauges should be supplemented by recording gauges providing a continuous record of rainfall depth and intensity. For preference, the recording gauges should be of the digital type so that data can be archived, processed and analyzed by computer and made readily available to potential users, particularly disaster-control agencies, through an e-mail or other Internet facility. Where recording gauges are located on flood-prone catchments as part of a flood-warning system, they should be of a type which provides for the immediate and direct telemetering of data to the headquarters of the disaster control agency.

In elevated watersheds where snowmelt may be a major contributor to flooding, it is desirable that well-designed recording snow gauges be located at selected sites. These should be supplemented by a network of snow depth and quality sampling sites at strategic locations on the catchment. In locations where hail is a hazard, the extreme difficulty of recording hail events mechanically can be partly overcome by careful observation of conditions during hailstorms and the making of post-storm damage surveys.

(b) *Wind and atmospheric pressure*

Detailed information about wind speeds and directions is essential for disaster management and mitigation in cyclone-prone areas. Point-site wind data need to be supplemented by regional or country-wide barometric pressure data for the preparation of synoptic weather charts and the assessment and forecasting of cyclonic, monsoonal or other storm and flood-producing rainfall events.

In cyclone-prone areas, an adequate covering of recording wind velocity and direction gauges is desirable. Such gauges should measure wind speed and direction continuously at a standard height of 10 m above the ground surface. For preference, the data should be recorded in digital form for the ready downloading and analysis of data and, desirably, for telemetered transmission to disaster control centres. A strategic location of wind recording instruments on the catchments of major flood-prone areas is also desirable for flood-warning purposes. The recording stations should be supplemented by three-hourly wind speed and direction observations at all principal weather observation stations.

Barometric pressures should also be observed at as comprehensive as possible a range of weather observation stations. At these stations, three hourly readings of atmospheric pressure are desirable. At key stations, recording barographs should be installed and daily radiosonde measurements of upper atmosphere pressures, wind speeds and directions and temperatures undertaken. Here again, the implementation of the observational programmes laid down under the various decisions of WMO would enable the fulfilment of these requirements.

(c) *Other forms of meteorological data*

There are several other categories of meteorological data which are of assistance in hazard assessment and particularly in the forecasting of hazard events. A variety of surface and upper atmosphere pressure and wind charts can be prepared from the basic data already discussed and these can be supplemented by cloud observations, satellite cloud pictures, radiosonde observations, radar observations, other satellite data and information reported by ships and aircraft. Temperature, humidity and dewpoint data are of considerable supplementary value in the prediction of storm rainfall conditions and the preparation of flood forecasting information, particularly if they include upper air profile measurements from radiosondes or aircraft.

3. Hydrological data

Hydrological data for hazard assessment ought also to be based on a comprehensive, nation-wide system of streamgauging stations. Because it is not possible to measure streamflow rates directly, the establishment of gauging stations and their progressive calibration or "rating" is an expensive, time-consuming and often long drawn-out procedure. For this reason, most countries within the ESCAP region have hydrological data collection networks which are inadequate in their areal coverage and are limited in the length of hydrological record available. In many cases these networks are operated by provincial or regional authorities, although it is highly desirable that they be made the responsibility of national governments particularly, as is the case in some parts of the region, where major river basins transcend the borders of two or more countries.

Streamflow measurement has two components. One involves the measurement of the depth of flow or "stage" at the selected gauging site, which preferably should be done on a continuous basis using recording instruments. There is a variety of such instruments available to suit site conditions; these include float recorders, pressure recorders, bubble-gauge recorders and a variety of electronic, electro-magnetic and sonic devices. For preference, these instruments should provide data in a down-loadable, digital form, rather than on charts, for ease and rapidity of analysis and archiving and, where appropriate, to facilitate the telemetering of data.

The other component involves the progressive calibration or "rating" of the site, to establish the relationship between the recorded depth of water and the corresponding volumetric flow rate in the stream. This requires periodical measurements of velocity distribution across the stream, from which, for a given area of cross-section, the discharge rate can be calculated. This procedure must be repeated over a range of flow depths to establish the stage/discharge calibration curve or "rating curve" for the station. Because high rates of flow will occur only infrequently, it may take many years to complete the rating curve. Furthermore, at many streamgauging sites the stage/discharge relationship is not constant, but changes either cyclically or even continuously so that a continuing rating process becomes necessary. For these reasons, it is highly desirable to maintain a trained workforce of hydrographic technicians available at short notice to undertake gauging activities.

Hydrological data are essential for a variety of purposes in relation to the management and prediction of water-based natural disasters. For flood control applications, good data regarding past flood events over as long a period of record as possible are essential for the design of all flood control structures and devices and the planning of non-structural flood mitigation measures. For flood forecasting and flood warning purposes it is highly desirable that streamgauging instruments be sited at key locations on flood-prone catchments, with provision made for them to be interrogated by telephone, e-mail or radio or alternatively, to download data continuously by one of these media to the flood control agency's operational headquarters.

Long-term streamflow data are also essential for the management and prediction of drought conditions and many aspects of water resources management and water quality management. For drought management, long-term streamflow or run-off data are necessary for the design of reservoirs and other flow-regulation devices and for the planning of drought management strategies.

In many localities within the ESCAP region, a key factor in drought management and drought preparedness is the availability of adequate supplies of groundwater, either as the principal source of supply or on a supplementary or emergency basis. Good data about the locations, depths, flow characteristics and quality levels of groundwater aquifers therefore form an important sub-set of the hydrological data requirements for disaster management in such localities.

4. Geological and geotechnical data

Geological and geotechnical data are of significance in relation to some aspects of water-based natural hazard assessment and in particular to land instability and land degradation.

A variety of geological and geophysical survey techniques is available for the investigation and assessment of slope stability and other forms of land instability hazard. The most basic requirement is for a broad-scale geological survey, undertaken in sufficient detail to allow for the identification of sub-surface conditions likely to be conducive to slope instability. Geological survey maps at a scale of at least 1:250,000 and preferably 1:100,000 are desirable for this purpose. The existence of land instability hazard zones can often be identified from remote sensing images, including aerial photography and, to less detailed extent, from satellite imagery. The use of these techniques has been discussed in Section V.B.3.

Within identified hazard-prone areas, more detailed geological, geophysical and geotechnical survey information is desirable. At reconnaissance level, electromagnetic surveys conducted from aircraft and particularly helicopters may be useful in locating hazard zones. Once they are identified, small-scale geophysical survey techniques, particularly seismic, electromagnetic induction and earth resistivity techniques, are particularly useful for locating and mapping shallow underlying strata, aquifer layers and other conditions conducive to slope instability. Within identified hazard-prone areas, soil and rock sampling is necessary to determine the engineering properties of the soils and underlying material, including particle size distributions and engineering classifications, shear strengths, permeabilities and drainage characteristics. Geotechnical mapping of these properties, to scales as large as 1:10,000, along with conventional soil survey mapping, is desirable within such zones.

Several of the forms of land degradation discussed in Chapter II are related to the physical and chemical properties of the surface soils, and the likelihood and potential severity of occurrence of these forms of degradation can be assessed from these properties, along with the geological, topographical and climatic features of the landscape at risk. This is particularly so in the case of water erosion, soil erosion and soil salinity.

The susceptibility of a soil to water or wind erosion is a function of many soil properties, of which the most important include particle size distribution, soil texture, soil structure, infiltration characteristics, in-situ moisture characteristics, shear strength, cohesion, and dispersibility. The likely erosion hazard can be assessed from standard soil survey mapping, particularly where the soil properties surveyed include those which influence erodibility or where there is an adequate local knowledge base regarding the erosion propensity of the soil types and profiles identified in the survey. For preliminary assessment, conventional soil survey data mapped at a scale of 1:100,000 provides a good starting point. Remote sensing photography or imagery, particularly black and white stereoscopic aerial photography at as large a scale as can be obtained, provides a very useful supplement. In most parts of the ESCAP region, erosion is already well developed in locations which are erosion prone and these areas are readily identified from aerial photography.

Areas which have been subject to land degradation as a result of soil salinity, whether dryland salinity or irrigation salinity, are also readily identifiable from aerial photography. In the early stages of salinization, characteristic changes in plant cover develop as salt-tolerant species replace the natural vegetation. In advanced stages, the absence or death of vegetation and the presence of white salt deposits on the land surface are readily identifiable. To identify a potential salinity hazard on land which is undeveloped or only newly developed, more detailed information based on a knowledge of soil properties and the underlying geology and geomorphology is required. Where sufficient information about the susceptibility of local soil types is available, conventional soil survey provides a good basis for hazard assessment, particularly where soil mapping has been undertaken at large scales, preferably 1:50,000 or larger. For preference, large-scale surveys should be supplemented by grid-pattern soil sampling undertaken for the specific purpose of measuring soil salinity, along with measurements of other soil properties and the depths to the water-table and underlying impervious strata. The most important single soil property to be measured in this way is the electrical conductivity of the soil water, which can be related to the concentration of salts in the soil. Electrical conductivity can be easily measured using a conductivity meter on a saturation extract sample of soil water, undertaken according to standard laboratory procedures which have been extensively described in the literature. Electrical conductivity can be correlated with the concentration of specific solutes in the soil solution, to give an accurate indication of salinity hazard. The US Salinity Laboratory has established criteria for the categorization of salinity hazard according to the value of electrical conductivity so obtained.

In recent years, a number of field techniques for the rapid assessment of salinity hazard using geophysical technology have been developed and refined. The electrical resistance of the soil can be measured *in situ* by various means and the results related to soil salinity by correlation. The two methods in most common use are to measure electrical resistance directly using sensor probes buried in the soil or to use portable electromagnetic induction (EMI) equipment.

The most usual probe method involves driving a set of four electrode probes in a line in the soil, applying an electrical current between the outer probes, and measuring the potential difference between the inner pair. The electrical conductivity of the soil is calculated from an empirical relationship. Whilst the probe method has the advantages of simplicity and cheapness, it has the major disadvantages that it is a slow and time-consuming process and that it is difficult to make accurate measurements when soils are dry.

The EMI method does not require electrodes to be inserted in the soil. It involves the use of a magnetic coil above the soil surface to create a magnetic field within the soil, the signals from which are measured by a second suspended coil. The equipment can be calibrated to read directly in electrical conductivity units. Small units can be mounted on light tractors or all-terrain vehicles and very rapid and detailed surveys can be undertaken in this way. It is also possible to tow larger instruments behind vehicles or even to mount the equipment in aircraft for rapid, large-scale survey purposes.

5. Damage cost assessment

The various categories of water-based natural disaster described in Chapter III and the various categories of land degradation described in Chapter II all have adverse consequences in economic, social and environmental terms. Most of these consequences can be measured, estimated or at least ranked as a basis for comparison in economic terms, sometimes directly, sometimes indirectly and otherwise intangibly or by inference.

Where new works, facilities, schemes or policies for the prevention or mitigation of future disasters or further degradation are under investigation, a range of alternative solutions will usually become apparent. It then becomes necessary to find some means for ranking these alternatives in order of merit and choosing the best alternative in terms of a selected set of criteria. Most commonly, these criteria are expressed in monetary terms, because this provides the most convenient yardstick for the ranking and comparison of a wide range of alternative plans or designs. Good integrated watershed management practice requires that other yardsticks, both quantitative and descriptive and assessing environmental, social and other parameters, be also used for ranking alternatives on a multi-objective basis. Nevertheless, the use of economic yardsticks remains essential, partly because of their universal application, partly because of the precision with which they can be assessed by comparison with other criteria, and partly because they can be manipulated in a timestream sense to place present and future costs and benefits on a comparable basis.

Where a set of disparate alternatives is identified, each offering as its outcome a different potential level of community satisfaction, the most appropriate basis for economic ranking is to express all the outcomes in monetary net benefit terms. Where each of the alternatives provides the same outcome, a much simpler economic comparison on the basis of least cost or cost effectiveness is possible. Whichever approach is to be used, the starting point is a detailed measurement of the past costs of damages associated with disasters or degradation of the kind under investigation, preferably at the subject site. Once details of damage costs are known, the benefits of mitigation alternatives can be assessed in terms of the reductions in damage cost that can be expected to accrue from them.

A considerable background of experience, literature and data is now available regarding flood damage costs, probably because floods are recurring and site-specific. Less information is available about the costs of cyclone damage, land instability or droughts or the various forms of land degradation, but most countries within the ESCAP region are progressively accumulating data in this regard. The techniques employed for flood damage assessment can be transferred with little difficulty to the measurements of other forms of disaster damage. The costs of land degradation are more difficult to assess, largely because of the progressive and incremental nature of this form of damage and the fact that many forms of land degradation arise from land-use practices which, at least in the initial stages, are undertaken because they are considered to be profitable and therefore beneficial.

The losses caused by a natural disaster may be classified under one of three headings as:

(a) *Direct* losses, actual or apparent, which can be evaluated in terms of the costs of replacement or repair of all the physical damage caused by the disaster event;

(b) *Indirect* losses, which can be expressed as the value of business, services or economic activity either lost or made necessary by the disaster event;

(c) *Intangible* losses, which are not capable of direct monetary evaluation, which include loss of life and effects upon health, social and economic security.

Damages within these three categories may be scheduled under a list of headings which could include:

- residential
- commercial
- industrial
- utilities
- rural
- transport
- public

Residential losses include damage to buildings and grounds, furnishings and personal possessions. In extreme events, dwellings might be completely destroyed; in less severe events, they may be extensively damaged by inundation, filled with mud, silt or debris, or undergo various forms of structural impairment, requiring substantial repair or refurbishment. The costs of evacuation during the event, the provision of emergency accommodation, damage relief costs and so on would constitute indirect costs under this heading.

Commercial losses comprise the losses sustained by establishments engaged in trade, such as shops, markets, banks, restaurants, hotels, professional offices, service providers etc. In addition to costs associated with the repair or reconstruction of buildings, damages in this category might include loss of goods and merchandise and loss of business accounts and records. Indirect losses under this heading might include lost wages, salaries and revenues, the loss of contracts and other business and additional operating costs imposed by the disaster event.

Industrial losses refer to losses incurred by the manufacturing and industrial sector and may include loss of, or damage to, buildings, land, equipment, raw materials and stored products. Indirect losses under this heading will be of a similar kind to those discussed under commercial losses.

Utilities as categorized here include all agencies and private or government organizations that provide or sell some kind of consumer service, such as electricity, gas, water, telephone and telegraph services. Destruction or damage of buildings, property, plant, equipment and distribution systems might all be included under this heading. Indirect losses would include the effects of interruption of service, loss of revenue and other income and the costs of providing emergency supply.

Rural losses might include a wide variety of losses resulting from damage to, or loss of, agricultural, grazing and forest land; damage to buildings, fences, and farm equipment; degradation of land or reduction of its productivity through deposition of mud, silt, debris and so on; or the loss of crops and livestock. Indirect losses under this heading would be similar in many ways to those incurred under the residential and industrial headings, along with loss of revenue because of the destruction or reduced quality of farm products and the costs of replanting or restocking.

Transport losses are those incurred within the transport infrastructure and may include damage to road surfaces, railway tracks, airports, harbours or canal systems; loss or damage of bridges, causeways, tunnels, and similar ancillary features; destruction or damage to buildings such as railway stations and airport terminals; damage to rolling stock, vehicles or equipment; and the loss of goods or freight in storage or transit. Indirect losses may be due to service and traffic interruptions, the costs of rerouting or alternative arrangements and loss of passenger or freight revenue.

Public losses relate to losses incurred by national, state, regional and local government bodies, and may include destruction of or damage to buildings, property, equipment and facilities, loss of records and accounts and interruption to services. Direct and indirect losses incurred under this heading will be generally similar to those discussed under the heading of commercial losses.

Under each of the foregoing headings, losses might also be categorized as *recurrent* and *non-recurrent* losses. The former category refers to all those losses which can be expected to recur every time a major disaster event takes place. The latter refers to losses which will not occur when a future event takes place, because of the nature of the repairs or replacements undertaken after the first event. For example, a bridge destroyed in a flood event may be replaced by a new bridge constructed at a new location well above flood level, or a damaged residential area might be relocated to a flood-free zone. In general, it is only recurring losses that need to be considered in the estimation of future flood benefits from a proposed mitigation measure, although the costs of zoning or relocation might be considered as part of the cost of such a measure.

To determine the magnitude of the losses associated with a disaster event, as a basis for the planning of measures to mitigate or prevent damage from future events, an extensive damage survey becomes necessary. For preference, such a survey should be undertaken as soon as possible after the event and on as comprehensive a basis as the available resources permit.

The most effective method of survey is to undertake a detailed survey of the entire area affected by the disaster under investigation. This will require a team of engineers, quantity surveyors and other assistants equipped to locate and interview every property owner or tenant within the disaster area. The investigators should be provided with detailed maps or airphotos of the area and a set of standardized data sheets embodying a carefully-designed questionnaire or set of questionnaires for appropriate categories of building or property. As a guard against exaggeration, the investigators should undertake independent evaluations of the losses incurred at a representative sample of sites within the area. The data so obtained should be supplemented by the data collected by the relevant state and local government agencies responsible for the area under investigation.

Where sufficient resources are not available, the investigators might have to be satisfied with a sampling survey. Where this becomes necessary, much care needs to be taken in the design of the survey, to ensure that the sample is reasonably representative. There is a variety of sophisticated sampling procedures available for such purposes.

Because major natural disaster events are sporadic in occurrence and vary widely in intensity and frequency, it is highly desirable that data from a range of such events be available for the planning and design of mitigation measures. For preference, it is desirable to establish relationships between levels of disaster intensity and the magnitudes of consequential damage costs, as a basis for determining the level of intensity for which protection or mitigation is provided. In the case of flooding, it is usually possible to relate the extent of damage costs to the depth of flooding. This is most commonly achieved through the preparation of stage-damage curves, which relate the total amount of damage to the river stage or depth. Where data from a range of past flood events is not available, it is still possible to prepare estimations of the stage-damage relationship through careful questioning and investigation, undertaken during the progress of a detailed damage survey by estimating what the levels of damage would have been at different flood depths. If data from two or more flood events is available, the accuracy of this procedure can be much enhanced.

For flood-prone areas, where adequate data relating flood depth to river discharge are available, stage-damage data can be readily converted to discharge-damage data and, if a reasonably long record of hydrological records exists, this information can be used to prepare relationships between flood damages and frequency of occurrence. This leads to the evaluation of information about average annual flood damages or expected values of flood damages on a present worth basis, which can then be used to determine the benefits associated with alternative flood mitigation schemes.

In many parts of the ESCAP region, floods occur annually and it is possible to accumulate sufficient data for the preparation of stage-damage and frequency-damage curves in a comparatively brief period of time. For other kinds of short-lived natural disaster such as tropical cyclones and land instability, occurrence is much more sporadic and it becomes necessary to transfer data from other locations where similar disasters have occurred. Major droughts present a different kind of problem again, because of the long-term duration and extensive areal coverage of such events. Apart from the study of State, regional and local government records relating to past drought events, well-designed sampling studies and carefully-worded questionnaires, including hypothetical scenarios of possible drought circumstances, might be utilized to build up scale-of-intensity/damage or frequency/damage relationships as a basis for drought mitigation planning.

Once a reasonable set of data regarding relationships between natural disaster damage and the intensity and/or frequency of occurrence is established, the economic benefits of proposed disaster-mitigation alternatives can be assessed in terms of the reductions in damage costs expected to result from them. Because of the unpredictable nature of natural disaster events, simple comparisons based on average annual damages or benefits, or expected values of damages or benefits in present worth terms, are an inadequate basis for decision-making. A statistical analysis is needed, in which careful consideration of the probabilities or levels of risk associate with events of a given magnitude is presented and the probability distributions of damage costs and mitigation benefits are assessed.

E. Hazard evaluation

1. Flood inundation mapping

In order to reduce the adverse impacts of flood disasters, it is essential to accurately delineate areas which are prone to future flooding. The exercise of assessing and delineating the zones subject to floods of different magnitude and different frequencies is usually termed flood risk mapping.

Accurate delineation of flood prone areas is a basic step in the formulation and effective implementation of either structural or non-structural flood mitigation measures. Flood risk maps are a particularly guide for the planning and implementation of land-use measures, including watershed management techniques and land-use zoning and regulation.

The approaches to flood risk mapping can be grouped into two general categories, *viz.*,

(a) Those which determine flood run-off or peak discharges in a river and then determine the area inundated under peak level conditions;

(b) Those which define the flood hazard directly from recorded or assumed inundated areas.

The first category is referred to as "the hydrological and hydraulic approach". In this approach the following methods of determining peak flows may be used:

- flood frequency analysis
- the regional flood method
- flood formulae

Flood frequency analysis uses records of past flood events on the river under investigation to define the statistical probability of floods of different magnitudes. For example, flood discharges likely to occur or to be exceeded once in twenty, once in fifty or once in one hundred years can be defined by this method. However, the method is demanding both of data and of expertise in computation.

Where river gauging records do not exist, or where the length of record is too short to be useful, discharges may be estimated by rainfall-run-off models or by statistical comparisons with adjacent river basins where records do exist. When the flood peak discharges have been determined by any one of these methods, the discharges must be routed through the river reach to determine the areas of inundation and to produce a flood risk map.

The geometric configuration or cross-section of the stream channel and adjacent overbank areas can be obtained using ground or aerial survey. The dimensions of culverts, bridges, flood control structures and other encroachments upon the floodplain are included within the cross-sectional information. Hydraulic analysis is used to determine how much of the floodplain is required to pass a given flood discharge and the corresponding flood elevation.

Using these methods, flood boundary maps can be prepared for floods of different magnitudes, say the 10, 20, 50 and 100 year floods. When combined, they provide a flood risk map which indicates the extent of the zones inundated by each of the indicated flood magnitudes. When superimposed on topographic maps, these permit an estimate to be made of the depth of flooding at specific locations.

The second category of flood hazard mapping methods includes methods based on recorded flows, geomorphological surveys, soil surveys and intelligent guesswork.

Perhaps the simplest way to define a flood hazard area is to equate it with the area actually inundated by a historic flood. Whilst this defines the hazard area, it does not provide information about the magnitude of the flood or its recurrence interval. To be useful, the recorded flood should be a fairly large one, but it may not be possible to determine just how large it is in relation to other possible floods, as in many cases the streamflow records required for flood frequency analysis will not be available.

Aerial photographs or satellite imagery taken at the height of a flood can be most useful in determining the flood outline. Excellent maps can be compiled from past flood surveys, from information collected on the ground, although this approach is generally more time-consuming. Ground survey has one major advantage, however, for not only can a record be made during or shortly after a flood event, but, if necessary, the outlines of past floods can be mapped even a decade later using local anecdotal or historical information about past flood events.

Geomorphological and soil mapping are generally useful where streamflow records are lacking or inadequate. They may be particularly suited to the study of large, wide floodplains where floodwaters may cover extensive areas to varying depths and velocities. A study of topography and sediments can reveal much of the history of past floods in the valley and can indicate the patterns of flooding likely to occur in the future. A detailed survey can indicate the extent of the area submerged by large floods, the direction of flood currents and the incidence of sediment deposits and erosion.

It should be appreciated that a certain degree of uncertainty can be associated with the boundaries of floods as delineated on the basis of the mapping methods discussed above, including methods which use past flood records. The pattern of future floods can be affected by a number of factors such as the accuracy of topographic mapping, hydrology, hydraulics and changes within the watershed and the river channel. Many land-use practices have the capacity to alter the run-off regime and increase flood risks. The many forms of watershed degradation can, either singly or in combination, accelerate the rate of delivery of floodwater to the river, thus producing higher flood peaks and more extensive inundation. Intensive urban development may produce similar effects. In addition, flood behaviour can be altered by changes in the river channel, caused by sedimentation or erosion, or the construction of bridges, levees and other works.

2. Erosion hazard survey and prediction

In areas which are susceptible to water and wind erosion, systematic surveys of soil erosion should be undertaken to assess the magnitude of the particular forms of erosion present, including the areal extent of occurrence and level of severity, and to determine whether there is potential for further erosion. For watershed management purposes, these surveys are best undertaken on a whole-of-watershed basis. They might also be undertaken on a whole river-basin, regional or provincial scale as part of a road-scale survey of existing and potential land degradation.

Erosion surveys are usually undertaken in association with soil surveys or land evaluation surveys. If they are mounted specifically for watershed management or river basin management purposes, they should be based on remote sensing techniques, supplemented as necessary and appropriate by field survey.

For broad-scale, regional or large river basin-scale surveys, the survey is best based on Landsat imagery, supplemented in areas of apparent severity of erosion by black and white or panchromatic aerial photography. Landsat-based mapping at a scale of 1:100,000 is appropriate for this kind of survey. For specific watershed management purposes, where land-use controls and/or modifications are expected to be necessary for erosion control purposes, larger scale mapping based on standard airphotos is most appropriate. Maps for this purpose might be presented at a scale of 1:50,000 or, for smaller upland watersheds, 1:25,000 or even larger.

The field verification or supplementation of the remote sensing survey may be undertaken in several ways, involving either grid sampling, transect sampling or stratified sampling in which areas identified from airphotos are selected and then subjected to more detailed ground survey. Where previous soil or land resource surveys have been undertaken using a land systems approach, the land systems already identified will provide a good picture of erosion occurrence or erosion hazard potential and a good basis for the selection of areas for the stratified erosion survey.

The susceptibility of an area of land to soil erosion, as well as the prediction of the likely effects of changes in land-use and farming practices on the extent of such erosion, can be readily assessed by using one of the several computer models available for this purpose. The best-known soil erosion prediction model is the Universal Soil Loss Equation (USLE), originally developed by the Soil Conservation Service of the US Department of Agriculture. In its original form, derived for the quantitative prediction of soil loss under arable farming conditions for the mid-Western states of the USA, it is an empirical equation which depends upon several parameters, which comprise a rainfall erosivity parameter, a length and slope parameter, a cropping practice factor and a management practice factor. These parameters are specific to the site for which they were derived, so that application of the model in other locations requires that they be re-evaluated. Extensive studies have now been undertaken to modify the model for use elsewhere in North America, Europe, Australia, Indonesia and other countries within the ESCAP region and various computer model formats are available. Typical of such a format is the SOILOSS programme developed for Australian conditions by the former NSW Soil Conservation Service.

Other more advanced modelling procedures have recently been developed in North America, Europe and Australia. In the USA, The USLE has been largely replaced by a computer-based modelling procedure called WEPP (Water Erosion Prediction Project), for which information is available from the US Department of Agriculture. Several more advanced models have been developed in Australia, notably by Professor Calvin Rose of Griffith University in Queensland.

3. Land instability hazard survey and prediction

In areas which are known to be susceptible to land instability, it is important to undertake hazard surveys and make detailed investigations of existing landslides and other instability events in order to provide a scientific basis for hazard management and future hazard prediction.

Reconnaissance hazard surveys are most conveniently undertaken using large-scale aerial photography. The airphoto interpretation should be accompanied by any existing large-scale topographic maps and geological maps, together with any other geotechnical survey information that might be available. If the region under investigation has already been surveyed or evaluated on a land systems basis, the land system mapping units will probably already have identified areas of potential instability hazard and will provide a useful basis for the concentration and stratification of the airphoto survey and any supportive field investigation. A special map showing in detail the areas of existing instability should be prepared, using as large a scale as possible e.g. 1:5,000 or even 1:1,000. Airphotos enlarged to the appropriate scale form an excellent base for such a map.

Detailed field investigation of any major instability features identified should be undertake to measure the extend of the landslide or slip and any potential downslope danger areas and also to determine the cause of the instability as a basis for the prediction of future movement. Such an investigation might include:

(a) A detailed site survey, involving a contour survey of the unstable area and mapping if its outline and the location of any surface cracking, slump circle features etc;

(b) An onsite geological and geophysical survey aimed at an understanding of the geological characteristics of the sliding area; depending upon the extent and significance of the site, this might include exploratory drilling and the use of a geophysical technique such as a seismic survey, an electrical resistivity survey or an electromagnetic induction (EMI) survey;

(c) A groundwater investigation looking at groundwater quality, depths to water table, drainage paths, pore pressures etc. which might also include geophysical investigation;

(d) Soil sampling for geomechanical analysis including soil classification, soil physical properties, shear strength etc.;

(e) Analysis of weather information and rainfall characteristics of the site;

(f) Collection and evaluation of historical data, newspaper records, and local anecdotal evidence.

On the basis of this information, a geological and engineering analysis should be undertaken with the specific objectives of establishing the causes of the existing stability, assessing the degree of danger of further instability, slope failure, landslip etc., and planning precautionary countermeasures. These might include engineering solutions, such as improved drainage, slope stabilization, retaining wall construction etc., as well as non-structural measures such as land-use rezoning, changed forms of land management, revegetation with deep-rooted species, or the introduction of warning systems and evacuation schemes.

F. Simulation modelling of watershed systems

1. Watershed system modelling concepts

Since the early 1960s, when digital electronic computers began to become readily available to engineers and hydrologists, these machines have increasingly been used to simulate the behaviour of watersheds and water resources systems for a variety of planning, design and operation applications.

Early watershed models, which were principally developed for flood estimation purposes, were essentially mathematical models involving sets of differential equations which were difficult to solve analytically. The development of the electronic analogue computer, which could rapidly solve differential equations by a process of successive integration, made it initially possible to use simple catchment models for flood routing and flood prediction. Hardware limitations considerably restricted the applicability of analogue computer solutions to complex water resource systems, however, and the rapid development of the digital computer, able to solve differential equations rapidly using finite difference techniques, soon made analogue approaches obsolete. With the development of catchment process models and water quality models based on discrete time-series computation using simple mass balance equations, the advantages of the digital computer soon became apparent. Digital computers have particular advantages for such purposes, firstly because they are able to store and process very large quantities of data, and secondly because they are able to undertake a very large number of calculations extremely rapidly.

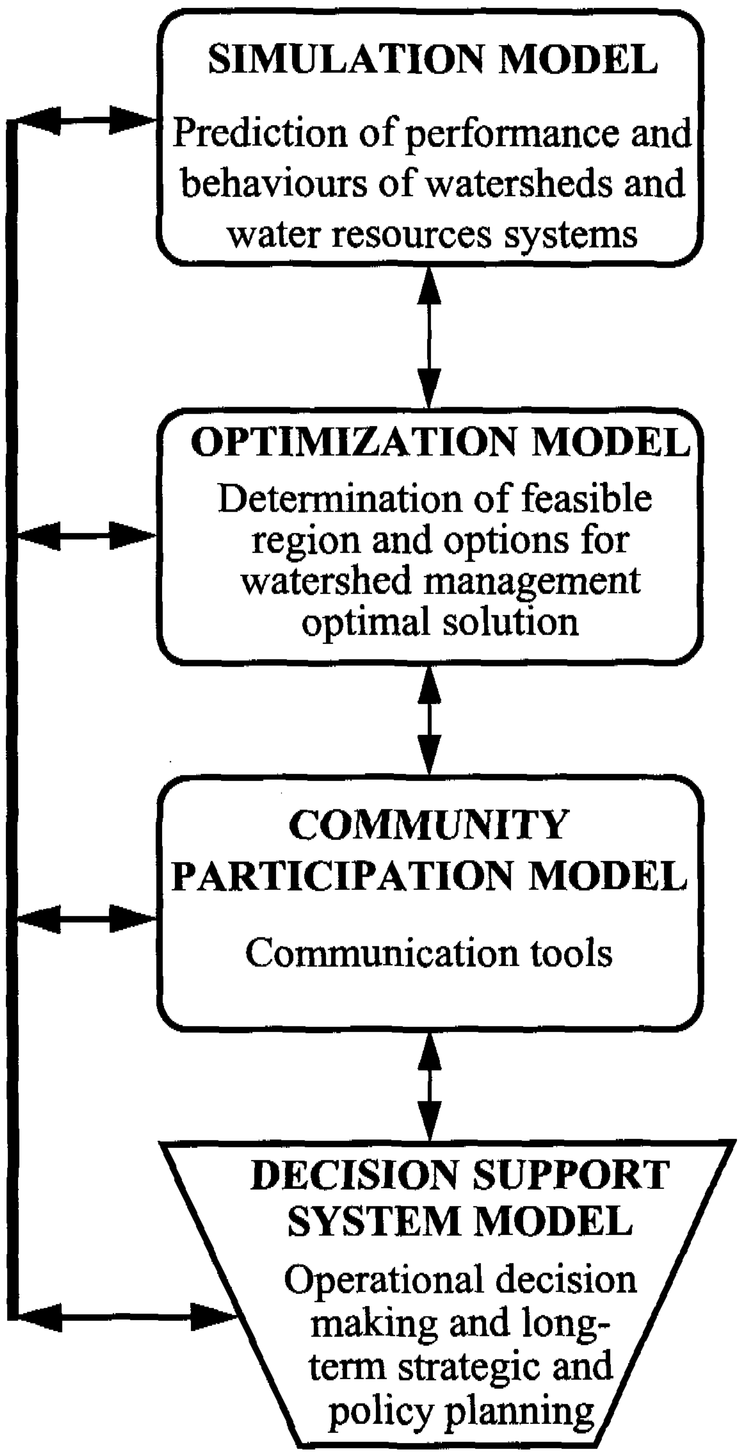
Within the last two decades the use of watershed models for a variety of planning and design purposes has expanded enormously, firstly through the increasing availability of comparatively low-cost computer work stations to academic and engineering organizations, and more recently, through the development of the personal computer (PC), which has made it possible for most engineers to have a sophisticated computer work station, capable of handling very complex modelling applications, available on their desks.

There is now an extensive literature on watershed modelling and a number of excellent computer programmes is available both commercially and in the public domain for a wide range of watershed management purposes. The field is in a constant state of development, with improvements continually being made to existing models and new models frequently being introduced. Because of the speed with which the field is developing, it is not feasible in this manual to do more than provide an overview of the scope of the modelling techniques currently available, indicate likely areas of application, and list some of the widely-used programmes available in the public domain. Readers planning to make use of modelling techniques for watershed management purposes are strongly cautioned to review the current water resources literature and contact appropriate government agencies before selecting a model for application.

There is a variety of ways in which watershed models may be distinguished and categorized. The more important of these categories (see figure 6) are discussed below.

Firstly, a distinction needs to be made between *simulation* models and *optimization* models. Simulation models are models which are set up to reproduce or simulate the behaviour of watersheds, catchments, river basins and various kinds of water resources management systems, including systems which have a substantial component of man-made works and structures. Simulation models are used to predict the performance or behaviour of a water resource system when subject to various input

FIGURE 6. MODELLING PROCESS IN WATERSHED MANAGEMENT



stimuli and/or various means of internal manipulation or operation. They are the principal subject of this Section. Optimization models are models which seek to find the best way of manipulating, designing or operating a water resource system; they are essentially decision-making models. Optimization models are the subject of Section V.G of this manual.

Before proceeding to further categorization and a discussion of currently-available model types, it is important to consider the steps that need to be taken in the development of a simulation model. Even though the users of this manual are most likely to be utilizing available public-domain or commercial models, these steps need to be understood and appreciated as a preliminary to model selection and application.

The essential steps in the development of a simulation model (see figure 7) are outlined below:

(a) Formulation of objectives. This requires a clear and quantitative statement of the purpose of the model;

(b) Review of theoretical background. This requires a desk study of previous attempts to formulate models for similar situations and an analysis of the processes to be simulated in the model;

(c) Formulation of the model. This involves a decision as to the type of model to be used and the processes to be included in it, and requires a practical decision regarding the degree of complexity to be provided in the model;

(d) Creation of the model structure. This involves an identification of the components of the model and the way in which they are to be linked in the model structure. This phase is facilitated by the use of sketches and flow charts to identify the flow of information through the model and the inputs, outputs and process transformations required for the model;

(e) Formulation of the model equations. Based on a consideration of the theoretical review and the proposed model structures, this step involves the mathematical expression of the relationships involved in the processes to be simulated in the model;

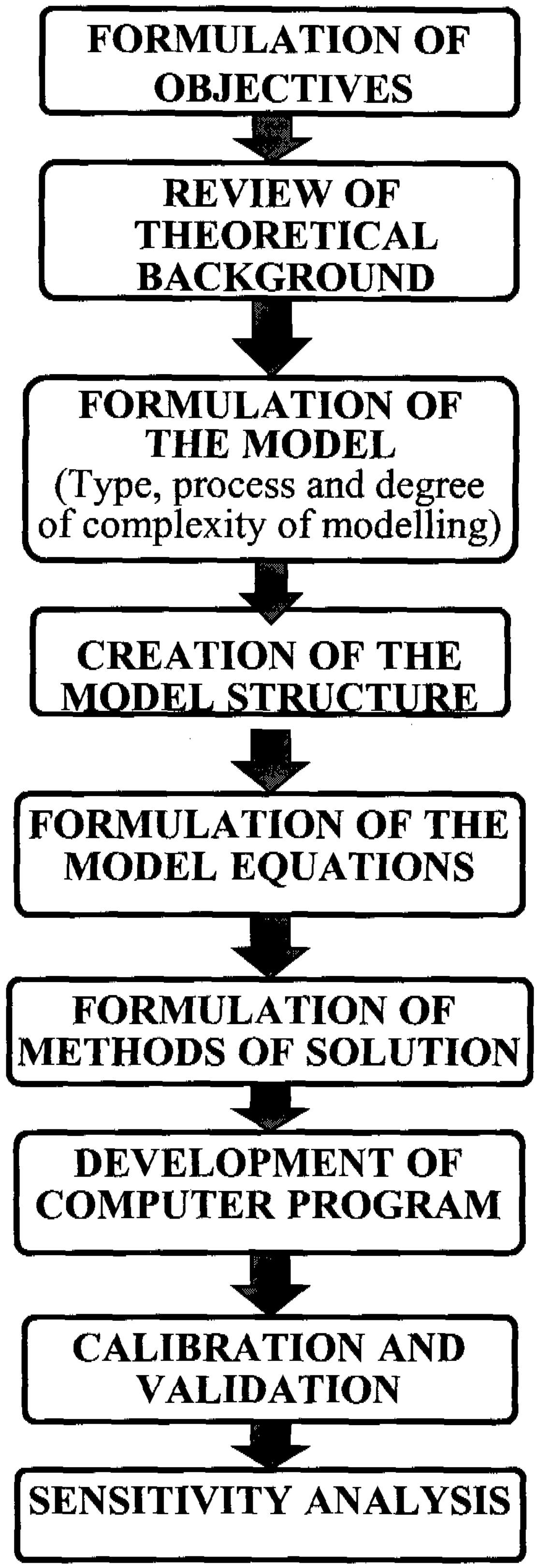
(f) Formulation of methods of solution. In some cases it may be possible to solve the model equations analytically. More commonly, the model will require to be solved by numerical methods and this step requires the selection of the solution algorithms is such a way as to minimize computational effort and facilitate computational efficiency;

(g) Development of computer programme. This requires the selection of an appropriate programming language and the writing of the computer programme. For a complex programme, this may require considerable effort and a great deal of trial and error in the progressive development of a computationally-efficient solution package;

(h) Calibration and validation. Calibration requires the progressive adjustment of the key parameters of the model until it satisfactorily reproduces a past performance record of the system behaviour. Once this is accomplished, verification requires the undertaking of additional computer runs with different sets of recorded data to verify that the model will predict system behaviour with an adequate degree of accuracy;

(i) Sensitivity analysis. This final step involves the examination of the sensitivity of the model output to changes in the values of the parameters. This provides a basis for determining the practical degree of accuracy with which the numerical values for the critical parameters need to be determined.

FIGURE 7. IMPORTANT STEPS IN WATERSHED SIMULATION MODELLING



It needs to be strongly emphasized that if it is proposed to use an existing public-domain or commercial package for watershed simulation, similar steps should also be followed through. In choosing such a model and applying it to a given situation it is necessary to clearly formulate the user's objectives; to review the theoretical background and decide upon the processes to be simulated; to choose a specific model; to examine and understand the structure of the model; to understand the mathematical basis of the model; to become familiar with and understand the methods of solution it employs; to understand the computer programme, which may need modification or extension, and become fully acquainted with its data and parameter input requirements; to test the suitability of the model for the user's purposes, which will generally involve its calibration for specific watershed conditions and the verification of the accuracy with which it reproduces historic data from the watershed; and to undertake some sensitivity analysis to determine the model's degree of dependence upon precise parameter values. If several alternatives models are under consideration, this process may need to be repeated several times before a final choice of model is made.

2. Classification of watershed models

There are many other categories under which watershed models can be classified. The more important of these are listed below.

Watershed models may be categorized as *event* models or as *continuous* or *sequential* models. An event model represents a single event, usually a flood event, which may last from a few minutes to several days. The principal application of these models is for flood estimation purposes. Continuous or sequential models operate over a long period of time, perhaps as long as 100 years, and represent the continuing behaviour of the watershed on a time scale which may be continuous or sequential on a daily, weekly, monthly or annual basis. These models are used principally for predicting long-term catchment yield or to predict the long-term behaviour of water quality parameters such as dissolved oxygen.

Watershed models may be *conceptual* or *empirical* models. A conceptual model (also known as a *process* model) is based on a set of equations which attempt to model the physical, chemical and biological processes acting within the watershed system. An *empirical* model (also known as a *black box* model) is formulated from a consideration only of the relationships between system input and system output, with no concern for the processes at work within the system. Empirical models are most commonly used for flood prediction, although some simple catchment yield estimation models are also empirical.

A watershed model may be a *measured-parameter* or a *fitted-parameter* model. A measured-parameter model is one in which the parameters are determined from the measurement of catchment system characteristics. In a fitted-parameter model, the parameters are determined by fitting the model with observed values of the hydrological phenomena modelled, which requires a trial and adjustment process.

Models may also be categorized as being either *distributed* models or *lumped* models. The former term applies to models in which spatial variations of watershed characteristics and processes are explicitly taken into account. The latter term applies to models in which these variations are averaged or ignored.

Models may also be categorized as being either *deterministic* models or *stochastic* models. Deterministic models have a fixed relationship between the inputs and the outputs, so that re-running the model with the same input data will produce the same outputs. Stochastic models contain some random elements, usually the input variables but sometimes the parameters, so that re-runs of the model will produce variable outputs.

A distinction can be made between *dynamic* models and *steady-state* models. In dynamic models the inputs and parameter coefficients may change with time, producing a time-variant or time-dependent output. In steady-state models all inputs and coefficients are constant in time, so that the output, whilst it might initially be variable, comes to a constant value.

Models can also be categorized as *generic* models or *site-specific* models. Generic models are designed to be applicable to a wide range of watersheds or water resource systems. Site-specific models have been developed for a specific watershed or system and should only be used to predict the behaviour or performance of that system.

Watershed models for predicting the behaviour of catchments and river basins, or studying the performance and operation of water resource systems embodying structures and control works, usually involve a representation of the physical structure of the system under simulation. There are two ways in which such models can be structured. In *cellular network* models the entire watershed area is represented by breaking it into sub-areas or *cells*. These cells may be rectangular, triangular or polygonal in shape; the size and complexity of the cell network depends upon the size of the watershed and the complexity of the model itself. Such models are particularly amenable to application in conjunction with GIS-based data systems, since the GIS cells can be based on the same cell structure as the model. For complex water resource systems incorporating control structures and works such as reservoirs and hydropower stations, along with discrete hydrologic features such as lakes and aquifers, an alternative structural approach called the *node-linked network* is used. In such a structure, the key features of the system are represented by points or nodes, which are connected by directional links representing the stream or river sections joining them. Such models can be much simpler and more computationally efficient because they do not involve the modelling of watershed processes across the watershed surface. They are particularly useful for operational studies and optimizing design studies, although they may also be used for such purposes as flood estimation or simulation of the behaviour of specific water-quality parameters.

Watershed and water resource system models used for planning and management purposes are most commonly sequential or continuous models in which the mathematics of the solution is based on mass balance equations of water flow quantities and water quality constituents. Models used for the prediction and management of water-based natural disasters, particularly floods, are usually event models of various types, which may include empirical and stochastic models or be based on complex relationships, in the form of linear and non-linear differential equations, requiring considerable computational sophistication in their solution.

3. Public domain and commercial models

The well-known public-domain and commercial models currently available for integrated watershed management and natural disaster management purposes can be classified into six groups, as detailed below.

(a) Catchment run-off models: these models simulate the relationships between rainfall inputs and run-off or streamflow outputs. They are frequently, but by no means exclusively, conceptual models which attempt to reproduce the hydrological processes at work on the watershed. Such models provide information about streamflow rates and volumes, either in continuous form for long-term flow estimation or in event form for short-term flood estimation;

(b) Fluvial models: these model the processes that govern fluid flow in rivers and channels when subject to external inputs. They provide information about river channel or reservoir depth time series and peak events, and inundated-area geometry;

(c) Alluvial models: these models represent the processes that govern the erosion and deposition of sediment during surface run-off and channel flow. They provide information about changes in landform due to erosion and deposition, as well as information about river and reservoir behaviour and inundated area geometry;

(d) Pressure flow models: these models relate to the processes that govern water flow in closed conduits. They are useful in providing information about urban run-off management;

(e) Statistical process models: the processes that govern run-off and sediment movement are in reality stochastic processes which exhibit randomness and variability, sometimes to a very large degree. These models attempt to take these factors into account and provided information about the probabilities associated with flow rates, volumes and depths;

(f) Water quality models: these models simulate the processes that govern water quality. There is a very considerable number of such models in use, including surface and groundwater quality models, rural and urban water quality models, and point-source or non point-source models. A number of the more widely-used models reproduce hydrological information and information about erosion and sediment movement as well as the behaviour of a wide range of water quality constituents such as dissolved oxygen, BOD, temperature, salinity, nutrients, toxics etc. Many of these models are particularly applicable to small watershed management problems.

As has already been indicated, there are many models within these categories which are currently available, either in the public domain or on a commercial basis. Many of them are offered in versions suitable for use on DOS-based, 386/486 or Pentium personal computers. Many of them are available from government water agencies and water laboratories in North America and Europe and some can be downloaded from the Internet. Some of these sources are listed at the end of this chapter. Brief details of several of these models are given below.

Perhaps the most widely-used models for large watershed and river basin modelling are the HEC series of models developed by the Hydrologic Engineering Center of the U.S. Army Corps of Engineers. HEC-1 is a catchment run-off model. It is a comprehensive, generic, single-event model which estimates run-off from a precipitation event and provides stream discharge time series and peaks, as well as run-off volumes. HEC-2 is a fluvial model which predicts water-surface elevations in streams and river channels and on flood plains. It also provides information about river velocities and other flow characteristics. It is widely used in the USA for the delineation of flood levels, and particularly for the establishment of the standard 1 in 100 flood level on floodplains.

HEC-6 is an alluvial model which predicts the effects of river sediment transport. It estimates changes in river bed profiles for single flood events or long-term flow sequences and is able to evaluate the lateral movement of a stream channel. HEC-FFA is a statistical model which provides information about the probabilities of extreme discharge magnitudes. The HEC EAD model is a flood damages estimation model which predicts stage-damage data and derives damage-frequency relationships. HEC-5 is an operational model which models the operation of a flood control reservoir or series of reservoirs. Detailed information about all these models and the availability of software and support can be obtained from the Hydrologic Engineering Center in Davis, California.

TR-20 and TR-55 are small-watershed run-off models developed by the U.S.D.A. Soil Conservation Service. They are single-event models which estimate design storm discharge hydrographs, peaks and volumes. TR-20 relates to single watersheds whilst TR-55 has routing procedures to compute run-off information from a series of sub-catchments. These models are widely used in the U.S.A. for small watershed flood design and the prediction of run-off under varying catchment land-use conditions. These programs are in the public domain and further information can be obtained from the Soil Conservation Service.

HSPF is a simulation model for predicting run-off from upland watersheds which is a development of the Stanford Watershed Model, first introduced in the 1960s. It is a comprehensive, continuous, distributed model which includes a variety of hydrological, fluvial, alluvial, chemical and biological processes. It provides information about stream discharge time series and peaks, river or reservoir depths, and landform changes due to erosion or deposition. Its most recent versions were developed for the U.S. Environment Protection Agency, from which further information about availability and backup can be obtained.

SSARR is a model developed for large river basins, although it has been applied to watersheds as small as 13 km^2. Although it is primarily a run-off process model, it includes fluvial process and reservoir operation features. It was developed for operational forecasting on the Columbia River basin.

SWMM is a widely-used pressure flow model, developed for the analysis of water quantity and quality in urban stormwater management systems. It provides information about discharge flow time series and peaks, water flow elevations, and various water quality parameters. It was developed for the U.S. Environmental Protection Agency, from which further information can be obtained.

There are several small-watershed models which combine the features of many of the model categories listed above, including run-off prediction, the prediction of erosion and sedimentation, and the simulation of water quality, and which can also model the effects of changes in land use, allowing the effects of changes in land-use management to be investigated. CREAMS is a widely-used continuous simulation field-scale model which is particularly useful for estimating the effects of a wide range of land uses, including the effects of animal waste and effluent disposal, aerial spraying and changing agricultural practices. GLEAMS is a development of CREAMS which models the 3-dimensional movement of pollutants in the soil zone. These models were developed by the Agricultural Research Service of USDA (USDA-ARS). ANSWERS is an event-based agricultural watershed model which simulates hydrologic and erosion response. This model was developed by Purdue University.

SWRRB is a continuous simulation model that has hydrological, erosion and water quality components and is essentially a large-scale development of CREAMS, applicable to large and complex rural watersheds. It also was developed by the USDA-ARS, from which further information is available. The HSPF model, already discussed, has similar application, particularly in situations involving mixed land use.

There is a wide variety of large-scale water quality models, applicable to large river basins, rivers and estuaries, which incorporate hydrologic response, fluvial and alluvial features. Some of the better-known include the QUAL2, SYMPTOX3 and WASP5 models available from the US EPA, the CE-QUAL range of models developed by the Waterways Experiment Station of the US Corps of Engineers and HEC5Q, a water quality version of HEC-5.

Some excellent, comprehensive, urban and rural water quality and alluvial models are available commercially from European water laboratories. They include MOUSE, a continuous simulation urban run-off system model and MIKE11, a comprehensive river basin and estuary model, which have been developed by the Danish Hydraulic Institute. The Wallingford Procedure series of urban run-off prediction and quality prediction models, and the comprehensive SALMON-Q river and estuary model, are available from the Wallingford Hydraulic Research Laboratories in the United Kingdom.

As the above listing indicates, there is now a wide range of models available both for the prediction and management of flood events and for a variety of integrated catchment management applications. These models can be valuable planning and management tools and when appropriate, the opportunity should be taken to make use of them. A strong note of caution is, however, necessary.

There are many possible pitfalls in the application of models for watershed management purposes. It must always be remembered that they are planning and design tools, not an end in themselves, to be used with caution and with full appreciation of their inherent shortcomings. The application of even the most comprehensive and sophisticated model does not absolve the user from the responsibility for taking a professional approach to problem-solving, planning or design activities and employing sound professional judgement in the final decision-making. The application of a model is only one step in the planning or design process; defining the problem carefully and accurately, analyzing the available data and the problem constraints, devising a rational set of alternatives for evaluation and comparison, interpreting the output from the model skilfully, and providing adequate conclusions to the decision-maker, are all essential and equally important aspects of the process.

G. Optimization models and decisions-support systems for integrated watershed management

1. Optimization model concepts

Integrated watershed management frequently involves the making of decisions about watershed management activities. Such decisions come into several categories, which include:

- decisions about land-use changes
- decisions about land-use policies
- decisions about the optimal scale of water resources management structures and systems
- decisions about the optimal dimensions of water resources management system components
- decisions about optimal operation of watershed management systems

Most commonly, these decisions are *optimization* decisions; that is to say, they require the selection of the *best* land use, policy, system or operating procedure. Most commonly also, if they are concerned with realistic, real-world problem solutions, they are complex, *multi-objective* or *multi-criteria* decisions, in which it is required to satisfy not one but a range of objectives, some or all of which may be conflicting or indeed incompatible.

Sophisticated techniques for the analysis and resolution of decision-making problems of this kind, in particular as they relate to the field of water resources management, have been under development since the 1930s, when the methodology of benefit/cost analysis was introduced in the U.S.A. They have been developed particularly since the 1960s, following the introduction of the digital electronic computer and its increasingly accelerating technological improvement, cheapness and ease of use, in parallel with the development of increasingly powerful techniques for systems analysis and optimization, themselves highly computer-dependent.

A key feature of most modern decision-making tools for water resources management and watershed management is that they depend to a greater or less extent upon a model of the water resources system under investigation. In simple applications, particularly where the criteria for decision making can be expressed solely in economic terms, this may be a mathematical model or even a graphical model, from which an optimal solution can be obtained by processes of mathematical or graphical maximization or minimization. For problems of any complexity, particularly where there are multiple objectives for which the decision criteria cannot all be expressed in economic or even quantitative terms, it is usual to resort to the use of a computer-based simulation approach, using a model which incorporates a water resource system simulation model with one or more of the many optimizing techniques now widely and readily available.

There is now a vast literature on this topic and the field is constantly evolving and developing. It is not feasible in a manual of this kind to do more than provide an overview of the scope of the field and briefly discuss some of the techniques currently in use. As in the case of the tools and techniques discussed in the preceding section, readers planning to use such aids to decision-making are strongly cautioned to review the current water resources literature and seek the advice of appropriate government agencies, many of which have developed or adopted such tools for their own conditions and circumstances, before selecting a model or procedure for their own application.

An essential feature of all optimization models, as distinct from simulation models, is that they provide for the systematic variation of the system design or planning parameters in order to develop a range of alternative solutions. Most commonly, this will be achieved through the successive running of a simulation model of the system under analysis. The relative performance of these alternatives is assessed in terms of a set of decision criteria or yardsticks, which enables them to be ranked and provides for the "best" alternative to be selected according to these criteria.

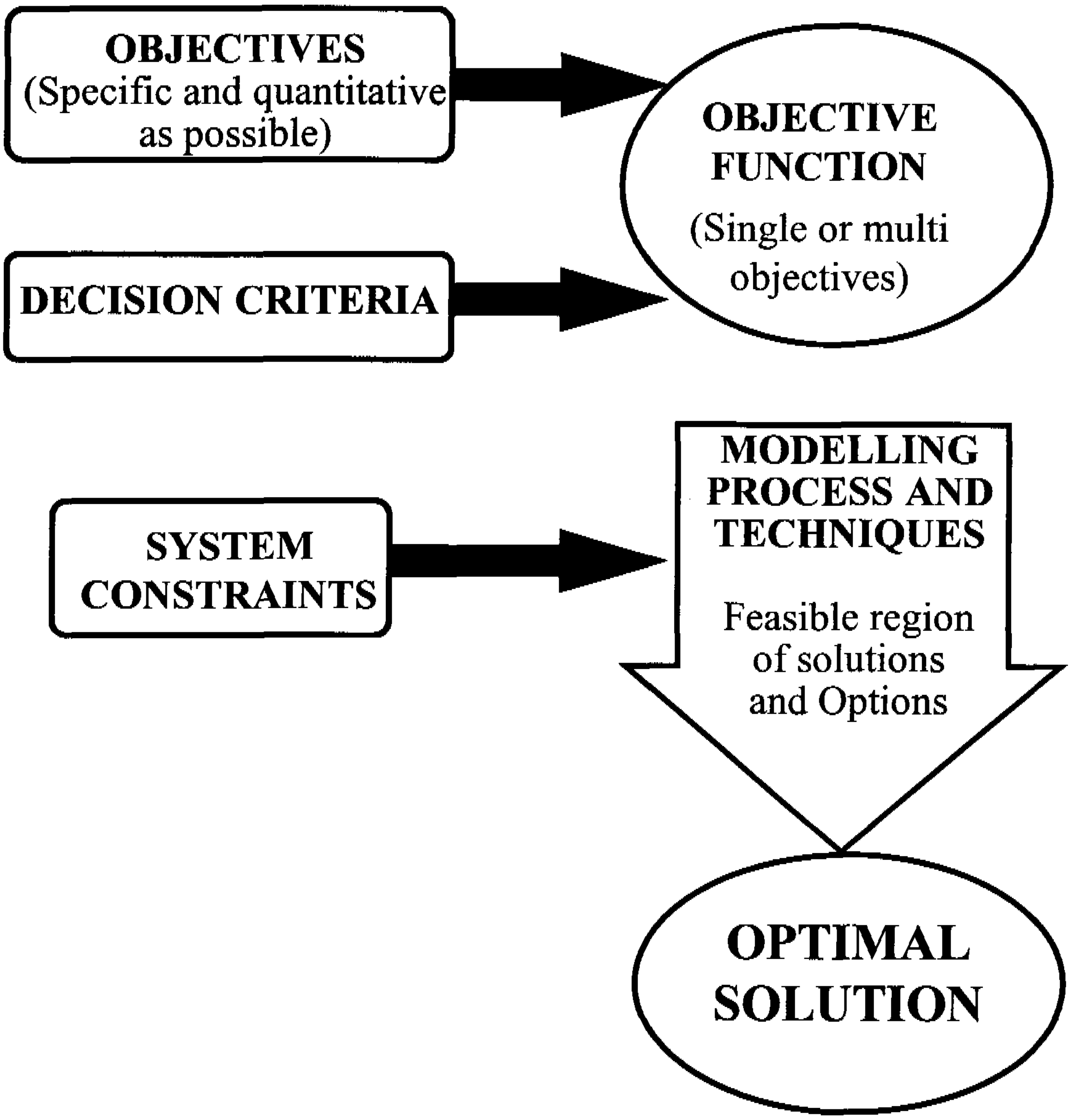
Before a system optimization study can be undertaken, it is necessary to define the *objectives* of the exercise. These need to be expressed in as specific and as quantitative a form as possible. It is then necessary to establish the *decision criteria* or yardsticks to be used to assess the extent to which each alternative satisfies the objectives, which also need to be expressed in as quantitative a form as possible. Putting these criteria alongside the objectives leads to an expression of the *objective function,* which is required to be optimized.

In association with this process, it is necessary to determine the *system constraints,* which specify the boundaries or limits on the acceptable alternatives. A solution or alternative which meets the constraints is a *feasible solution* – more correctly, a feasible solution is a set of the decision variables which simultaneously meets all the constraints. The *feasible region* is a set of all the feasible solutions. The optimization process requires a search of this region to seek the feasible solution which "best" meets the objectives (see figure 8). This is the *optimal solution*, which can be defined as a set of values of the decision variables which meets all the constraints and produces the optimal value of the objective function.

Where there is a single objective, most commonly expressed in terms of economic efficiency and measured in monetary units, the optimal solution can be found by mathematical processes for the maximization or minimization of an objective function subject to constraints. There are many such techniques available, some of which are briefly discussed below.

Where there are several objectives, which are likely to be in conflict and not necessarily even expressible in the same units, the concept of optimality becomes inappropriate and it becomes necessary to search for some kind of "best compromise" solution. In multi-objective analysis, this requires a search for a set of what are called *non-inferior solutions.* This is a feasible solution compared with which there is no other feasible solution that can yield an improvement in one objective without causing a degradation in at least one other objective. Multi-objective programming requires the selection of a set of feasible solutions, usually by simulation modelling, and the making of tradeoffs between conflicting objectives to arrive at the choice of a best compromise solution, which basically depends upon the decision-maker's priorities and preferences. Some of the techniques available for this purpose are also briefly introduced below.

FIGURE 8. OPTIMIZATION MODEL CONCEPTS



2. Optimization techniques

There is a considerable range of available and proven optimization techniques and programming methods. *Linear programming* problems are those for which both the constraints and the objective function are linear, or can be approximated by linear equations. Techniques for the solution of such problems have been extensively developed and are readily available as computer software packages – they have been widely applied to resource allocation problems, particularly in the water resources field. *Integer programming* is a variation on linear programming applicable where the decision variables must be integer-valued, which is the case with many water resources engineering problems.

Non-linear programming, as its name suggests, is appropriate where the constraints and/or the objective function are expressed as non-linear equations. The solution of such problems is difficult, but there are many techniques available which include various iterative search techniques or procedures which effectively convert the problem to a linear form.

The programming methods described above are essentially designed for the solution of static, spatial problems, such as the allocation of resources or land units to different purposes or uses. They thus have particular application to watershed management problems. *Dynamic programming* problems are essentially concerned with sequential or multi-stage decision making situations, particularly where successive decisions have to be made in time, as in the case of the operation of a flood control reservoir or an irrigation system. They thus have particular application to problems relating to the optimal operation of resource management systems, although they may be adapted to solve spatial resource allocation problems if they can be couched in a multi-stage format. Dynamic programming has also been extensively developed and widely applied in the water resources management field and there is a considerable literature describing such applications.

The methods available for the solution of multi-objective programming problems can be grouped broadly into two categories; *generating techniques* and techniques which depend upon the *articulation of the decision-maker's preferences*. In the former category, set values of objective functions or constraints are used to convert the problem to a single-objective problem which can be solved by a linear programming approach. The problem is repeatedly re-solved for a range of values of the set parameters to build up a set of inferior solutions, from which the decision-maker is expected to make a choice on the basis of the programme's evaluation of the trade-offs between these solutions. In the *weighting method*, the relative weights of the various objectives are specified and the decision-maker must select those weights which best reflect his trade-off preferences between them. In the *constraint method*, one of the objective functions is arbitrarily selected for evaluation whilst all the others are temporarily assumed to be fixed and expressed in the form of constraints.

The preference articulation approach requires the decision-maker to specify his preferences in respect to relative weightings or trade-offs between competing objectives prior to the analysis, which then evaluates the consequences of these specifications. The two techniques most commonly employed are *goal programming* and the *surrogate worth tradeoff* method. In the former, goals are set for the values of the objective functions and the penalties associated with shortfalls in meeting the goals are assessed. In the latter, prespecified values of the objective functions are assumed and the tradeoffs between objectives are evaluated in terms of the marginal rates of transformation between them, which are accorded values which are called *surrogate worths*. The solution involves the optimization of a surrogate worth function. Both these techniques require continued iterative computation and considerable communication and feedback between the systems analyst and the decision-maker, which is generally considered to be a beneficial feature.

There is now a considerable literature on multi-objective programming in general and its applications to water resources management problems in particular, and readers are referred to the relevant literature for further information.

3. Community participation models

The optimization models described in the foregoing pages of this section are all essentially expert models, the application of which is dependent upon considerable technical expertise and computer programming skills. They are principally for use by engineers, resource managers, planners and other professionals, employed by planning and management agencies or consultants, and there is little opportunity for non-professional or community input to them or involvement with their operation.

An important aspect of good integrated watershed management practice is the extent to which it depends upon community involvement and public participation in planning and management activity. A comparatively recent development in the application of simulation and optimization modelling to this field has been the use of computer models specifically for the purpose of achieving community involvement through the harnessing of the accumulated experience and practical knowledge of landholders, environmentalists and others living in the watershed.

The best known of the techniques employed in this kind of application comes under the general heading of *adaptive environmental assessment and management,* or AEAM. Originally developed by C.S. Holling at the University of British Columbia, it has been further developed and refined for a number of applications in watershed and river basin management in Canada, Australia and elsewhere. Perhaps its most interesting feature is that it focuses more on the *building* of the model than on its *operation,* involving the catchment community from the outset in the construction and development of the model itself, as well as its actual running for the purpose of exploring watershed management and policy options.

The AEAM approach uses a modelling workshop procedure to build and refine the model as a group participation exercise. The construction of the model focuses particularly on the interactions that take place between the various components of the system being modelled, with the specific objective of improving understanding of the system and the way it functions. The approach also seeks to improve understanding between land holders and other members of the community and the planners, managers and other professionals involved in the management of the system.

The AEAM workshop process involves a considerable number of people, but preferably not more than 30, comprising representatives of the following groups:

(a) Research scientists, having a specialist scientific understanding of the various components of the system and the processes at work in the system, who are also familiar with the available sources of data and relevant research information;

(b) Managers and decision makers, whose principal functions are to put the objectives of the model into an institutional framework, to ensure that what is being modelled is relevant to the problem being addressed, and to ensure that the time frames being modelled and the level of detail provided for in the model are appropriate to the scale and scope of the problem;

(c) The practitioners, including computer modellers and programmers, information critics and facilitators, who guide the rest of the participants through the modelling process and act as adjudicators for points of conflict or deadlocks in discussion;

(d) The community members, who represent an appropriate range of community interests and have an accumulated knowledge of the components and functions of the system under examination, including practical experience of its behaviour under stress.

There are two other persons who are selected to play special roles in the workshopping process. One of these, called the *wise person,* is preferably a well-known and respected community leader or elder. This person's role is to provide overall guidance in the development of the model and to act as a bridge between the community representatives and the scientific and technical representatives involved in the workshop. The other, called the *devil's advocate,* has a complementary but clearly different role, being present to induce debate, to ensure that all sides of key issues are discussed, and to maintain the validity of the information being presented.

Because this is an adaptive and interactive methodology, there is not set procedure for its implementation. The general approach has the following components.

Firstly, well before the actual workshop meetings are convened, a small core team of practitioners is set up to lead the project and organize the workshops. Before the first workshop is held, a scoping exercise is undertaken to clarify the issues to be addressed, identify the workshop participants and develop a preliminary statement of the objectives of the modelling project.

At the commencement of the first workshop, there is a general introduction to the AEAM procedure and the general process of computer simulation modelling. The next step is to undertake what is called the bounding exercise, with the aim of establishing the boundaries of the model. This has three aspects. The first involves discussion about, and the definition of, the objectives. The second involves definition of the level or depth of detail to which the analysis is to be undertaken, including the selection of appropriate time steps for the model operation and output, the time horizon for simulation, and the detail and extent of spatial representation and coverage. The third involves the selection and refinement of the list of indicators and actions to be included in the model, which needs to be as simple as possible whilst maintaining the integrity of the system description.

To facilitate the development of the model, the system under analysis is divided into a small number of logical subsystems. The workshop participants are then allocated into subgroups, one for each subsystem, according to their relevant expertise. With the assistance of a computer modeller, each subgroup then proceeds to develop a model for its subsystem. Once this has been satisfactorily accomplished, the subsystem models are brought together to produce the whole system model.

The entire workshop next participates in the testing of the model, in which it is first checked for programming errors and then run for a series of hypothetical management scenarios. Following appropriate modification and/or refinement, the model can be used to investigate the effects that various management strategies would have on the system. It should be emphasized that the model so produced is essentially a descriptive, qualitative model: it is not intended that it be an accurate, quantitative model for which the usual detailed calibration and verification procedures are necessary. The AEAM model is intended primarily as a communication tool, and the team process of building the model is as important as the actual running of the model for system simulation.

Once the model has been satisfactorily tested and demonstrated, further workshops might be convened to develop it further and explore a variety of possible management scenarios. In a large river basin, workshops might be held in various parts of the basin and with different community representatives, in order both to investigate a wider range of management options and to educate community members regarding management problems and proposed management strategies. Once such strategies have been determined, continued use of the model as a community education and involvement tool may become an important aspect of watershed management policy.

It should be noted that an AEAM model developed in the way described above does not necessarily have to be system-specific; once a model has been constructed it might be a relatively simple matter to adapt it to use for other watershed and river basins. Some Government agencies and research institutes have recently developed models of this kind which are essentially generic models, capable of being adapted to a wide range of watersheds and conditions. Information about some of them is available in the recent water resources management literature.

4. Decision support systems (DSS)

The term "decision support system" or DSS has come to be applied to a variety of computer modelling packages which have been developed to assist decision-makers in the planning and management of complex natural, man-made and hybrid systems, particularly where the system is complicated and multi-purpose, the objectives of management are multiple and generally in conflict, and the operation of the system and/or the inputs to the system are subject to uncertainty. These circumstances apply in most water resources management and watershed management situations. Decision Support Systems can be defined as computer-based systems which integrate information about the state of the system with dynamic or process information and plan evaluation tools into a single software implementation package. They provide information on the historic, current and future states of a resource system, the future states being computed by one or more simulation and/or optimization models. This information is communicated in forms which are directly useful both for operational decision-making and for long-term strategic and policy planning.

The application of DSS to the water resources and watershed management fields has only occurred during the past decade. Whilst they are coming increasingly into use, the art of constructing and using them for practical watershed management purposes appears to be still under development. They appear to have been most successfully applied in the area of operational management of large engineered water resource systems. The models which have been developed for this purpose are often based on generic water quantity and water quality simulation models, such as HEC-2 and QUAL2E, with optimizing features usually based on a linear programming approach. Some quite complex basin-specific models have been developed which are successfully used for day-to-day system operation decision-making. Examples of such models are the TERRA model, which is used for the routine management of the Tennessee Valley Authority's complex river, reservoir and power system, and the CRSM model developed for the management of the Colorado River power and irrigation system.

DSS models designed for integrated watershed management applications, including land-use policy decision-making, appear to be under development in several countries. Many of these models appear to utilize GIS packages as well as the sophistical drafting and mapping packages, such as CAD and ARC/INFO, which are now widely available. This provides them with the ability to store, retrieve and manipulate large quantities of resource inventory data, explore a variety of land-use management scenarios, and present management options in a variety of useful graphical formats to the making of decision choices.

Several governments and other organizations within the ESCAP region have developed, or have under development, decision support system planning models of various kinds and levels of complexity.

By way of example, one such model is the "decision support system for the sustainable land management of sloping lands in Asia", or DSS-SLM, under development by the International Board for Soil Research and Management (ISBRAM). This system is specific to hillsides and uplands in South-east Asia and is being developed through case studies based on long-term research sites in Indonesia, Thailand and Viet Nam. It utilizes a commercial Expert Systems shell package known as EXSYS and incorporates a GIS mapping package along with simulation and other models, including EPIC, for predicting soil loss and other forms of land degradation. It is an inter-active system which will permit the simulation and evaluation of a variety of possible land-use management options. When fully developed, it should prove to be a very useful tool for watershed management application.

Another model of this kind is the complex Adaptive Policy Simulation or APS model being developed by the International Centre for Integrated Mountain Development in Nepal. This model is intended for the evaluation of land use, agricultural and natural resources management policy options for rural regions of the Kathmandu Valley. It is a detailed and complex model which predicts regional income consequences and environmental impacts of a wide variety of land-use options. When fully developed, it should be appropriate for much wider application on rural regions of Asia.

It would appear, nevertheless, that the optimizing and mechanical decision-making abilities of these and similar packages are as yet limited, which is a consequence of the fact that, for watershed systems of any complexity, decisions are multi-faceted, multi-objective, and very much dependent upon the judgement and values of the decision-maker.

Therefore, whilst packages of this kind may prove to be very useful as aids to decision-making, they may never become decision-making tools in their own right. On the other hand, they offer very considerable advantages as tools for exploring a wide range of management options and their implications, as tools for achieving very effective community involvement in the planning and implementation of management strategies, as tools for community education about management problems and options, and as devices for improving the quality of decision-making by bureaucrats and politicians who have little expertise in resource management or economics. For these reasons their further development should be encouraged, and the availability of suitable public-domain or commercial packages for application to major watershed management problems should always be investigated.

VI. OPTIONS FOR WATERSHED MANAGEMENT AND HAZARD REDUCTION

A. Introduction

As has been explained in some detail in earlier chapters, and particularly in Chapters II and III, the problems of land degradation and the occurrence of water-based natural disasters are often interrelated. The natural balance of the soil, water and vegetation resources of a watershed can easily be disrupted by changes in land-use practices, by mismanagement or through poor land-use planning. Problems such as accelerated soil erosion and salinity can result from deforestation or other forms of interference with the natural balance of the catchment. The planning of land use and the careful management of soil, water and vegetation resources, through such means as the use of appropriate conservation practices and structural works, can retard run-off, increase the infiltration rate, improve production and enhance the productivity of the land. Land treatment measures which bind the soil and increase infiltration rates in the upper reaches of the watershed or on areas of degraded land can be effective in reducing the amount of run-off, especially during less intense storm events. Large-scale structural measures such as flood mitigation reservoirs, levees, channel modifications etc., when installed and operated in conjunction with a comprehensive programme of land management measures and land-use controls, can be effective in mitigating the impact of water-related natural disasters.

A wide variety of structural and non-structural options is available for the solution of watershed management problems. These may be employed either to control or to rehabilitate land degradation, to control or mitigate the occurrence or effects of water-based natural disasters, or to achieve both concurrently. The more commonly used of these options are briefly described below. More detailed information about them can be obtained from a variety of textbooks and manuals, some of which are listed in the Bibliography which follows this chapter.

B. Land management measures

1. Introduction

Land management measures for the control of land degradation and the mitigation of natural disasters may include a variety of structural and non-structural approaches. The structural approaches comprise a number of small and relatively low-cost mechanical devices whose function is to reduce run-off rates or volumes, to control or retard overland flow or to give protection against erosive or scouring forces. The non-structural measures comprise a variety of farming, cropping and cultivation techniques whose purposes are to maintain a protective vegetative cover, to increase infiltration and to impede overland flow. For the most effective results, a number of these approaches will generally be used in conjunction, utilizing a combination of structural and non-structural measures in an integrated fashion to achieve optimal management results.

2. Sheet and rill erosion

The most basic requirement for the control of sheet and rill erosion is to provide and maintain a dense, protective vegetative cover for as much of the time as possible. Special cropping methods and tillage practices can be employed to minimize the time periods during which the ground must be unprotected during land preparation and seed planting or after harvesting, or to reduce the total area of ground exposed to erosive rainfall at any time. In addition, farming practices or small-scale structural measures can be employed to improve infiltration, retard run-off and reduce the erosive energy of overland flow.

On cropping lands, low-till and no-till cultivation practices can be employed to reduce the breakdown of soil structure and avoid the necessity for leaving soil bare under fallow for long periods. These practices involve the use of selective herbicides for weed control and the employment of special cultivation implements such as sod seeders and chisel ploughs. The retention of crop residues and stubble, or the incorporation of vegetative mulches, undertaken in order to provide a protective soil surface cover, is commonly associated with these practices. Cover crops, mixed crops where one crop provides protection for the other during cultivation or germination, or the use of green manure crops for incorporation into the soil, are commonly used for erosion control, particularly where intense rainfalls are experienced during wet seasons or where crops must be grown on steep side slopes. Various forms of rotational cropping can be employed for the dual purposes of erosion control, soil moisture control and the enhancement of soil fertility. Strip cropping and alley cropping, where alternating strips of different crop types and different stages of the cropping cycle are planted, are effective methods of erosion control which act not only to maintain effective crop cover but also to retard overland flow and reduce the erosive energy of run-off. The application of techniques of this kind is usually termed "conservation farming".

Special cultivation techniques provide the simplest and cheapest means of structural erosion control. The simplest of these techniques is contour ploughing, which should be standard practice wherever mechanical cultivation is undertaken on sloping land. More effective erosion control can be achieved through supplementary cultivation in the form of listing or ridging, which involves the formation of alternating furrows and ridges on the cultivated land. This is most effective when the formation is undertaken strictly on the contour, where it serves not only to reduce soil erosion but also to reduce run-off and improve soil moisture conservation. In many parts of Asia, the ridges are formed by hand or with animal-drawn ridging devices; under these circumstances, care in aligning furrows and ridges accurately along the contour is particularly important. Water control can be more effectively achieved through the technique of basin listing or tied listing, which involves the additional formation of small dams along the furrow to produce a multitude of small water-holding basins. Basin listing can also be employed as an effective measure against wind erosion.

A wide variety of terrace-like structures is employed for erosion control under a range of topographic and farming conditions. In general terms, terraces are artificial earth embankments, or combined embankments and channels, which are constructed across sloping land, usually at fixed vertical intervals down the slope. They may be constructed for several purposes, which can include run-off diversion, run-off detention, the slowing-down of overland flow velocity, the reduction of erosive slope length, improved infiltration and soil moisture retention, slope stabilization or the retention of ponded water for irrigation, particularly for rice production.

On gently sloping agricultural or grazing lands, low channel-type terraces can be so constructed that crops or pastures can be planted on them and they cause little loss of productive land. On steeper country, terraces have to be more substantial structures and they make take significant areas of land out of production. On steep land, bench terraces become very substantial and expensive structures which completely alter the appearance of the landscape and serve not so much for erosion or moisture control but principally to permit farming and cultivation to be undertaken on country where agriculture would otherwise be quite impossible.

Channel terraces comprise a low, flat-sided earth bank with a shallow, similarly flat-sided channel formed on the uphill side. They are constructed by excavating the channel and using the spoil to form the embankment. Their purpose is to break up slope length and to retain a significant volume of water, which can either be diverted away from erosion-prone cropped or pastured areas or absorbed into the soil to improve soil moisture. Provided that the side slope is relatively flat, crops or pastures can be planted right across the terraces, which can be cultivated or harvested mechanically. On cropping lands, they are usually formed up following cultivation but before planting and destroyed and replaced during the following cultivation season. On grazing lands they may remain in place for a number of seasons.

Terraces which are built strictly on the contour, principally to retard overland flow and absorb moisture into the soil, are known as graded terraces or banks. They are most suitable in relatively low-rainfall areas. Terraces which have a slight fall or gradient and are designed to divert water to one side of the field in which they are constructed are called graded terraces or banks. These are used in areas of higher rainfall and their purpose is not only to reduce erosion slope length but to allow for the safe disposal of excess run-off , through a constructed waterway system into the nearest watercourse. Channel terraces are most suitable for use on relatively gentle slopes, not exceeding 20 per cent and preferably less, where farm sizes are large, cropping or livestock production is extensive, and suitable farm machinery for their construction and maintenance is readily available.

Bench terraces are relatively wide, flat terraces which convert sloping land into a series of platforms or steps. As indicated above, their purpose is to enable crops to be grown on very steep land where farming would otherwise not be possible. They are widely used in mountainous areas in many parts of Asia, particularly where population pressures are high and there is a scarcity of land suitable for cultivation.

Bench terraces are formed by placing soil behind substantial banks built across the slope, which may be constructed of stone, vegetated banks or bare earth according to local conditions and practice. They are expensive to build and maintain and require considerable care in lay out and construction. Relatively low-cost bench terraces can however be formed up over a long period of time – perhaps five to seven years – by growing barrier hedges of tall grasses across the slope and allowing them to develop gradually by siltation from erosion uphill. The process can be assisted by adding trash to the barriers and undertaking continuous downhill ploughing above them. The terraces may be long and narrow or formed as a series of irregular staggered platforms. They may be level or slightly graded according to their purpose. They are extensively used for irrigated rice production in China, Japan and the Philippines, where they may be built exactly on the contour, for still-water flood irrigation, or have a slight gradient for intermittent running water irrigation.

Bench terraces are most successful where the available soil is both deep and stable. They should be provided with a lip along the front and a slight back slope to prevent overtopping and facilitate drainage; when used for irrigation, a substantial bank along the front edge is essential. The retaining walls, if of earth construction, should have a slope not steeper that 1:1 and because of the limited depth of soil, vertical intervals between terraces are generally limited to the order of 1 metre. In practice, terrace design and construction methods vary widely according to soil type and depth, climate and slope, cropping purpose and local custom.

On grazing lands, ground cover can be improved by various measures, which include the careful management of stocking rates, the distribution of grazing pressures by installing more watering points, applying fertilizers, including trace elements for known deficiencies, and removing stock when ground cover levels fall below critical limits or if erosion levels are severe. The construction of works such as graded terraces and diversion banks to control surface run-off across bare areas and assist revegetation can also be effective. On timbered lands, sheet and rill erosion rates can be kept low by reducing the incidence of wildfire and maintaining a good ground cover of litter, grasses, herbs and shrubs.

3. Gully erosion

The control and rehabilitation of gully erosion is best undertaken in two phases. The first involves the introduction of land management measures and diversion structures upstream of the eroded gully area, to reduce the volume and velocity of run-off entering the eroded site. The second involves management and structural measures in the gully itself, aimed at controlling further erosion and promoting the stabilization and restoration of the gullied land. For the most effective results, an appropriate, integrated mix of these techniques should be employed.

Areas that have an extreme level of gully erosion are best treated by changing the land use. If they are currently used for cropping, they should be converted to grazing or rested completely and allowed to revert to native forest. If they are currently used for grazing, they should be withdrawn from livestock production and natural reforestation allowed to take place.

Treatment of the land upstream of the gullied site may require any of the land treatment and structural measures described in the previous section, such as the maintenance of a dense vegetative cover, the use of farming techniques such as strip cropping, and the construction of graded terraces and grassed waterways to collect surface run-off and divert it around and away from the gullied zone.

If gully erosion is not severe, and the upstream treatment just described is effective in controlling erosive inflows, the gullied section can be stabilized and reclaimed by fencing it to keep out stock and allowing natural vegetation to re-establish. In more severe cases, the planting of grasses, shrubs or trees which are appropriate to or adaptable to the local soil and climate can be undertaken. Rehabilitation may be assisted by cutting back the steep gully sides and filling in the gully floor, which can be undertaken by hand or using farming or earthmoving machinery as appropriate. This serves to control further erosion and scouring and to facilitate revegetation, whilst enabling the gully to function safely and effectively as a waterway under intense rainfall conditions.

Where gully cutting is deep and gully floors are steeply inclined, structural works become necessary. There is a very wide range of such devices in use, depending upon available funds, local customs and practice, and the ingenuity of the designer. With very severe and deep gully heads, the construction of expensive concrete drop spillways, chute spillways or flumes may be necessary. Alternatively, a variety of low-cost gully head control structures may be constructed from such materials as rock, sawn timber, logs, sandbags, galvanized iron, gabions, sprayed or formless cement or geotechnical fabrics. The purpose of such devices is to control gully head scouring and undercutting by conveying and discharging inflowing run-off over and away from the active erosion site and protecting the site itself from further scouring by providing some form of armouring and energy dissipation.

Downstream of the active gully head, a further wide variety of devices might be used to form check dams or weirs which serve to reduce erosive velocities, reduce further scouring, promote siltation and facilitate revegetation. These may be constructed from such materials as gabions, rocks, sawn timber, logs, brush, wire or timber fencing, earthworks, dense, rapidly-growing vegetation such as willows or vines, or even waste or trash materials such as old tyres and motor car bodies. Hydraulically, these structures should be designed to function as broad-crested weirs. Once they have served their purpose they may be removed or covered with earth or sediment and vegetated over.

A useful alternative, when gully erosion is severe but gully floor gradients are not unduly steep, is to construct large earthwork dams across the gully at intervals down the slope to form a series of ponds or reservoirs. The stored water acts to control erosive velocities and promote sedimentation. Under conditions of very heavy erosion, the ponds may eventually fill entirely with silt and provide useful additional land for cultivation. Alternatively, the reservoirs may provide a useful water supply for domestic, stock or irrigation purposes or make possible fish farming and other forms of aquaculture. This approach is used with considerable success in China.

4. Wind erosion

As is the case with broad-scale water erosion, the single most effective solution to the problem of wind erosion is to provide and maintain a good vegetative cover. There are times and circumstances where this is not possible, such as during long fallow periods on cropping lands or following a long period of severe drought on grazing lands. In such cases, additional measures must be taken.

At the watershed scale, wind erosion control is most effectively achieved through land-use planning and control. In areas which, because of climate, soil type, farming practices or conditions or other factors are particularly susceptible to damage from wind erosion, land-use controls must be applied to restrict farming activities to those which are sustainable under the prevailing conditions. Depending upon the circumstances, this may require the changing of crop types or farming practices, the replacement of arable farming with pastoral activities, the prevention of large-scale clearing of natural vegetation, or the prevention of any kind of intensive land use.

At the farm scale, measures for the control of wind erosion can be considered in two broad categories. The first involve the use of vegetative "structural" devices to reduce wind velocities and control erosive forces. The second involve the use of special tillage and farming practices aimed at reducing wind erosion by managing the aerodynamic nature of the ground surface.

Devices which fall into the first category include windbreaks and various forms of strip cropping. The most effective windbreaks are formed from several rows of shrubs and trees, designed to provide optimal downwind protection without increasing turbulence to leeward. These devices have the disadvantage that they take a significant area of land out of production and they are only really effective if climatic conditions are such that the severe prevailing winds come predominantly from one direction. An alternative is to use strip or alley cropping methods, in which farming is undertaken in alternative strips of crop and fallow, or of high value shrubs and crops, oriented at right angles to the direction of the prevailing wind. Again, these devices are only really effective if the prevailing winds blow predominantly from one direction.

A variety of conservation farming methods and techniques has been developed for wind erosion control on croplands. These involve stubble retention techniques, which seek to maintain some vegetative ground cover for as much of the time as possible, along with cultivation techniques which enable weed control, seedbed preparation and planting to be undertaken with minimal disturbance to the vegetative cover and maintain the roughness of the soil surface. This may involve chemical weed control and the use of special farming implements, such as stubble and sod seeders and chisel-type ploughs, which permit the cultivation of vegetated surfaces and maintain a rough, well-textured surface. Under extreme conditions, special cultivation techniques such as basin listing may be employed to form a special surface which not only resists wind erosion but serves also to trap and absorb rainfall. These conservation farming techniques are similar to those which are used to control water erosion, and may be equally effective for both purposes.

On grazing lands, wind erosion control is effected principally through management of vegetative cover and management of stocking rates. Stocking rates in particular must be carefully managed to maintain sufficient vegetative cover, particularly during drought conditions, and prevent overgrazing and denudation. In severe circumstances, this may require destocking or even total cessation of livestock production. Control of vegetative cover can be assisted by the strategic location of fencing, the use of portable or temporary fencing and the strategic location and management of watering points. The control of feral animals and grazing wildlife, including the use of appropriate of fencing and the restriction of these animals from water sources, may also be necessary for wind erosion control, particularly during severe drought conditions.

5. Mass movement

As is the case with all forms of land degradation, a range of non-structural and structural or mechanical means is available for the avoidance of mass movement disasters and the mitigation of their effects.

Photo 7: Although the area disturbed by individual landslides is usually small, these can be disastrous. The event depicted in this photograph occurred in Shanxi Province, China

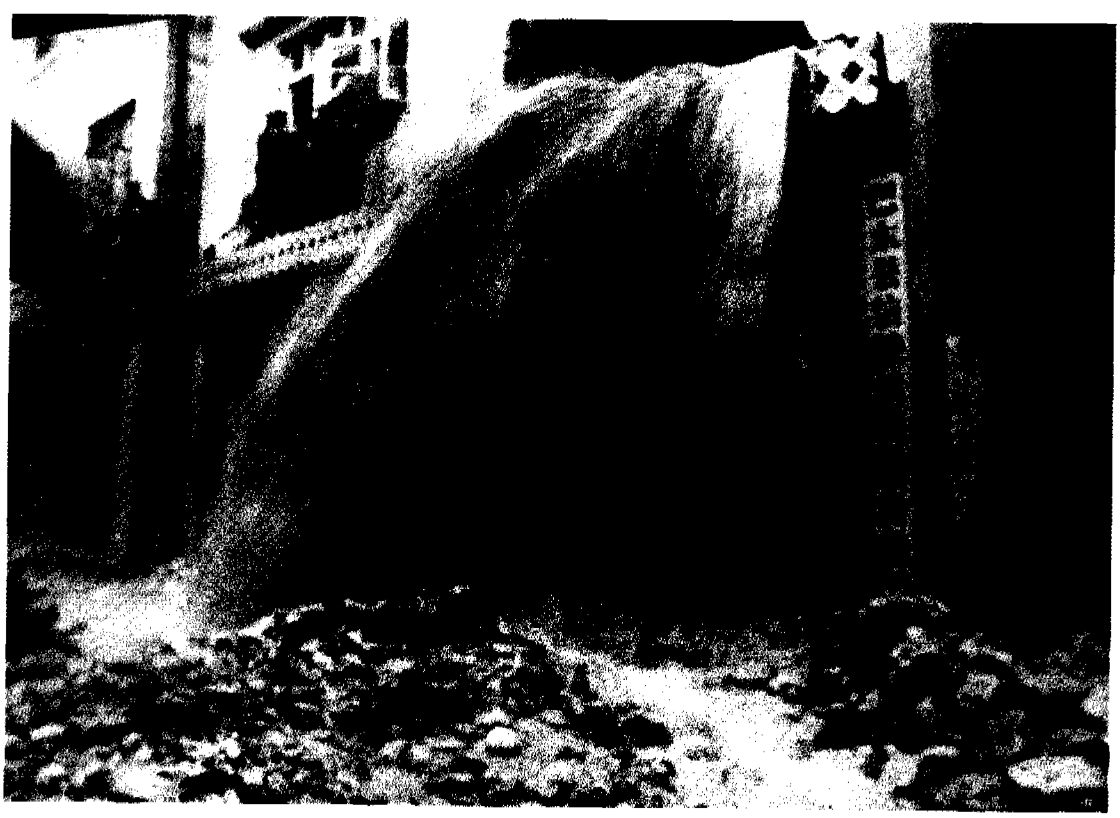


Photo 8: Mud and rock flows occur when unstable foundation material is associated with poor drainage conditions

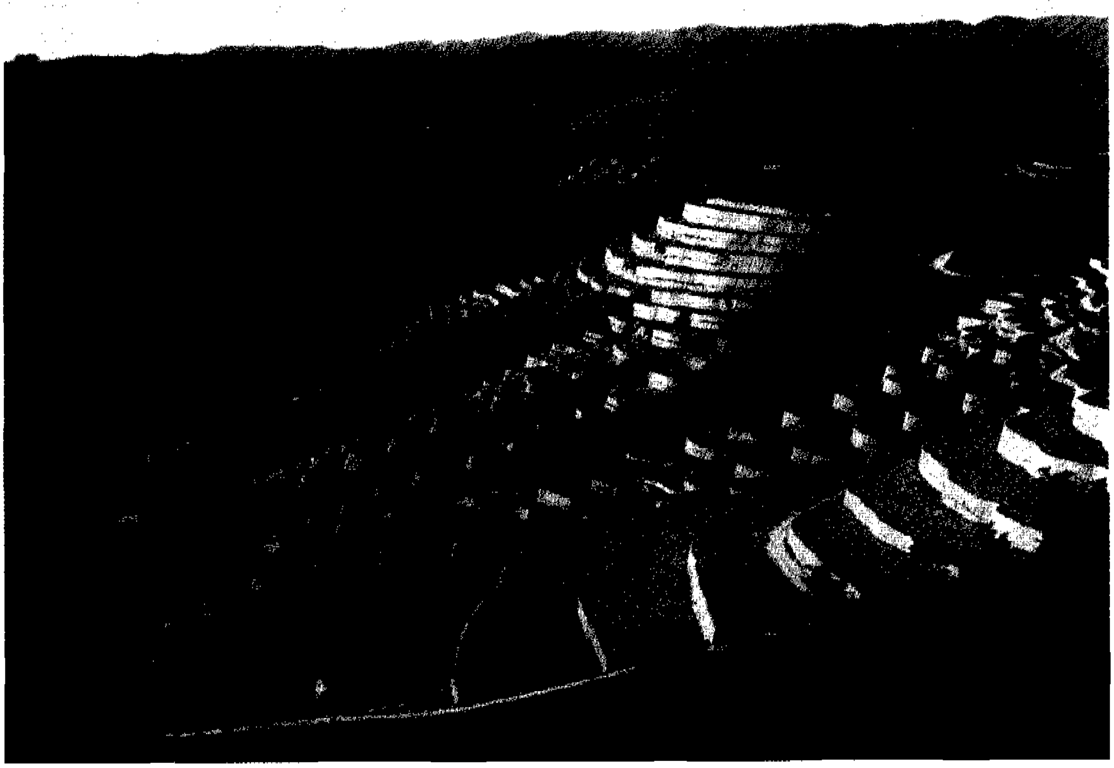


Photo 9: Dry terracing is an effective gully control measure. It is used here in the loess hills of China

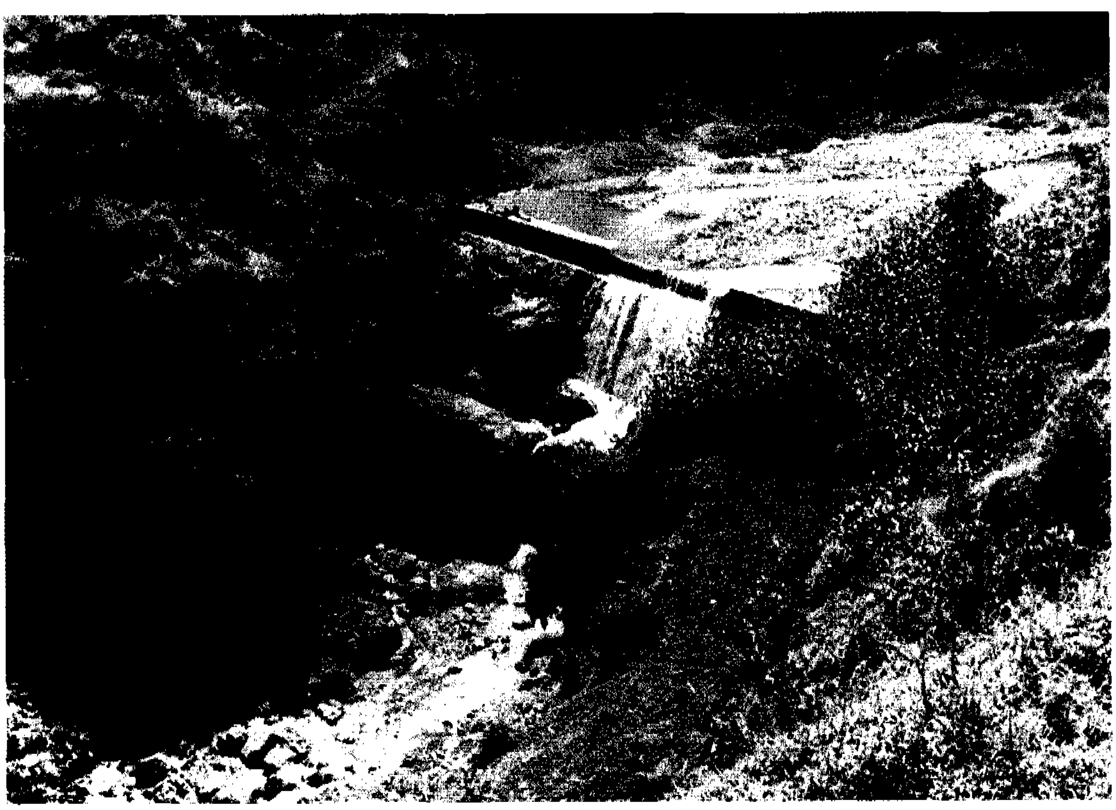


Photo 10: Structural gully control works are an effective means for the control of sediment movement

Where it is economically and socially acceptable, and population pressures and the demand for additional productive land allow it, land-use zoning provides the most effective and least costly solution. This simply requires the prohibition or restriction of agricultural development or urban settlement in locations which are particularly susceptible to land instability. Where this is not feasible, land-use controls might still be employed to restrict the use of the land to activities which are compatible with potential instability or result in minimal damage and loss of life should disaster events occur. This might include such means as the prohibition or restriction of clearing or logging, the restriction of cropping, or the prohibition of urban settlement from land areas at hazard. It might also include the requirement for precautionary land management practices and farming techniques which minimize disaster potential.

There is a variety of structural or mechanical measures which can be applied to reduce the potential for land instability in areas where occupation cannot be prohibited. These measures might include the following:

- preventing or diverting run-off flows around critical sites
- de-watering sites using drainage systems
- planting trees or shrubs which remove sub-surface water by transpiration
- planting deep-rooted vegetation to bind sub-soil material
- underpinning foundations to stable rock
- battering slopes to stable grades
- constructing retaining walls along the toes of critical slopes

6. Dryland salinity

As has been explained in some detail in Chapter II, dryland salinity is essentially the consequence of inappropriate alteration to site hydrology, and particularly the removal of vegetation which otherwise would function to maintain water table levels at a safe depth and prevent the discharge of saline groundwater along critical zones.

To avoid the future development of this form of land degradation, land-use controls need to be applied in locations where geological and hydrological conditions, sub-soil salinity and groundwater salinity levels indicate that a potential problem exists. Such controls should prevent extensive clearing on susceptible sites, or at least ensure that excessive clearing is not undertaken in critical sections of the watershed, particularly in upland groundwater recharge zones.

Where dryland salinity problems already exist, various land management measures can be taken. These include the following:

(a) Fencing off salt outbreaks;

(b) Reducing stocking rates or totally excluding stock;

(c) Using salt-tolerant vegetation on the saline areas;

(d) Undertaking surface tillage and deep ripping of the site to assist plant germination;

(e) Installing subsurface drainage;

(f) Installing interceptor banks to divert water away from the site;

(g) Introducing strategic soil conservation works to control the soil erosion hazard on salt-damaged areas;

(h) Changing the management of the sub-catchment to promote high rates of groundwater usage by pastures or deep-rooted crops;

(i) Regenerating vegetative cover on groundwater intake zones using deep-rooted trees or shrubs.

7. Irrigation salinity

The possible future development of irrigation salinity problems can largely be overcome by ensuring that proposals for new irrigation areas are thoroughly investigated. This requires a careful study of such aspects as irrigation water quality, soil types, sub-soil conditions, watertable depths and drainage conditions, undertaken in sufficient detail that problem areas or conditions can be identified and land-use zoning plans devised to prevent or control development on hazardous areas.

New irrigation schemes must be carefully designed to ensure that efficient control of water application rates is available and to ensure that tailwater and sub-surface drainage provisions are adequate. Farmer education and the provision of extension and advisory services are essential to ensure that sound irrigation methods are employed and the development of high water table, salinization or waterlogging problems is avoided.

On existing irrigation areas there are many non-structural and structural measures which can be taken to maintain sustainability of production and avoid the development of land degradation problems. Appropriate land management techniques and land-use controls might include the following:

(a) The restriction of crop types, cropping practices and farming methods to those which are sustainable on the site;

(b) The use of water application techniques which provide optimal water use efficiency and prevent the development of rising water table or waterlogging problems;

(c) The introduction of improved land preparation techniques to ensure uniform and efficient water application;

(d) Changing where necessary to alternative irrigation methods or equipment which utilize less water and apply it more efficiently;

(e) Ensuring that adequate leaching practices are employed by irrigators;

(f) Improving irrigation distribution systems and water ordering or rostering procedures to minimize water loss and wastage.

Structural measures that might be undertaken to control irrigation salinity problems include the following:

(a) Installation of adequate surface drainage systems to provide for effective disposal of tailwater, excess irrigation water or run-off from irrigated fields;

(b) Installation of adequate sub-surface drainage facilities to maintain appropriate water table depths, with appropriate provision for the safe collection and disposal of drainage water;

(c) The installation where necessary of groundwater pumping networks using tubewells, spearpoints and similar dewatering techniques to control groundwater accumulation;

(d) Provision where appropriate for the safe disposal of drainage waters, such as pumping to safe disposal areas or processing in evaporation basins or vegetated transpiration fields.

C. Land-use control measures

As has already been explained in Chapters II and III, land degradation can cause significant changes to watershed ecosystems. These changes usually produce adverse effects upon the natural hydrology of the watershed, which can lead to degradation of the natural resources of the watershed and an increase in the intensity of natural disasters.

The vulnerability of watersheds to land degradation and water-related natural disasters can be reduced by structural works and land treatment measures. The potential impact of these adverse developments or events can be further reduced by the imposition of land-use controls, designed to manage degradation and minimize exposure to the risk of disasters which cannot be avoided. To achieve this objective, legislative controls which empower the relevant government authorities to direct land-use planning policies and practices related to watershed management should be adopted and implemented. These controls should strive to ensure that an effective and comprehensive legal and administrative system is adopted which addresses the problems of land degradation, environmental protection, and the maintenance of ecosystems and is consistent with the principles of sustainable resource development. Such a system requires an integrated approach to the management and protection of natural resources, including land, water, vegetation and human activity, undertaken on the basis of the total watershed. This approach recognized that changes to the natural environment in the upper watershed will influence conditions in the downstream areas.

Legalization should establish national standards for watershed management which relate to the use, development and protection of land in a way which will minimize the risk to populations during the occurrence of water related natural disasters and the degradation of natural resources. Activities within a watershed should be controlled and protected through a comprehensive watershed management plan which places restrictions on those activities which can increase the risk of damage. Under this type of legislation, consent would be required for:

- large-scale land clearing
- rural land development and use
- forestry, mining and extractive industries
- rezoning of land for urban use
- occupation of flood plain land, steep slopes and other hazardous areas

D. Large-scale structural or engineering measures

1. Levees and flood walls

The principal purpose of levees and floodwalls is to confine floodwaters to the stream channel and a selected portion of the floodplain. These barriers protect only the land area immediately behind them, and are effective only against flood depths up to the chosen level for which they were designed.

A major advantage of levees and floodwalls is the flexibility they offer to protect either a specific site or a larger area. For example, they can be used to protect a single community or a portion of a community. However, they may create a false sense of security about the degree of protection provided. Floods exceeding the levels for which the levees and floodwalls are designed can cause disastrous losses of life and property.

Levees and floodwalls may increase flooding in other areas unless they are designed to form part of a comprehensive programme. If they restrict the extent of flooding, levees and floodwalls tend to increase water surface elevation, velocity and maximum discharge within the confined stream reaches and also to increase the rate of flood wave travel downstream. These structures may also have undesirable environmental aspects, such as destruction of natural habitat and the loss of scenic views.

The requirements for the design and construction of levees and floodwalls are governed by degree of hazard to life and property within the protected area and by site conditions. Levees are normally constructed of earth and require significant space to accommodate the required base width. Floodwalls are usually constructed of concrete or steel and take up far less room. They are more suitable for use in congested areas.

The intensity of investigation for levees and floodwalls depends upon the importance and economic value of the land being protected from flooding. Items covered by the investigation should include levee location, determination of design water level, foundation conditions and embankment materials. Investigations undertaken for levees should also incorporate geotechnical investigations of suitable borrow pits for embankment material.

Because levees and floodwalls can fail by overtopping, undermining, slumping and excessive seepage, the design of these structures should attempt to reduce the possibility of failure from these causes. Ample freeboard, which takes into account the settlement of levees, wave action, sedimentation of the river channel and inaccuracies in estimation of flood levels, reduces the possibility of overtopping of levees or floodwalls. Undermining is minimized by locating levees or floodwalls far enough away from channels to eliminate exposure to high velocity or scour. Proper side slopes and construction methods minimize slumping of earth levees. Excessive seepage can be reduced by the provision of seepage protection works. Damage can also be caused by termites and burrowing animals. Regular inspections are necessary to locate and remedy the damage in an early stage of development.

Levees and floodwalls complicate the drainage of land they protect and provision must be made for the discharge of internal drainage water unless adequate storage is available. Discharge through levees or floodwalls can be achieved by gravity flow through pipes equipped with gates. When prolonged flood stages prevent gravity outflow, the internal drainage water must be stored temporarily, removed by pumping or disposed of using a combination of these methods.

To be effective levees should be subjected to proper maintenance. Such maintenance should include regular inspections as well as periodical patrols during and immediately after severe floods. Vegetation, grazing and traffic on earth levees should be controlled. Proper attention to any defects will help ensure against levee failure.

The following disadvantages are associated with levees and should be recognized:

(a) Economic and other constraints limit the height to which levees are constructed and it is usually statistically certain that rare flooding will result in overtopping;

(b) Levees can create a false sense of security;

(c) If overtopping does occur the resulting damage can be far in excess of that which would have occurred if the levee had not been constructed;

(d) Levees tend to promote increased development in the areas protected which in turn leads to even greater damage if overtopping occurs;

(e) Levees can be unsightly and can divide communities.

For safety purposes, earth levees should be constructed with gentle backslopes to reduce the risk of scour and failure if they are overtopped by a large flood. Consideration should be given to the provision of measures which allow controlled overtopping and thus minimize damage if the design height of the levee is exceeded.

2. Channel modification including river training works

Most natural watercourses have a river channel of limited capacity, which may be exceeded annually, with excess floodwater overflowing onto the floodplain. Hydraulic improvements to the watercourse or to the floodplain, and/or flood channels constructed within the floodplain, enable flood waters to be passed at a lower level than would occur naturally. In urban areas, such works also permit the optimization of land use through improved residual drainage.

The various types of channel modification include:

- straightening, deepening or widening of the channel
- removing vegetation or debris
- lining the channel
- raising or enlarging bridges and culverts which restrict flow
- removing barriers which interfere with flow
- installing river training works

All of these modifications contribute towards reducing the height of a flood. It is sometimes possible, by extensively reconstructing a stream channel, to contain major floods within the banks. Caution should be exercised, however, as channel modifications can facilitate the transfer of floodwaters downstream and may impose problems on downstream communities.

Channel modifications are similar to levees and floodwalls in that they can be used to protect a specific site or region. They can also provide the community with other positive benefits, such as improved navigation and recreation.

Channel deepening is not very well suited to major streams, because sediments can quickly fill the excavated area. Frequent re-dredging is often necessary to maintain the deeper channels and this can involve a significant maintenance cost.

Channel modifications are likely to be most effective on steeper, smaller streams with overgrown banks and narrow floodplains. Channel modifications are unlikely to have any significant effect in flooding situations where there are extensive areas of overbank flooding, or where flooding effects are dominated by tide levels.

River training works are structural measures of various kinds which are undertaken in order to provide a more effective channel for the passage of flood flows and sediment loads. Such works may be designed either to retard flow rates along a river bank, in order to reduce erosive velocities and increase the deposition of sediments, or to provide protection for the bank against erosion or scouring.

Permeable groynes and revetments, constructed of piling, rock, concrete, fencing materials, vegetation or other materials, are generally used for these purposes. Groynes protrude into the channel and are designed to divert flow away from the bank, whilst at the same time causing an accumulation of sediment along the toe of the bank and on the downstream side of the groyne structure. Revetments, on the other hand, are constructed along or parallel to the bank, where they serve to reduce the velocity of flow along the bank, thus reducing bank erosion and allowing the river bank to stabilize.

Which of these devices should be used in a given situation depends upon characteristics of the stream channel and the extent and nature of the existing erosion damage. Whichever kind of device is employed, its satisfactory long-term performance will be very much dependent upon its continuing maintenance.

Disadvantages which are related to the use of channel modifications include the costs of proper maintenance, the destruction of riverine habitat for fish and wildlife, and the potential for the aggravation of channel scouring and bank erosion if the structures are not intelligently designed, well constructed and carefully maintained.

3. By-pass floodways

These structures serve two functions in flood mitigation. Firstly they create large, shallow reservoirs which store a portion of the flood water and hence decrease the flow in the main channel below the diversion. Secondly, they provide an additional outlet for water from upstream, improving flow characteristics and decreasing water levels for some distance below the diversion. Opportunities for the construction of floodways are limited by the topography of the area and the availability of low-value land which can be used for the floodway.

There are two types of by-pass floodways, natural and constructed. A natural floodway follows the course of an existing cross-country depression and carries floodwaters that can no longer be carried within the river channel. The land in the floodway is generally not different from other farmland, except that it may be low-lying. Some floodways have control banks constructed across them, or may be bordered by levees, in order to control the spread of floodwater. Restrictions are usually placed on land development in floodways to ensure that future loss and damage from major floods is reduced to a minimum and to ensure that the floodway functions as designed.

When required, controls in the form of spillways and gates are provided at the entrance to a floodway. Spillways take the form of a lowered and protected section of levee which is designed to control the amount of floodwater diverted into the floodway from the river. As spillways can be overtopped for long periods by high velocity floodwater, they have to be specially designed to avoid failure. Protection can be provided by rock gabions or, where appropriate, by building the spillway with gentle backslopes which are well grassed.

If the floodway possesses comparatively steep bed-slopes, control banks may be built perpendicular to the direction of flow at intervals along the length of the floodway. These banks are similar in design to the entrance spillway, and form a series of basins which reduce the water velocity by dropping the floodwater in progressive steps down the floodway alignment.

Diversions are works constructed to intercept flood flows upstream of a damage-prone area and route them around the area through an artificial channel. Diversions may either completely re-rout a stream or collect and transport only those flows that would cause damage.

Diversions sometimes offer the advantage that they can be located to protect several nearby communities with one major facility. They are, of course, subject to surcharging if floods exceed their design capacity.

Diversions are particularly well suited for protecting developed areas, because they do not usually require land acquisition or construction within the protected area. However, opportunities for diversions are often limited by the nature of local land formations and soil conditions. There must also be a receiving water body or stream channel with sufficient capacity to carry the flow bypassed through the diversion without causing flooding.

4. Retarding basins and flood storage areas

Flood storage and retardation involves the deliberate, controlled flooding of designated areas in order to minimize overall flood losses. It permits floods exceeding a specified magnitude to spread over low-lying lands situated behind levees in a controlled fashion, accomplished by the operation of gated structures or spillway sections incorporated in the levees. The diversion of floodwater, when carefully controlled, will reduce the flood peak at downstream locations and confine flooding to within the flood control system.

Areas selected for flood storage and retardation are traditionally low-lying locations which have a history of flooding. By the formulation of proper controls it is possible to utilize these areas for habitation and agricultural purposes, on the understanding that they will be flooded periodically. This calls for the preparation of a comprehensive programme of flood operation, a knowledge of the depth and extent of area inundated, the imposition of controls to ensure predictable flood behaviour and the implementation of a reliable flood forecasting and warning system to ensure timely and safe evacuation. Special provisions are also required for the protection of emergency services and for flood refuge areas.

To reduce the damages associated with controlled flooding, it is necessary to provide drainage works capable of emptying the flood storage area as quickly as possible after the cessation of main river flooding.

Retarding basins reduce downstream flood flows in both mainstream and urban drainage situations. They allow small flows to pass unimpeded but trap a portion of larger flows. In urban areas, retarding basins are most suitable for small streams which respond quickly to rainfall and/or stormwater flooding. However, they introduce a number of inherent problems, which should be carefully evaluated for each particular situation. These may include the following:

(a) Basins may require a substantial area to achieve the necessary storage;

(b) Long duration or multi-peak storms (when the basin is filled from a previous peak) can increase the risk of overtopping or breaching;

(c) The impact on floods larger than those for which they are designed is limited.

Although such basins can be very useful in reducing the flood problems of both proposed and existing development, it is particularly important to make provision for downstream management of the resulting floodwater if the capacity of the basin is exceeded.

Sites for retarding basins in developed urban areas are generally limited. Available sites are usually restricted to established recreational areas, such as parks, playing fields and parking lots. In new urban developments or re-developments, the incorporation of a system of retarding basins at the planning stage can result in effective flood protection for those areas.

Retarding basins are sometimes constructed by building an earth embankment across the watercourse and providing outlet facilities to control releases appropriate for the capacity of the downstream channel. The outlet facility usually takes the form of a box or pipe culvert. If earthworks are used for the construction of the basin embankment, the provision of adequate spillway capacity is essential to protect the basin from failure by overtopping if flows exceed the design flood.

Retarding basins can play a role in the improvement of water quality by the removal of floating rubbish and the collection of sediment. When they are used for this purpose, they require continuous maintenance.

Land along the river and natural depressions on the floodplain can be utilized for the off-river storage of floodwaters. Flood flows are diverted into them in order to reduce flood peaks downstream. The efficiency of operation of such storages can usually be improved by providing them with suitable intake structures for controlled filling and outlet structures arranged to permit controlled releases when downstream conditions allow.

5. Flood mitigation reservoirs

In appropriate circumstances dams can be constructed to create reservoirs which control major flood flows by temporarily storing flood waters and releasing them at a safe flow rate. Such devices may be used to control floods arising from existing catchment conditions or to offset the impact of proposed land-use changes. The amount of storage required depends upon the degree of protection needed and the downstream channel capacity.

The degree of mitigation provided by a flood control reservoir depends on the combination of dam storage, spillway capacity and the pattern of flood inflows. The effect of storage is to decrease the flood peak without reducing the total volume of floodwater. The reduction of the flood peak is achieved at the expense of an increased duration of dam releases at lower rates. For dams equipped with gates or valves, the way in which these controls are operated will determine the rate of release and the degree of downstream mitigation.

The protection afforded by a surface reservoir is greatest in the area immediately downstream of the dam. Protection further downstream is reduced by tributary flows and by run-off from land adjacent to the river. Protection may also decrease over time if the reservoir capacity is diminished by siltation. Surface reservoirs have the greatest potential to mitigate floods when they are empty.

Flood mitigation reservoirs are mostly used on small and moderate-sized streams. The large areas of land required to store the flood flows of major rivers are generally no longer available, especially where they involve the flooding of valuable agricultural lands. Many sites that are geologically and topographically suitable may require very considerable and expensive land acquisition and the displacement of large populations. The cost of large reservoirs can generally only be justified where they protect heavily developed urban areas and are the only practical means for significantly reducing flood damages. It is usual practice to reserve a component of the available storage capacity in multi-purpose dams for flood mitigation purposes. In such cases, careful coordination is necessary to permit flood mitigation reservoirs to serve also for water supply or irrigation purposes.

A major disadvantage of flood mitigation reservoirs is that downstream residents often do not appreciate that they can only control floods up to the peak rate for which they were designed. Complementary land-use controls need therefore to be enforced to prevent unsafe development and encroachment on the downstream floodplain.

6. Drainage evacuation systems

Drainage water produced by storm run-off from within the protected area behind levees or floodwalls may be disposed of by various means, which include:

(a) Gravity release through pipes fitted with gates during periods of low river flow;

(b) Temporary accumulation of drainage flow in storage areas;

(c) Pumping of interior drainage water during periods when gravity drainage outflow is restricted by backwater.

Pumping is usually required for the disposal of interior drainage water whenever sufficient discharge by gravity flow cannot be achieved, which may be because of limited outlet capacity, insufficient storage capacity or the effects of backwater caused by flooding.

The design of drainage works for the removal of flood waters accumulating within the low-lying areas behind levees or floodwalls requires consideration of the entire drainage network servicing the protected area. Coordinated use of storage areas, channels, pipe systems and gravity outlets is needed so that the pump capacity, size and period of operation can be optimized. The efficient planning and design of pumping plants will involve careful selection of the required water removal rate, the auxiliary drainage facilities needed to minimize the pumping requirements and the location of the pumping plant to provide an effective outlet to the entire drainage system.

The required capacity of the pumping plant should be determined on the basis of direct hydraulic analysis. This analysis should give consideration to such factors as the size of the area served; the amount, rate and timing of rainfall and run-off; and the period of flooding when gravity flow is restricted. For protected areas in coastal plains which are located along rivers, the effect of tides should also be taken into account.

The period of pumping may be reduced by increasing the amount of available storage. This may be achieved by excavation. Where this is not practical, adequate pumping capacity must be installed to safely discharge any drainage inflow volume in excess of the available storage capacity.

Pumps installed for drainage evacuation systems must be selected to operate efficiently whilst moving large quantities of water at low heads. They may also be required to handle substantial amounts of sediment and rubbish in the drainage effluent. Axial flow, mixed flow or radial flow centrifugal pumps are best suited to this application. It is advantageous to install two or more pumps, in order to provide efficient pumping over a wide range of pumping rates and ensure that the breakdown of one pump will not stop all pumping. Discharge of drainage water by gravity flow is achieved more efficiently by using a battery of small gates, rather than by one or two large gates.

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ANNEX

CONTACTS FOR COMPUTER MODEL PROGRAMMES

HEC series models:
US Army Corps of Engineers (USACE)
Hydrologic Engineering Centre
609 Second St
Davis CA 905616 USA

SSARR:
US ARMY Corps of Engineers (USACE)
North Pacific Division
Attn: CENDP-EN-WM-HES
PO Box 2870
Portland OR 97208-2870 USA

USACE Water Quality Models:
Environmental Laboratory
US Army Engineer Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg MS 39180 USA

HSPF, SWMM, SYMPTOX3, QUAL2E, WASP5:
Environmental Protection Agency (EPA)
Center for Exposure Assessment Modelling (CEAM)
960 College Station Road
Athens GA 30605-2720 USA

CREAMS, GLEAMS:
US Department of Agriculture (USDA)
Agricultural Research Service (ARS)
Southeast Watershed Research Lab
PO Box 946
Tifton GA 31793 USA

SWRRB:
US Department of Agriculture ARS
Attn: Dr. J. Arnold
808 East Blackland Road
Temple TX 76502 USA

ANSWERS:
University of Georgia
Department of Agricultural Engineering
Coastal Plains Experiment Station
PO Box 748
Tifton GA 317973 USA

Information about US Federal Government agency models and their availability can also be obtained from
National Technical Information Service
US Department of Commerce
5285 Port Royal Road
Springfield VA 22161 USA

WALLINGFORD series and other UK models:
Wallingford Software
HR Wallingford Limited
Howbery Park
Wallingford, Oxfordshire
OX108BA United Kingdom

MOUSE and other Danish models:
Danish Hydraulic Institute
Agern Alle 5
DK2970
Horsholm, Denmark

NOTE: that many of the agencies listed above have Internet sites, from some of which model programmes can be downloaded (e.g. all the EPA programmes listed above). They can be located using search engines such as AltaVista and Yahoo. The following home pages provide a good starting point:

US Corps of Engineers: http://www.usac.army.mil/
US Environmental Protection Agency: http://www.epa.gov/
US Department of Agriculture: http://www.usda.gov/