6. Landslides

Investigations within the framework of the IDNDR are focused on the following goals:
- development of prevention strategies and improved programs for disaster prediction,
- offering of comprehensive education tailored for the needs and qualifications of the population in the concerned regions; and
- performance of faster relief after the occurrence of a disastrous landslide.

6.1 Definitions

The definition of the UNESCO-Working Party on World Landslide Inventory of landslide is: "A movement of a mass of rock, earth, or debris down a slope." The largest moved volumina comprise approximately 20 km^3 (Seidmarreh, Iran) and 12 km^3 (Flims, Switzerland)

Landslides occur if the balance of resisting forces (shear forces) and active forces (weight, water pressure) is disturbed. Stability is based on the geological structure and the geomorphological development of the region. Therefore, knowledge of the geology (material, structure, tectonics) of endangered regions, as well as knowledge of the present geomorphological dynamics, is necessary for risk assessment, rehabilitation, and securing of unstable terrains. Factors reducing stability, and possibly leading to landslides, are, on the one side, permanently effective natural processes (of geologic-geomorphological nature) and, on the other side, episodically effective natural and anthropogenic influences. In many cases, landslides are triggered by other natural events (e.g., earthquakes, volcanic activity, heavy rainfalls).

6.2 Classification

Landslides are generally classified according to the kinematics of movements.

6.2.1 Kinematics of landslides

The international classification uses the way masses move as the main criterion.

The moved material is distinguished between rock (hard, solid) and soil (loose, consolidated, overconsolidated). Soils are further divided into debris and earth.

The differentiation of the mechanisms of movement is made, according to Skempton and Hutchinson, between five main types: falls, rotational slumps, combined slides, translational blocks, and flows. Varnes classifies landslides using the terms fall, plunge, slide, flow, and their lateral dispersion.

The classification made by Savarenski and Degro differentiates, according to the way sliding masses are moving, between asequent, consequent, and insequent landslides. Asequent slides are movements alongside a cylindrical slip circle. They are formed in homogeneous, unbedded, and cohesive rocks. A consequent slide moves along the bedding plane or at other given downslope surfaces. Insequent slides, which are commonly quite large, have deep-reaching, sliding planes.

In the *Multilingual Landslide Glossary* of the UNESCO-Working Party on World Landslide Inventory, landslides are divided into.

- fall,
- topple,
- slide,
- spread, and
- flow (creeping belongs to the type flow).

6.2.2 Morphology of landslides

Morphology offers another criterion for classifying landslides. Falls occur at steep slopes, such as rock cliffs, erosion shores, and banks, or building excavations. In these cases, moved masses partially lose their inner cohesion and underground contact. The movement of falling predominates flowing and toppling.

6.2.3 Special cases of landslides

The range of variation in material composition, morphology, and velocity distinguishes debris flows and lahars (mud flows of volcanic ashes) from other types of landslides. Debris flows are rapid movements of slope debris, sand, or sandy gravels. They form if non-cohesive, loose material is suddenly saturated with water. The ratio of water to solid components usually is 1:1. Debris flow also can be rapidly moving masses of rock debris in connection with phreatic volcanic eruptions; they can be regarded as relatively dry because no water, only steam, gas, and air, occurs as a dominant pore fluid. Lahars are also rapid, but are water-saturated streams of rock debris induced by volcanic eruptions. Another special case of landslides are large subaquatic slides at the continental slopes along the deep sea In many cases, these slides are triggered by seismic events that result in changed stability of both loose and solid masses at a subaquatic slope. Subaquatic slides also may cause tsunamis.

6.3 Causes of landslides

In most cases, there is more than one cause that induces landslides. It is presumed that the processes leading to slope instabilities are based on the geological structure. Landslides occur because of changes in the balance of forces at slopes as a result of physical and/or chemical processes. A distinction is made between long-term geogenic processes, such as weathering, oversteepening of slopes by tectonic movement, erosion or denudation, earthquakes, and volcanic eruptions, and, as a rule, comparatively short-term anthropogenic influences, such as the construction of traffic ways or dams Other man-made influences (deforestation, overgrazing, undergrazing) also may have destabilizing effects (Fig 6)

In assessing the degree of slope stability, the relation between acting and resisting forces at given or probable surfaces or lines of rupture is usually considered. Acting forces result more or less from gravity, resisting forces from shear stress consisting of cohesion and friction Slope stability is influenced by the conditions of the groundwater, which in turn depends on precipitation and the occurrence of flowing or standing surface water and its infiltration, and by the permeability-dependent distribution of springs, backwater, and groundwater horizons, as well as by joint water pressure and seepage pressure. There is a strong correlation between slope movements and years of unusually heavy precipitation.

The main factors influencing slope stability are:

- morphology (height, inclination, form, and age),
- geology (rock and soil material, structure, joint system, and tectonics),
- hydrogeology (water catchment, groundwater level, rate of infiltration, water routing, and water saturation),
- climate (precipitation, temperature, and direction),
- biology (vegetation),
- age (weathering, disintegration), and
- human influence.

6.4 Research needs

Types of landslides and their mechanical laws are investigated to a degree that allows the recognition of critical situations. Research results of the last years allow risk assessment of landslide-prone areas and the development of kinematic models, whereas the development of dynamic models is just beginning. In this respect, not only the study of the spatial distribution of landslides and their kinematics, but especially the quantification of the parameters controlling the entire system, is necessary to deduce models suitable for prognosis. A detailed and comprehensive exploration of selected current and potential landslides in various regions of different morphology, geology, and climate should promote the insight into processes that occur before, during, and after landslides, including their consequences. Former and presently active landslides, as well as regions potentially in danger because of their geological set-up, should be chosen and thoroughly investigated in an interdisciplinary approach. Man's influence in connection with the occurrence of potentially disastrous events must be considered Interdisciplinary research between engineering geology, geomorphology, geodesy, and engineering sciences is a must.

Open questions are:

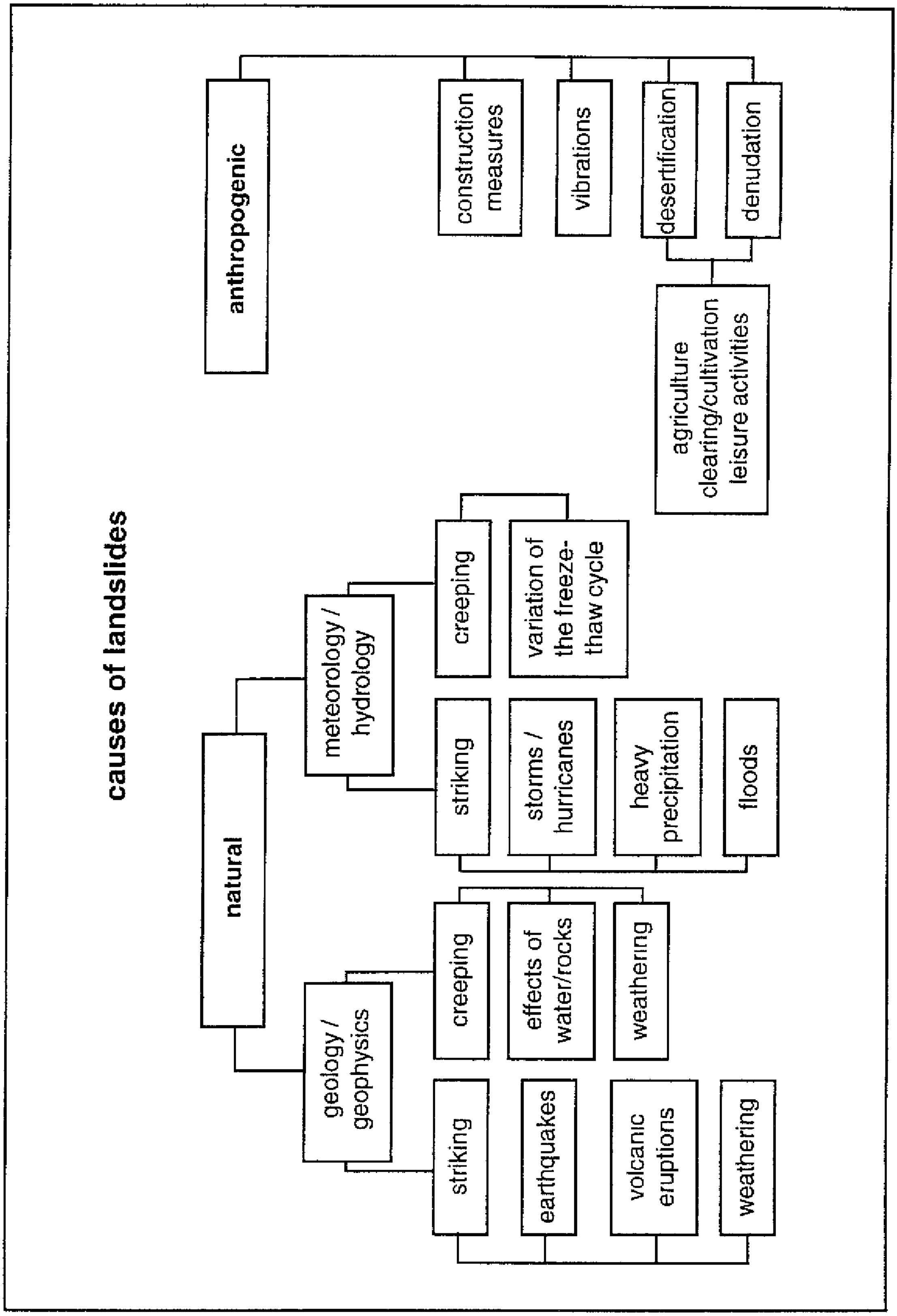
- the connection between precipitation, groundwater, and the acceleration of the slope movements,
- the development of expert systems concerning landslides,
- the documentation of landslides, and
- the compilation of landslide hazard and risk maps.

The interpretation of aerial or satellite images, including further in-situ and laboratory tests, is one possibility for the detection, reconnaissance, and observation of unstable terrains.

According to the states of activity of landslides, eight types can be distinguished (Multilingual Landslide Glossary):

1	*active:*	currently moving;
2	*suspended:*	moved within the last 12 months, but not active at present.
3	*reactivated:*	active landslide that has been inactive;
4	*inactive.*	not moved within the last 12 months, inactive landslides can be subdivided into states 5-8;

Figure 6: *Causes of landslides (after Matteß)*


causes of landslides
natural
anthropogenic
geology / geophysics
meteorology / hydrology
striking
earthquakes
volcanic eruptions
weathering
creeping
effects of water/rocks
weathering
striking
storms / hurricanes
heavy precipitation
floods
creeping
variation of the freeze-thaw cycle
construction measures
vibrations
desertification
denudation
agriculture clearing/cultivation leisure activities

5 *dormant.*	inactive landslide that can be reactivated by its original causes or by other causes;
6 *abandoned*	inactive landslide that is no longer affected by its original causes;
7 *stabilized:*	inactive landslide that has been protected from its original causes by artificial remedial measures;
8 *relict:*	inactive landslide that developed under climatic or geomorphological conditions considerably different from those at present.

A measuring technique often used for landslides is the monitoring of displacement lines: movable measuring stations are distributed across the unstable terrain, and a fixed station is established on the stable ground of the slope. Through use of these stations, the absolute movement of the terrain over time can be recorded.

Measuring methods should be established in order to make permanent monitoring possible. The GPS method (Global Positioning System) is used more and more. With the geophysical methods of acoustic monitoring, motion sounds within a potential slide body are registered by recording the sounds of failures in the material. Other geophysical methods are soil-gas measurements (CO_2), georadar, and refraction seismics.

A standard description and depiction of landslides should be based on the Multilingual Landslide Glossary of the UNESCO-Working Party on World Landslide Inventory.

Other topics of investigation are:
- investigations on the occurrence of fossil landslides as dependent on climate history; research is aimed at providing time series; the data gained should allow the possible transfer to regions of different climatic conditions.
- basic research of failure mechanisms, especially concerning alternations of hard and soft rocks;
- quantification of climate-controlled factors initiating movements and identification of typical sequences of movements.
- development of models for prediction of landslides on the basis of time series and hazard criteria, including, among others, the prognosticated climate development and anthropogenic influences as important triggering factors of landslides, with the help of expert systems;
- development of safety measures on the basis of reliability, expediency, and success of earlier measures;
- local/regional hazard zonation and risk assessment; and
- application of GIS (Geographic Information System).

The investigations should be conducted at a few comprehensively studied areas of different relief types in different geologic and climatic regions. This should be done on an international level. The results serve the mitigation of natural hazards, the goal of the IDNDR.

6.5 Procedure

Standardized methods of compiling hazard and risk maps seem to be of primary importance. For some regions, such maps already exist.

Improved prediction on the basis of better knowledge of failure mechanisms, as well as improvement in monitoring, has to be done to reduce damage potential and damage effects. Also, methods for managing and reducing a disaster that is already happening must be provided. Important supplementary measures are education in the recognition of potential hazards and risks and suggestions for rehabilitation or avoidance of ecological damage (Fig. 7).

In addition, awareness by the population in disaster-prone regions with respect to landslides induced by man-made influences must be awakened.

Figure 7: *Knowledge on landslides - collection, distribution, application (after Krauter)*

Interdisciplinary research

Knowledge

Information and training

Decision makers	**Administration**	**Public**
legislation	risk and disaster plans	reaction
national institutions	prediction/forecast	responsibility
promotion of research	monitoring	
aid programs	warning	
	infrastructure	

7. Floods and droughts

Disasters associated with water can have very different aspects. Too much water in the form of floods may be a hazard for people and objects, but water shortage can have disastrous effects in the form of drought. There is practically no place on Earth totally immune from disasters related to water. Moreover, both extremes occur almost everywhere, though in relatively different degrees. A special type of flood is the massive displacement of water bodies in the form of storm surges and tsunamis. Water also can be involved in health disasters that result from water pollution, such as high pollutant loads in water courses (e.g., from agriculture or sewage) during periods of extreme low-water flow. The degree of self-purification and the dilutant effect of water frequently are insufficient to ensure adequate buffer effects. In addition, the permanent stress on groundwater resources leads to a concentration of pollutants. Contamination of drinking water may suddenly result in disaster.

Although floods, as a rule, produce a sudden onset of disaster with a clearly defined beginning, a shortage of water develops disastrous effects only over longer periods. A drought may thus be called a "silent disaster," and, in this case, it is difficult to determine at what point in time shortages take on the proportions of disaster. Extremely long drought periods, possibly intensified by human activities, may cause the desertification of a region, which, in contrast to drought, will produce irreversible damage.

7.1 Forms and causes of flood disasters

Natural disasters caused by floods originate, as a rule, under conditions of extreme precipitation (rain, snow). A differentiation between locally concentrated, excessive rain of short duration and high intensity, longer-lasting, extreme precipitation over large areas is necessary. In the former case, precipitation results in flood waves that are confined to single river basins, thus leading to local disasters. Sometimes, these floods are accompanied and intensified by landslides triggered by precipitation. Frontal extreme precipitation leads to rainfall over a large area and long, persistent flood waves, which develop gradually and, by superposition of floods from tributary sources, bring about large-scale disaster

The foregoing climatic factors influencing flood disasters are governed by process dynamics of great intensity. Thus, the question of anthropogenic influences on climate gains special importance. However, quantification of definite trends for future development may not yet be possible

Additional anthropogenic influences are evoked by technical structures which make it impossible to avoid all residual risks. Levees and dams, in the case of structural failure during extraordinary flows, may intensify a natural disaster. Apart from the potential anthropogenic influences already mentioned, there are additional causal connections between human interference in the balance of nature and the increased flood-risk potential. The transformation of woodlands into agricultural or settlement areas or the clearing of forests for timber belong to those activities that add to local flood danger. The continuously increasing world population and the urbanization of large regions connected with this increase also increase potential flood damage. The urbanization of more and more regions affects the flow regime by increasing impermeable areas, thus contributing to runoff and floodwave acceleration. Frequently, natural retention areas are lost as a result of settlement or flood-preventive canalization, thereby producing the risk of flood crests.

7.2 Quantification of risk potential

Worldwide, floods have the greatest damage potential. Even comparatively minor natural events may induce major damage because of a concentration of property in flood-prone regions.

Knowledge of damage potential is fundamental in planning protection measures. Quantification is based on damage functions that provide information—depending on use, region, or load—on the maximum damage to be expected during an extreme event. For damage assessment, land-use catalogues are needed that allow classification of localized areas of the regions under investigation.

The necessary instruments for the assessment of damage potential and the quantification of flood discharge constitute methods of differing complexity These methods range from simple regression or black-box methods to spatially and temporally high-resolution simulations and forecast models. Damage analysis is aimed at the determination of widely standardized damage functions by investigating as many damage scenarios as possible.

Based on data from historical events, land-use-dependent damage functions may be deduced. The final determination of flood damage, as a function of the assumed hydrologic and hydraulic design loads, can be carried out for different regions and varying scenarios through use of computer models.

7.3 Reduction of risk potential

Methods used to reduce risk potential include planning, structural, engineering, and statutory acts. These acts constitute measures aimed at protection and minimization of damage in the event that disaster occurs.

The application of active warning, protection, and safety measures requires advance warning systems that permit the forecasting of flood disasters well ahead of time. Because the meteorological factors used to determine runoff are highly stochastic processes, the possibilities for forecasting are quite restricted. In hydrology and water resources planning, however, there are well-tested methods to simulate processes in river basins using mathematical models. Based on these deterministic rainfall-runoff models, forecasts of future runoff can be made, ranging, according to the chosen approach, from short-term via medium- to long-term forecasts. Other than in the geosciences, the term *forecast* in the hydrosciences is used for estimates of the temporal and spatial size of an event that is ongoing or anticipated. In forecasting the progress of an extreme flood event that is already happening, the crucial factor is the determination of the future development of precipitation, together with the modeling of the system in question. For this purpose, stochastic precipitation forecasts, as well as radar measurements of precipitation for large-scale observations, may be applied. A flood-forecast system has to work operationally (i.e., present information on the state of the river basin will be transferred on-line to the runoff model, thus providing the basis for a continuously updated forecast). For some regions, such a runoff-forecast system already exists. As a measure for reducing damage potential, these systems should be combined with warning systems, which are aimed at launching response activities and the realization of already developed scenarios for action in case of disaster.

Forecast systems must be supplemented by control strategies for existing flood retention basins. Regulating discharge from these basins permits maximum advantage to be taken of the available storage capacity, taking into account the present and forecasted flow. The specification of flood plains and the introduction of restrictions in flood-prone areas (building and use prohibition) may prevent further increase of existing flood potential.

In the design of flood protection structures, standardized design values are useful (extreme values of precipitation and discharge). Currently, methods for the determination of probable maximum precipitation and extreme discharge values are to be evaluated in Germany by a committee of the Deutsche Verband für Wasserwirtschaft und Kulturbau (DVWK, German Association for Water Resources and Land Improvement). This evaluation will serve as a basis from which the above mentioned goals can be achieved. Prediction models also may be applied to the reduction of damage potential as a result of latent low-water or groundwater disasters. However, modified boundary conditions are necessary.

7.4 Prevention of disasters

Possibilities for preventing disasters are, first of all, the numerous flood-protection measures. Structural measures include: central or decentral construction of flood retention basins; building of dams, weirs, and levees, flood-safe lining of water courses; and activation of natural retention areas. Crucial to the effectiveness of these protection works are permanent inspection and control. In the future, decentralized measures will become more and more important in controlling the generation of floods at their sources. Apart from structural measures and flood management, the legal establishment of flood plains offers another possibility for the mitigation of disastrous flooding. Measures for improving controlled surface infiltration of rainwater in urban areas lead to the same goal.

The latent disaster potential connected with low water or groundwater may be responded to with groundwater management and measures to support groundwater recharge

7.5 Disaster management

The establishment of an efficient disaster management system presupposes an optimal exchange of information and communication between the institutions involved in disaster management. Deficits are evident worldwide in both communication and the allocation of competences

Forecasting systems, if operationally available, are regarded as a part of disaster management. Disaster management is characterized by the necessity to make decisions when time is pressing and knowledge of consequent effects is still (at some level) insufficient. Therefore, it is advisable to develop specific disaster scenarios beforehand and to practice them in advance.This can be done by simulation, using the same models as that used in water resources management. Possible instruments to meet the demands for an interdisciplinary approach to the respective disaster management are *knowledge-based decision support systems*. Through actual employment of knowledge-based systems in disaster management, it is possible to analyze the system interactions for flood-prone regions and to test the mechanisms of different strategies of action during exercises and during a disaster. These techniques can give the people involved (disaster staff) the opportunity to rehearse and realistically simulate different disaster scenarios, especially interaction with the people affected (population). Additionally, such systems provide valuable experience in selecting the best probable approach during a disaster

7.6 Marine risk potential

The considerable hazards for environment and civilization emanating from the ocean can be attributed to natural and anthropogenic causes. The natural hazard potential comprises secular changes in the sea level, fluctuation of the atmospheric-oceanic circulation system (El Niño), storm surges, and tsunamis. The anthropogenic hazard potential emerges from the intensification of natural hazards by anthropogenic changes of climate and pollution of the marine ecological environment

7.6.1 Natural risks

Secular changes in the sea level occur as a consequence of long, periodic changes of climate (e.g , in ice-age rhythm) and tectonic or isostatic movements of the Earth's crust. Climate-induced sea-level changes are caused primarily by the thermal expansion of sea water (largest natural increments are on the order of 2 m per century) and by the melting or growth of glaciers and the polar ice-caps. Present-day levees would have difficulty in coping with a 1-m increase in sea level

A peculiarity of the Pacific Ocean, and a further hazard source, is the El Niño phenomenon. The El Niño is manifested by a large-scale change in atmospheric and oceanic circulation connected with anomalies of temperature and salt concentration, which lead, together with other factors, to a collapse in primary bio-production in the South American offshore regions. The generating mechanism of this (more or less) periodic anomaly of the climatic system of the Pacific is not fully understood; forecast and protection measures are not yet possible.

Storm surges must be viewed worldwide as the largest acute danger for people living along the coasts. These surges are caused by stochastically distributed excessive winds The generating mechanism, mode of release, and duration of storm surges are quite different in higher latitudes than in tropical regions. They particularly endanger low-lying coastal regions such as Bangladesh and the North Sea coast lines of the Netherlands and neighboring countries

In addition to storm surges, the coasts of the northern Pacific particularly are threatened by tsunamis. Tsunamis are long, gravitational waves mostly induced by submarine earthquakes. Only dikes can provide protection against tsunamis and storm surges, but early warning systems are of great importance.

7.6.2 Man-made risks

The very probable warming of the Earth's atmosphere, induced by the greenhouse effect, can lead to a sea-level rise of approximately 1 m in 100 years. Low-lying regions, such as the German-Dutch coast or Bangladesh, are especially threatened. Because all measures to counter the greenhouse effect produce only long-term results (if any at all), short- and medium-term adjustment of coastal protection is necessary.

By now, the effect of pollutants and nutrients (e.g., heavy metals, radionuclides, petroleum) on the marine ecological environment has reached, via rivers and the adjacent seas into which they flow, the open ocean. Seaweed blooms, oxygen deficits, or large-scale animal mortality occur more and more frequently and provide unmistakable warning signals. Oil catastrophes of hitherto unknown proportions (Persian Gulf, Prince-William-Sound) add to the situation, so that climate change can only serve to deteriorate the present conditions still further.

Pollutant monitoring, including computer-assisted warning systems, may have short-term influence on reducing the hazard potential. In the long run, preventive legislation and international conventions (e.g., *Conference on the Protection of the North Sea*) are indispensable for protecting the oceans.

7.7 Droughts

Disasters induced by droughts show their effects mainly through famines. They are of increasing importance to social groups and regions vulnerable to this phenomenon. However, famines can be prevented or mitigated through social and technical development. The primary future goal will be to reduce the vulnerability of societies to famine and to provide the basis for social and economic security.

The various phases characteristic for the generation of a famine can be summarized as follows. During the first phase, a *baseline vulnerability* to famine becomes distinguishable. The reasons for this are socio-economic, political, and/or demographic instabilities relating to the environment and resources. The supply system is unstable. The second phase sets in when, proceeding from this baseline vulnerability, a lessening of food supply and thus a state of *current vulnerability* can occur. A drought may then trigger the third phase, namely that of a *famine crisis*. In the event that the situation worsens, the system trends toward a point where the famine disaster starts if the situation does not improve. Knowledge of this drought-famine relationship is necessary if the potential of the respective society for self-help is to be improved.

Arid zones, semiarid or semihumid regions, and arid/semiarid alpine regions are especially vulnerable to drought. Therefore, research will have to concentrate on these regions. Attention must be paid to the rural region, to the rural-urban interface, and to the metropolitan cores. The central mechanisms of coping with the threat of famine, such as the free market, also are important. In this respect, a differentiation must be made between autonomous activities of the groups concerned and external intervention.

Methodologically, there are three different types of analyses:

- the *longitudinal* analysis concentrates on a vulnerable group and/or a location and/or a food system and covers all phases of the famine process;
- the *cross-section* analysis includes several groups and/or locations and/or food systems, and investigates them, however, only during a particular phase of the famine process;
- *case studies* analyze a specifically vulnerable group, a location, or a food system; or
- a combination of the three types.

7.8 Research needs

7.8.1 Floods

Analysis of disaster generation under changing climatic conditions

- initialization of a priority program for analyzing the generation of extreme precipitation and discharges and for deriving design parameters; and
- participation in national and international projects to study the effects of anthropogenically influenced climatic change.

Coordination of international data collection for specific disaster events

- establishment of a national data pool for disaster- and damage-relevant data,
- preparation of national maps for the determination of zones of similar hazard potentials as a basis for disaster prevention planning; and
- national/international initiative for the standardization of damage assessment methods.

Establishment of a disaster forecast concept

- extension of radar precipitation monitoring and the use of satellite hydrology as a basis for forecasting floods;
- working out practice-relevant methods for short-term, large-scale precipitation forecasts;
- establishment of a national center for operational flood forecasting;
- establishment and installation of a real-time flow forecast system in a test region with high damage potential;
- establishment of a priority research program for the improvement of forecasting techniques; and
- intensification of international exchange of experience in the application of forecasting techniques.

Development of concepts for disaster management

- preparation and coordination of national and international emergency plans;
- preparation of instructions to inform the population of the proper procedures and conduct in the event of flood disaster;
- national coordination of communication and responsibilities of institutions and authorities involved in disaster management;
- development and employment of methods for simulating disasters together with integrated training of action strategies;
- derivation of rules for decision making from the simulation of disasters; and

- intensification of research with respect to knowledge-based systems for supporting a disaster training system.

7.8.2 Marine systems

- prognostic calculation of sea-level change at the coasts;
- quantification of the change of frequency and intensity of storm surges induced by global climate change;
- far-reaching predictions on the effects of protective measures with regard to toxic agents;
- assessment of the future of polluted marine ecosystems under changing climatic conditions, and
- effects of sea pollution in shelf regions on the open ocean.

7.8.3 Droughts

Determination of hazard potential
- for vulnerable groups,
- for vulnerable regions, and
- for vulnerable food systems.

Recognition of imminent famines/development of warning systems
- identification of appropriate indicators under various ecological, demographic, and social conditions; and
- finding adequate solutions after the recognition of imminent famine.

Coping strategies (behavior of population groups confronted with drought risk)
- recognition of short- and long-term coping strategies,
- temporal succession of various coping strategies:
- assessment of factors influencing the vulnerability to starvation/drought;
- guidelines for avoiding the break-down of local coping strategies; and
- suggestions for strengthening drought-resistant structures.

Search for adequate political measures
- reduction of the vulnerability of societies through developmental aid; and
- assessment of success prospects (reduced vulnerability) under prevailing political and economic conditions/pressures.

Resources management in endangered regions
- recognition of causal responsibility for the deterioration of environmental conditions;
- assessment of the influence of land-use on droughts; and
- identification of solutions for avoiding further deterioration of environmental conditions.

8. Storms

The occurrence of disasters induced by windstorms and precipitation events does not depend only on meteorological parameters, but also on underlying technical and social conditions in the respective countries and regions. Factors, such as time of onset of the event, dissemination of warnings, and availability of personnel and technical means, are of significant importance. Therefore, mitigation of the effects of a disaster requires regionally differentiated knowledge on storm hazards A world-wide survey should figure out the events that have caused disasters in the past.

During the last years, the damage potential of storms has reached a new dimension. There are several reasons for this development. Apart from the general increase in population density, industrialization, living standards, etc., more and more hazard regions are being settled and industrialized. In this respect, socially weak groups in particular are existentially threatened by storms and the heavy rainfalls that usually accompanying them. Windproof, flood-resistant, and, at the same time, low-priced structures are badly needed. Wind protection, for instance by plantations, plays an important role. A further rise in disaster potentials may be checked in the long run only by fully applying scientific, engineering, and organizational possibilities of damage prevention. The main prerequisite for providing adequate protection measures is statistical analysis of storm events.

As storm disasters are rare events, statistics of storms and multi-parameter statistics of storms and precipitation often are not sufficient to identify extreme events through observation. A problem with wind statistics is the absence of self-documentation of storms, as is the case, for instance, with flood events. Besides, it is not obvious from the beginning whether to classify disastrous storm events according to the average wind velocity, the peak gust, or the area struck. The damage may not be assumed to be simply proportional to the dynamic pressure. Buildings and trees become vulnerable only above a certain threshold value; thereupon, however, chain reactions may occur, for instance by debris in the air. As a consequence, storm damage does not increase with the square of the wind velocity, but rather with the third to sixth power. Because of the different technical designs of buildings, the interaction of buildings with the atmospheric air flow should be investigated. This should be done by examining different types of atmospheric loads and buildings in wind tunnel studies with respect to an optimal reduction of the vulnerability of a building to wind.

Prediction is possible only in a limited way because of the knowledge gaps in the deterministic description of atmospheric processes and the comprehension of generation processes that lead to strong winds and heavy precipitation Similarly, the frequency of certain types of events also is poorly documented for many regions on Earth.

8.1 Storm events in various wind climates

Damage by wind is caused by the transmission of kinetic energy from the atmosphere to objects and living beings. Potentially disastrous damage may occur anywhere on Earth, yet the frequency of such events differs vastly in the various climatic zones. Two kinds of meteorological basic information are required in order to reduce damage and damage consequences induced by storm events. First, a data base that combines probability of occurrence with intensity of event is needed. Such data may be used to work out land-use recommendations. Then, information is needed for the forecast and warning of individual storm events.

In the following, the most important meteorological processes that may lead to windstorm events are described. "Windstorm" here stands for a strong wind event with wind velocities of more than 15 m/s striking an area larger than 1 km^2 over a time longer then several minutes

8.1.1 Baroclinic storms

Baroclinic storms occur at the mid- and subpolar latitudes. These storms have been investigated scientifically for many years. The theoretical elements for the comprehension of storm cyclones and the data supplied by measuring networks of weather services are starting points for the weather forecast. The description of flow conditions for cyclones in the mid-latitudes is possible through numerical solution of the respective equation systems. However, as shown in numerous studies, only part of the forecasts are of reliable quality because of the multitude of parameters involved, the errors in determining initial and boundary conditions, and the necessity to cut off part of the spatial-temporal continuum for numerical reasons. With regard to the movement of cyclones, inaccuracies in propagation velocity and direction contribute to forecasting errors Additionally, the temporal development of intensity can take a different course than forecast. On average, accuracies of 80-95 percent are achieved in the 24-hour forecast. A possible improvement in describing extreme events through the use of mathematical-numerical models has emerged during the last years by means of scientific investigations of small-scale processes. During these investigations, attention is paid especially to processes connected with clouds and precipitation; on the other hand, the role of surface properties for the spatial-temporal development of cyclones is taken into consideration in detail. Some of these approaches also can be used in ensemble forecasts; they are, however, not yet fully operational.

Buildings are designed, in accordance with common experience, by making certain that the load does not exceed a given resistance. For this, natural loads with a statistical recurrence interval of 50 to 100 years are used. To determine the exactness of statements about threshold values or of the exceedance probability, a good data base is essential Often, the available samples are small and the length of the homogeneous part of the observed record is not sufficient to guarantee the inclusion of a representative number of extreme events. Even in the Central European region, not all wind load values can be regarded as statistically secure. Therefore, the statistic reliability should be investigated for a model region. This requires parameters that influence the statistic reliability (such as accuracy and frequency of measurements) and statements about the minimum length of an observation series for different types of events. An extensive data archive in which the extreme events are recorded in the best possible way also is necessary.

An additional problem is the quality of wind measurements that depends, for instance, on long-term changes in the surroundings. Local influences must be filtered out of the long-term observations of strong wind events. The methods and procedures used for that purpose are based on the description of flow around and over small topographic structures. With that, an areally representative wind velocity value for strong wind events can be determined, and the influence of local conditions can be assessed. Knowledge of the causes of strong winds, statistically processed observations, and the inclusion of local changes in the wind field allow the frequency mapping of damage events for different recurrence periods.

8.1.2 Tropical cyclones

Damage induced by cyclones is a phenomenon primarily of tropical and subtropical coastal regions. These cyclones have relatively large-scale effects and affect about a third of the world population. Damage is caused not only by immediate effects of the wind, but to a high degree is induced by the effects of storm surges and ocean waves directly generated by tropical cyclones. The frequency of such events, however, is far lower than that of storms in mid-latitudes. Even in regions of frequent tropical cyclones, damage-causing wind velocities are observed only in intervals of several years on the average. The observation time needed for reliable statistical assessment is thus considerably longer than that required for achieving a similar quality of statement in mid-latitudes. In addition, the observation density is relatively low in many affected regions. Thus, up to now, a statistical statement about the occurrence of strong wind events for a certain region is possible only with limited reliability. A comparison with mid-latitude storm frequencies, however, may help to obtain supplementary information for model regions. These results should be compared with the results of other approaches on an international level.

With the help of satellite data, novel types of short-term and other forecast techniques are possible. For that, in the United States, Japan, India, and Australia extensive investigations have already been carried out. The forecast model of the *European Center for Medium-Term Weather Forecasting* should be used to check the forecast quality both for tropical cyclones and for strong wind events in mid-latitudes. This could be done, for instance, by comparisons with other forecasts and through international cooperation between weather services.

8.1.3 Convective storms and tornadoes

Convective storms are generated at unstable thermal stratification (i.e., by the strong vertical ana- and katabatic winds connected to it). These vertical movements develop in a characteristic way and eventually cause strong winds at the Earth's surface as well. Storm events induced by convective processes, such as descending gusts, hailstorms, or tornadoes, have small-scale effects in comparison to tropical cyclones. In most cases, they extend across areas of only 10 to 1,000 km^2. The meteorological preconditions for the generation of tornadoes or tornado-like twisters exist in large parts of the Earth, with the seasonal dependency being very distinct. The high wind velocities pose extremely high demands on the measuring instruments; often the velocities cannot be measured with the existing anemometers. At the present time, it is not possible to compare maximum values of wind velocities measured with different sensors.

8.1.4 Orographic storms

In special orographic situations, density differences are caused by different rates of cooling of the air. The strong winds generated in this way are locally (valleys, valley mouths) and temporally confined. Prevention measures against damage by orographic storms, therefore, may be brought about very effectively.

8.2 Precipitation events in various climates

8.2.1 Rain

In most cases, precipitation in the form of rain produces its disastrous effects only when it accumulates within the surface drainage system. The areal extent of precipitation events in mid-latitudes is determined by two different meteorological processes. On one hand, there are baroclinic cyclones with their interrelated small-scale processes as a whole and, on the other hand, the convective cloud areas and cloud cells embedded into them. Whereas cyclones with their fronts may produce large precipitation quantities in areas from 1,000 to about 100,000 km^2, heavy rain from cloud areas and cloud cells stretches over areas of 10 to 1,000 km^2. The reason for this lies in the different modes of generating the vertical movement. Coordinated efforts to homogenize the existing world-wide precipitation data are still lacking.

8.2.2 Hail

Hail may cause considerable damage because of its mechanical energy. This holds not only for buildings, vehicles, or airplanes, but also for agriculture. Always linked to convective cloud cells, hail events cover areas of about 10 to 1,000 km^2. In some countries, programs of hail protection have been part of damage reduction measures for some time, but they have yet to show any guarantee of success. These programs should, therefore, be further developed on the condition of improved meteorological knowledge about hail generation processes.

8.2.3 Snow

Snowfalls occur regionally and are temporally limited. The induced damage potential is large with regard to the frequency of the event and the size of the concerned region, but smaller than the damage potential of excessive rain. However, damage by major snowfalls is intensified by combination with other meteorological features. Statistically usable data material exists for a number of countries, but in most cases, combined data on the occurrence of snow, wind, and low air temperatures are missing. The uncertainty of snowfall measurements is considerable and may lead to errors of the order of tens of percent. Correction methods that are available for mean values are not yet transferable to extreme events.

Knowledge gained in recent years about small-scale processes at fronts, in cloud areas, and in the atmospheric boundary layer in mid-latitudes allows the modeling of regional and local precipitation processes and the forecasting of events with improved accuracy. The operational employment of the new technical means could, however, be realized only in a few examples. At present, quantitative assessments on the improvement of forecast quality for heavy precipitation and winds are not yet available. Therefore, it is necessary to assess—through coordinated efforts—the potential for increased forecasting accuracy by better incorporation of small-scale processes.

8.3 Joint occurrence of extremes of wind and precipitation

The determination of damage potentials in the form of maps at various scales is aimed at a world-wide comparability of natural hazards. Two principles should be followed in the presentation: first, the description of the generating mechanisms of large wind velocities and, second, the extrapolation from existing empirical data. Figure 8 shows the first attempts in this direction.

An analogous approach can be pursued to determine the maximum possible precipitation. The presentation in map form depends, however, on the evaluation and quantification of the described problems and approaches. For this, data are needed on the occurrence probability of events and the accuracy rate of forecasts.

8.4 Research needs

- installation of measurement facilities (where non-existent) that will not fail even in extreme situations,
- standardization of wind velocity parameters for maximum winds;
- determination of maximum probable gusts and mean values for various climatic zones;
- effects of climatic changes on storm and rain hazards;
- determination of forecast quality with regard to large-scale forecast models for extreme events;
- regional classification of extreme events investigated with the help of various approaches for describing meso- and microscale effects;
- mapping of damage potentials in consideration of local building design and the spatial and temporal intensity distribution of various types of events and scenarios,
- compilation of observed extreme events and comparison with various building codes, in particular, consideration of local building designs;
- review and analysis of traditional building designs with regard to their inherent experience potential, as well as to their examination and possible improvement with the help of recent scientific findings,
- development of methods for reducing the wind load by wind protection plantations and/or structural measures at buildings and education of the concerned population; and
- acceptance of recent, tradition-void developments in the field of low-cost housing (e.g. concept of *geodesic dome*) by the population (information programs).

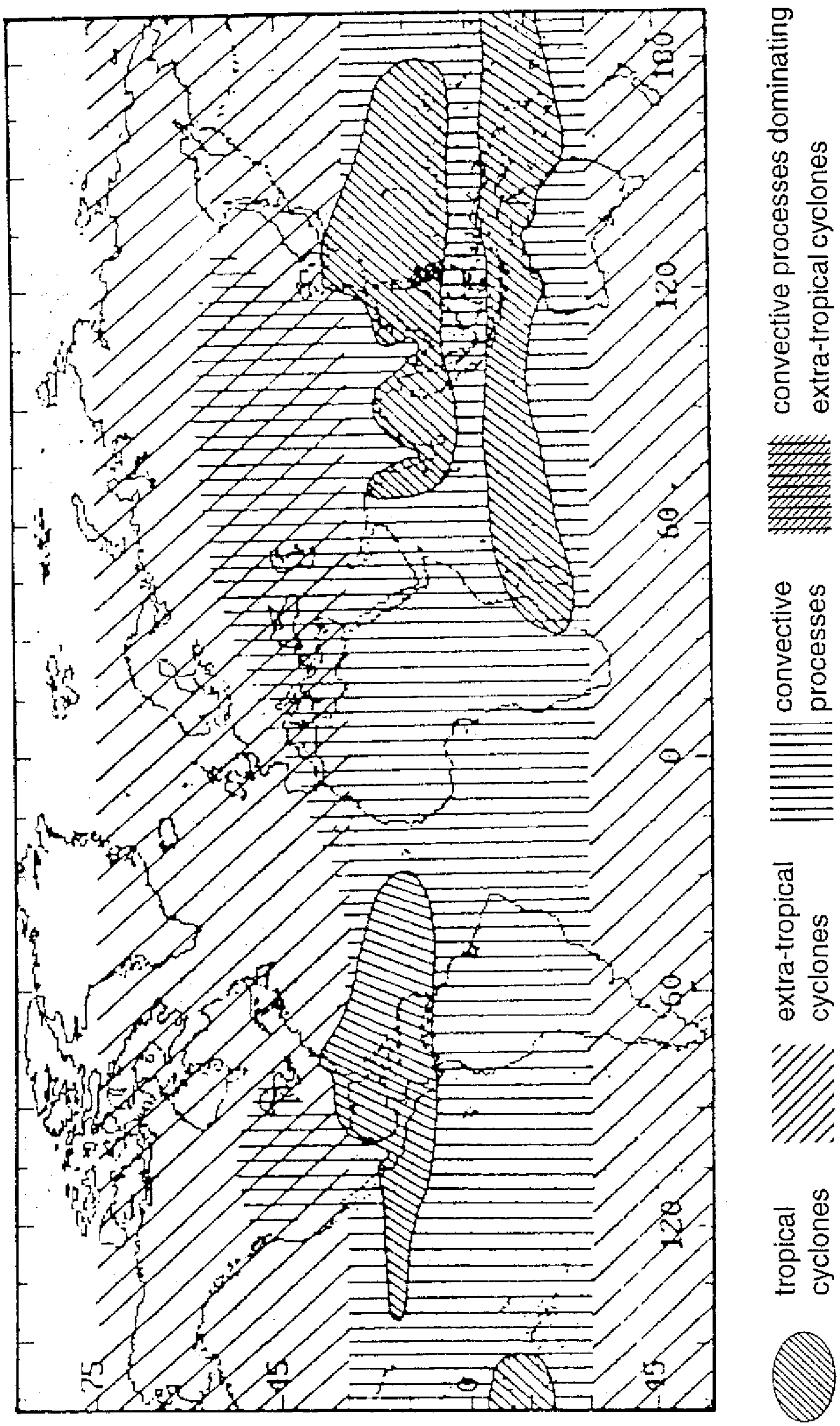


Figure 8: Regionally prevailing formation processes of the 50-year gust (after Wachs)