Disaster, Planning and Development: Managing Natural Hazards to Reduce Loss

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Department of Regional Development and Environment Executive Secretariat for Economic and Social Affairs Organization of American States

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A Contribution to the International Decade for Natural Disaster Reduction

Cover: *Casma, Peru, following the May 31, 1970 earthquake*

This report was produced by the Natural Hazards Project of the Department of Regional Development and Environment with support from the Office of Foreign Disaster Assistance/U.S. Agency for International Development. AID does not necessarily share all the views expressed, but welcomes this publication as a means of encouraging further discussion of natural hazard issues in development planning.

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Preface

Following the El Niño occurrence of 1982-83, the member states of the Organization of American States (OAS) expressed the need for technical cooperation in natural hazard management. In response, the Department of Regional Development and Environment (DRDE) initiated the Natural Hazard Project with support from the Office of Foreign Disaster Assistance (OFDA) of the U.S. Agency for International Development (AID). OAS by that time had been providing services in regional development planning for over twenty years and in 1984 published *Integrated Regional Development Planning: Guidelines and Case Studies from OAS Experience*. In keeping with the principles set forth in that book, the OAS approach incorporates natural hazard management issues into the development planning process.

The services of technical cooperation, training, and technology transfer focus on hazard assessment and mitigation as elements of the processes of environmental assessment, natural resource evaluation, and project formulation. The technical cooperation concentrates on hazard and vulnerability assessments, inclusion of hazard mitigation measures in the formulation of investment projects, use of geographic information systems for mapping and analysis, and urban watershed planning for hazard and resource management. Training includes workshops and formal courses in a variety of aspects of disaster mitigation and integrated development planning. Personnel from virtually every member state have been trained in new hazard management skills. Technology transfer to date has focused on the establishment of emergency information management systems, including provision of equipment and training of personnel. The effectiveness of reducing the impact of disasters by including natural hazard management as an element of development planning has been confirmed by the recipient countries and by other international organizations.

After seven years of field work it is now possible to prepare this synthesis of OAS experience with natural hazards. The material comes with a broad set of objectives, a reflection of the breadth of the issues involved in hazard mitigation. At the policy level, it is hoped that national planning ministries, development agencies, and international financing institutions will be encouraged to systematically include analyses of natural hazards in their economic development programs. Specifically, it is hoped that the experience will persuade:

- development agencies in the member states to incorporate natural hazard considerations into the process of integrated development planning;

- international technical cooperation and financing agencies to incorporate hazard considerations into the formulation of investment projects at the earliest stages;

- governments and financing agencies to place more emphasis on risk awareness in evaluating investment projects, and to assume a stance of risk avoidance rather than risk neutrality; and

- bilateral and multilateral aid donors to re-evaluate the distribution of their disaster assistance funds, increasing the proportion for prevention activities.

At the operational level, it is hoped that development practitioners can be provided with some of the tools for conducting natural hazard assessments and implementing mitigation measures. Among these tools are sectoral vulnerability analyses, mechanisms for incorporating hazard mitigation measures into development strategies and projects, and applications of geographic information systems in hazard management.

To reach both policymakers and practitioners, OAS has prepared complementary documents, each for a distinct audience. The present document, *Disasters, Planning, and Development: Managing Natural Hazards to Reduce Loss*, is directed at policy-level personnel in the member states, international development banks, and technical cooperation agencies. It is divided into two main sections:

- Part I presents general principles for integrating hazard management into development planning and project formulation. Its main intent is to establish two ideas: that the damage caused by natural hazards is great and growing but can be reduced; and that the best way to reduce the impact of natural hazardous events is in the context of integrated development planning.

- Part II is a set of guidelines for applying the methodologies of hazard management. Avoiding excessive detail, it is intended to provide decision-makers with enough orientation for discussing the issue with technical staff, reaching conclusions, and evaluating work accomplished.

A companion document entitled *Primer on Natural Hazard Management in Integrated Regional Development Planning* is directed at planners and other development practitioners and is essentially a technical reference work. It is a compilation and analysis of field experience not available from other sources.

It is hoped that these principles, guidelines, and technical approaches will help planners and decision-makers gain an understanding of the relationship between natural hazard mitigation and the development planning process in Latin America and the Caribbean. These publications come at a time when the region is facing the challenge presented by the International Decade for Natural Disaster Reduction, which was established by the United Nations General Assembly for the 1990s. These documents demonstrate that reducing the impact of natural hazards can only be done by changing the way development takes place. They have been prepared to contribute in some small way to that change.

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The principal compiler-editor was Arthur M. Heyman with the assistance of Beatrice E. Edwards. The principal technical author was Stephen O. Bender. Major contributors to the text were Enrique E. Bello, Jerome V. DeGraff, Morris Deutsch, Ana Lea Florey, Stephen J. Garawecki, Rose Mary García-Spatz, Arthur M. Heyman, William J. Kockelman, Randall Kramer, Stewart P. Nishenko, Richard E. Saunier, Jan C. Vermeiren, and Donald R. Wiesnet. Betty Robinson thoroughly edited the text. Enrique E. Bello, Patricia V. Long, and Claudio R. Volonté prepared the document for publication. The draft text was reviewed by Edward G. Echeverria, Alberto A. Giesecke, José Grases, Barry N. Heyman, William J. Kockelman, Alcira I. Kreimer, Shirley Mattingly, Franklin McDonald, D.D.C. Don Nanjira, and Gilbert White, whose insights and observations were gratefully incorporated. The overall project was under the direction of Stephen O. Bender, chief of the Natural Hazards Project.

Important sources for the book include *Integrated Regional Development Planning: Guidelines and Case Studies from OAS Experience, Primer on Natural Hazard Management in Integrated Regional Development Planning, and Incorporating Natural Hazard Assessment and Mitigation into Project Preparation,* a publication of the Committee of International Development Institutions on the Environment (CIDIE) prepared by the OAS.

Executive summary

The United Nations declared the 1990s the International Decade for Natural Disaster Reduction. The 1990s is also a time when for many developing countries coping with disasters is becoming virtually synonymous with development: the cost of rehabilitation and reconstruction in the wake of disasters is consuming available capital, significantly reducing the resources for new investment.

The toll is appalling. Since 1960 earthquakes, hurricanes, floods, droughts, desertification, and landslides in the Latin American and Caribbean region have killed 180,000 people, disrupted the lives of 100 million more, and caused more than US$54 billion in property damage. Rates of destruction increase decade after decade. The adverse effects on employment, balance of trade, and foreign indebtedness continue to be felt years after the occurrence of a disaster. Activities intended to further development often exacerbate the impact of natural hazards. Worst of all, the poorest countries and the poorest segments of their populations feel the severest impact. International relief and rehabilitation compensates the stricken countries for only a small part of their losses.

The good news is that, of all the global environmental problems, natural hazards present the most manageable of situations: the risks are most readily identified; effective mitigation measures are available; and the benefits of vulnerability reduction may greatly outweigh the costs. Moreover, experience shows that **the impact of natural hazards can be reduced**. Improved warning and evacuation systems have cut the death toll of hurricanes dramatically. Combinations of structural and non-structural mitigation measures have been shown to alleviate the effects of earthquakes, landslides, floods, and droughts.

Yet the countries of the region are slow to undertake actions of vulnerability reduction or to request financing for them, development financing and donor agencies are reluctant to finance them, and most development cooperation agencies provide little service in this subject area. Despite the cost-effectiveness of mitigation measures, more than 90 percent of international funding for natural hazard management in the region is spent on disaster preparedness, relief, rehabilitation, and reconstruction, leaving less than 10 percent for prevention before a disaster.

There are reasons for this seemingly anomalous situation. More important, actions can be taken to change it. This book, a synthesis of the natural hazard experience of the Department of Regional Development and Environment of the Organization of American States (OAS/DRDE), argues that **the most effective approach to reducing the long-term impact of natural hazards is to incorporate natural hazard assessment and mitigation activities into the process of integrated development planning and investment project formulation and implementation.**

The book is directed toward decision-makers in the member states and in development assistance agencies with the hope of influencing them:

- to incorporate natural hazard considerations **early in the process** of integrated development planning and investment project formulation.

- to put a higher value on **risk reduction** in evaluating investment projects.

- to increase the proportion of expenditures for **prevention activities** relative to rehabilitation and reconstruction.

Guidelines for incorporating natural hazard considerations into development planning and project formulation can be summarized as follows:

HAZARD MITIGATION STRATEGIES FOR DEVELOPMENT PLANNING

Natural hazard management is often conducted independently of integrated development planning. It is important to combine the two processes. Of the many components of hazard management, the following techniques are the most compatible with the planning process:

- ***Natural hazard assessment:*** an evaluation of the location, severity, and probable occurrence of a hazardous event in a given time period.

- ***Vulnerability assessment:*** an estimate of the degree of loss or damage that could result from a hazardous event of given severity, including damage to structures, personal injuries, and interruption of economic activities and the normal functions of settlements.

- ***Risk assessment:*** an estimate of the probability of expected loss for a given hazardous event.

Integrated development planning is a multidisciplinary, multisectoral process that includes the establishment of development policies and strategies, the identification of investment project ideas, the preparation of projects, and final project approval, financing, and implementation. The OAS/DRDE version of this project cycle consists of four stages: Preliminary Mission, Phase I (development diagnosis), Phase II (project formulation and preparation of an action plan), and Project Implementation. The development planning and hazard management activities in each of these stages are summarized in the diagram on the next page.

The advantages of incorporating hazard management into development planning include the following:

- Vulnerability reduction measures are more likely to be implemented as part of development projects than as stand-alone mitigation proposals.

- The cost of vulnerability reduction is less when the measure is a feature of the original project formulation than when it is incorporated later.

- The planning community can help set the science and engineering research agenda to focus more on the generation of data suitable for immediate use in hazard mitigation.

- Building vulnerability reduction into development projects benefits the poorest segments of the population.

HAZARD MITIGATION STRATEGIES FOR PROJECT FORMULATION

Examples of **structural measures** that can mitigate the effects of natural hazard events include building codes and materials specifications, retrofitting of existing structures to make them more hazard-resistant, and protective devices such as dikes. **Non-structural measures** concentrate on identifying hazard-prone areas and limiting their use. Examples include land-use zoning, tax incentives, insurance programs, and the relocation of residents away from the path of a hazard. A strong case can be made for emphasizing non-structural mitigation in developing countries, since structural mitigation measures have a direct cost that must be added to the costs of a project. Non-structural measures may have some capital and/or operating costs but these are usually less than structural costs.

Several questions enter into the issue of risk vis-a-vis investment projects:

> ***Should risk be considered in the evaluation of investment projects?*** Governments may argue that they should be indifferent between high-risk and low-risk public sector projects that have the same expected net present value because the risks, being widely shared throughout the society, are negligible to each individual. But this ignores governments' obligation to consider the opportunity cost of each investment. International financing agencies can be indifferent to risk because the country will be obligated to repay the loan whether or not the structure is destroyed by an earthquake. But this ignores the agencies' efforts to inculcate fiscal responsibility. Economic arguments notwithstanding, it simply makes common sense to include natural hazard risk in project evaluation just as the risk of market loss is considered.
>
> ***How should competing project objectives be evaluated?*** This question should be addressed even before the search for project ideas begins. One approach to incorporating societal goals and priorities into the selection of projects is multicriteria analysis. This involves convening a meeting of a cross-section of a society's interest groups to array important social and economic objectives and agree on discriminatory weights for each. Projects can then be evaluated in terms of their capacity to fulfill the stated goals. Reducing vulnerability to natural hazards can be established as one of the goals.
>
> ***How can the conflicting demands of different interest groups for the use of the same natural good or service be resolved?*** This is the classic problem that often goes under the misnomer "environmental impact." A feature of good planning is the identification of potential competition over the use of natural goods and services and seeking resolutions to these conflicts that are reasonably satisfying to all parties.
>
> ***What are objective measures for evaluating natural hazard risk as an element of overall investment project evaluation?*** Two kinds of methods are available: those based on the availability of limited information and those based on probabilistic information. Several techniques in each category are described and the conditions under which each is applicable are noted.

INTEGRATED DEVELOPMENT PLANNING PROCESS, NATURAL HAZARD MANAGEMENT, AND THE PROJECT CYCLE

> Source: OAS. Primer on Natural Hazard Management in Integrated Development Planning (Washington, D.C.: In Press)

STRATEGIES FOR SPECIFIC HAZARDS

How do planners incorporate natural hazards into an integrated study for the development of an area? First, they must determine which hazards, if any, pose a serious threat. Next, they must prepare an assessment of any threatening hazards. Up to now planners have relied largely on existing information because conducting hazard assessments was too costly and time-consuming to fit comfortably into a development planning study. Using techniques developed by the OAS, it is now possible to conduct assessments and introduce hazard mitigation measures in the context of a development study.

Hurricanes

Hurricanes occur in well-defined belts in the Caribbean and on the west coast of Central America. If a study area lies within these belts, the planner can proceed to determine risks and seek mitigation measures. Since storm surge (a rise in sea level due to the low barometric pressure of the storm) is by far the most damaging hurricane hazard, lowland areas close to the sea are the most jeopardized. Storm monitoring and improved warning and evacuation measures are the most effective mechanisms for saving lives. Some low-cost structural mitigation measures can reduce damage (e.g., ensuring that roofs are tied down, covering large glass panels, and removing projections that can easily be blown off). Small towns and villages must depend largely on their own resources to defend against hurricanes.

This requires preparing community leaders and establishing a national program for training and maintaining communication with local personnel.

Desertification

This human-induced hazard is defined as the creation or spread of desert-like conditions beyond desert margins. Desertification occurs in narrowly circumscribed arid or semiarid areas; the text classifies the status of desertification for political subdivisions of South America and Mexico. Development actions that could cause or exacerbate desertification in these areas should be avoided. If a study area is located in one of the areas listed as having desertification potential, a hazard assessment can be prepared quickly using four widely available parameters: precipitation, soil texture, slope, and the ratio of precipitation to evapotranspiration. The technique defines 16 mappable units, each with a set of characteristics that indicate preferred management practices. Once the potential problems are pinpointed, mitigation and rehabilitation measures for animal husbandry, dry-land agriculture, soil erosion, and salinization can be applied.

Geologic hazards

Enough scientific information exists to determine whether earthquakes, volcanic eruptions, or tsunamis constitute a significant threat in virtually any area of Latin America and the Caribbean. It was not readily accessible up to now, but this document assembles the information and puts it into a form suitable for use in planning. Areas that have a high probability of a large earthquake in the next 20 years are listed by political subdivision. All volcanoes that have erupted in Latin America and the Caribbean in the last 10,000 years are categorized as having long-or short-term eruption intervals: any study area within 30 km of a volcano having short-term periodicity must be considered as being under threat of an eruption. Large tsunamis strike only on the west coast of Latin America, and so rarely that mitigation measures can be economically justified only for large urban concentrations. A list of all cities so threatened shows the maximum likely height of a tsunami.

Floods

The existing information is rarely sufficient for evaluating flood potential in a study area, but using remote sensing interpretation, a flood hazard assessment can be prepared that fits the time and budgetary constraints of a development planning study. Such an assessment is useful for designing both new projects and mitigation measures for existing development threatened by floods.

Landslides

As with flooding, the existing information is rarely sufficient for evaluating landslide potential in a study area, but new techniques make rapid analysis of the potential possible. Past landslides can be located on aerial photographs or satellite imagery, and a landslide zonation map can be compiled showing the relationship of landslides to causative factors-bedrock, slope, and moisture conditions.

STRATEGIES FOR SELECTED ECONOMIC SECTORS

Economic sectors such as energy, tourism, agriculture, and transport can benefit from an analysis to determine their vulnerability to natural hazards. Conclusions synthesized from sector vulnerability studies to date include the following:

- Vulnerability reduction measures can be cost-effective, either as stand-alone projects or, more commonly, as components of overall sector development programs.

- Sectoral studies reveal previously unrecognized linkages between disasters and development.

- A sector may have to select between competing objectives to arrive at an acceptable vulnerability reduction strategy.

TOOLS AND TECHNIQUES FOR NATURAL HAZARD ASSESSMENTS

Geographic Information Systems (GIS)

A GIS, a systematic means of geographically referencing information about a unit of space, can facilitate the storage, retrieval, and analysis of data in both map form and tables. It can be a manual system, but most GIS are computerized, as dictated by the overwhelming number of pieces of information needed for natural hazard management, particularly in the context of development planning. A GIS can be surprisingly inexpensive; it can multiply the productivity of a technician; its use can give higher quality results than can be obtained manually regardless of the costs.

Remote Sensing in Natural Hazard Assessments

Remote sensing refers to the process of recording information from sensors mounted either on aircraft or on satellites. These techniques can be used to reveal the location of past occurrences of natural events and/or to identify the conditions under which they are likely to occur, so that areas of potential exposure can be distinguished and applicable mitigation measures can be introduced into the planning process.

The kinds of aerial and satellite remote sensing techniques available for the preparation of natural hazard assessments and the applicability of each to the various stages of a development study are explained.

Special Mapping Techniques

Multiple-hazard maps combine assessments of two or more natural hazards on a single map. Such a product is excellent for analyzing vulnerability and risk since the combined effects of natural phenomena on an area can be determined and mitigation techniques suitable for all can be identified. Critical facilities-transport and communication facilities, utilities, large auditoriums, hospitals, police and fire stations, etc.-must also be mapped as a part of the process of emergency planning. Combining critical facilities mapping with multiple hazard mapping provides information to guide the identification of projects and mitigation measures.

STRATEGIES FOR DEVELOPMENT ASSISTANCE AGENCIES

Activities that **technical cooperation agencies** can undertake to promote natural hazard assessment and mitigation include:

- Strengthening planning institutions' ability to incorporate natural hazard considerations into the planning process.

- Supporting pilot projects of natural hazard assessments.

- During relief and reconstruction efforts in the aftermath of a disaster, stimulating the interest of the government and development assistance agencies in natural hazard assessment and mitigation.

- Building natural hazard assessments into sector planning.

- Including in the preparation and evaluation of investment projects the costs and benefits of incurring vs. avoiding the impacts of natural hazards.

- Preparing case studies of noteworthy experiences that show how funding activities can be made more responsive to natural hazards.

A strategy to promote **lending and donor agency** interest in hazard assessment and mitigation consists of three elements:

- ***Change the context in which the lenders and donors perceive governments and technical cooperation agencies to be addressing natural hazard issues.*** Recipient countries can show their capacity to deal with natural hazards by focusing on priority hazards and sectors; by choosing simple, practical information collection and analysis systems; and by demonstrating a commitment to implementing study findings. Technical cooperation agencies can make study outputs appeal to lenders and donors by seeking practical and cost-effective solutions to recurrent problems and can identify mechanisms of cooperation with financing agencies such as pooling technical resources, exchanging experiences, and joint staff training in natural hazard issues.

- ***Establish incentives for analysis.*** Development financing agencies will be more willing to incorporate natural hazard considerations into project preparation and evaluation if minimum change in existing procedures is required. Ways to promote this include providing reusable information, integrating hazard concerns into existing review mechanisms, promoting proven mitigation measures in relation to specific types of projects, incorporating appropriate costs and benefits of hazard mitigation into economic appraisal, and sensitizing staff members.

- ***Assign accountability for losses.*** Bank directors and staff should be made more aware that projects they help plan or fund may suffer losses from natural disasters. Losses from natural disasters should be evaluated in the context of the lender's program area and its project design and repayment performance. The inclusion of techniques to deal with natural hazards in the professional standards of bank staff should be promoted.

Introduction

Natural hazards, like natural resources, are part of the offering of our natural systems; they can be considered negative resources. In every sense natural hazards are an element of the "environmental problems" currently capturing so much public attention: they alter natural ecosystems, heighten the impact of those ecosystems' degradation, reflect the damage done by humans to their environments, and can affect large human populations.

While virtually every book about natural hazards contains a chronicle of death and destruction, a similar accounting of damage avoided is almost never included. But the effects of the disasters caused by natural hazards can be greatly reduced by action taken in advance to reduce vulnerability to them. Industrialized countries have made progress at reducing the impacts of hurricanes, floods, earthquakes, volcanic eruptions, and landslides. For example, Hurricane Gilbert, the most powerful hurricane ever recorded in the Western Hemisphere, was responsible for 316 fatalities, though less forceful hurricanes killed thousands of people earlier in the century. A combination of zoning restrictions and improved structures together with new prediction, monitoring, warning, and evacuation systems made the difference. Latin American and Caribbean countries have reduced loss of life from some hazards, principally through disaster preparedness and response; they now have the opportunity to reduce economic losses through mitigation in the context of development to a much greater extent than they have to date.

The disasters caused by natural hazards generate a demand for enormous amounts of capital to replace what is destroyed and damaged. The development community should address this issue because it affords, among all environmental issues, the most manageable of situations: the risks are readily identified, mitigation measures are available, and the benefits that accrue from vulnerability reduction actions are high in relation to costs.

THE TOLL

With depressing regularity, natural disasters become international headlines. Each year one or more hurricanes strike the Caribbean region. Particularly destructive ones, such as Gilbert in 1988 and Hugo in 1989, can cause billions of dollars of damage. Flooding, too, occurs annually, but no reliable estimates are available of the cost in human lives and property. Earthquakes and volcanic eruptions occur unpredictably with disastrous effects: the mudslide precipitated by the eruption of Volcán Ruiz in Colombia in 1985 killed 21,800 people, and earthquakes in Mexico (1985) and El Salvador (1986) together killed more than 10,000. Landslides are limited in area, but occur so frequently that they account for hundreds of millions of dollars in damage every year. While not as spectacular, drought can be more harmful to agricultural production than hurricanes. After the 1971 drought, for example, banana production in Saint Lucia did not recover fully until 1976. Disaster aid, however, is scarce in the region for this type of pervasive, slow-onset hazard.

Over the past 30 years the average annual costs of natural disasters to Latin America and the Caribbean were 6,000 lives, adverse effects on 3 million people, and US$1.8 billion in physical damage. Moreover, the impacts are increasing: during the 1960s approximately 10 million people were killed, injured, displaced, or otherwise affected; the number for the 1970s was six times larger, and for the 1980s, three times larger.

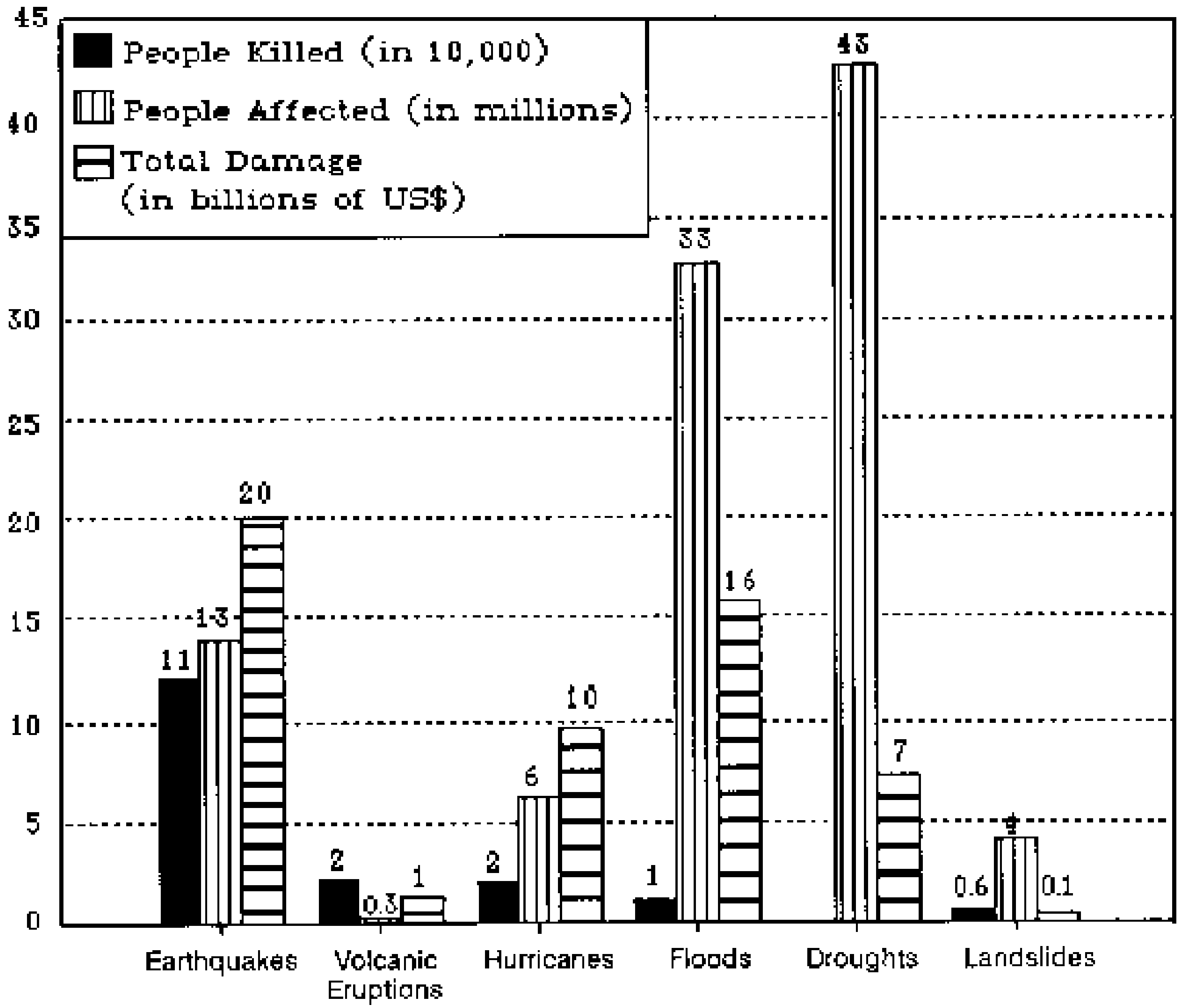
A conservative estimate of the impact of disasters on the region from 1960 to 1989 is given in Figure 1. It can be seen that droughts and floods affect the largest number of people; earthquakes account for the most deaths; and earthquakes, floods, and hurricanes cause the most financial damage. Hurricanes are the most devastating natural hazard in the Caribbean region, earthquakes in the Mexico-Central America region. Floods, droughts, volcanic eruptions, and earthquakes are all very destructive in South America. Figure 2 summarizes the effects of some of the worst recent disasters.

In addition to the direct social and economic impact, natural disasters can affect employment, the balance of trade, and foreign indebtedness for years after their occurrence. After Hurricane Fifi struck Honduras in 1974, for example, employment in agriculture decreased by 70 percent.[1/] Funds intended for development are diverted into costly relief efforts. These indirect but profound economic effects and their drain on the limited funds now available for new investment compound the tragedy of a disaster in a developing country. Furthermore, international relief and rehabilitation assistance has been insufficient to compensate countries for their losses; during the period 1983-1988, reconstruction assistance amounted to only 13 percent of the estimated value of losses.

[1/] World Bank. Memorandum on Recent Economic Development and Prospects of Honduras (Washington, D.C.: World Bank, 1979).

Yet natural hazards appear to generate little constituency for their prevention.

Figure 1 - IMPACT OF NATURAL DISASTERS IN LATIN AMERICA AND THE CARIBBEAN: 1960-1989



Source: Office of Foreign Disaster Assistance/United States Agency for International Development. Disaster History. Significant Data on Major Disasters Worldwide, 1900-Present. July 1989 (Washington, D.C.: USAID/OFDA, 1989).

NATURAL HAZARDS AND DEVELOPMENT

The losses are a concern not only for the countries in which they occur but also for international lending agencies and the private sector which are interested in protecting their loans and investments. The investments are often at risk of both natural hazards and the side effects of development projects that exacerbate these hazards. For example, excessive erosion and siltation reduces the useful life of large multipurpose dams. Many smaller dams in the region also experience this type of damage: accelerated erosion caused by a hurricane filled half the storage capacity of a reservoir in the Dominican Republic virtually overnight. As a result of these concerns, one important lender, the Inter-American Development Bank, is studying the process of evaluating dam projects on the grounds that more realistic methods of estimating life expectancy and cost-benefit ratios will have to be introduced if the problem of erosion and siltation cannot be resolved satisfactorily for any project.

While the development efforts of the past have brought economic advancement to many parts of the world, they have also brought unwise or unsustainable uses of the natural resource base. Indeed, in recent years, the United Nations specialized conferences on the human environment, desertification, water management, deforestation, and human settlements all point to environmental degradation brought about by development, and the corresponding reduction in the capacity of an ecosystem to mitigate natural hazards.

Nevertheless, development agencies often continue to operate as though their activities and natural disasters were separate issues. As Gunnar Hagman points out in *Prevention Better than Cure:*

> When a disaster has occurred, development agencies have regarded it as a nuisance and tried to avoid becoming involved; or even worse, the risk of existing or new potential hazards has been over-looked in the planning and implementation of some development activities, it is now being observed that intensive development may be the cause of many new disasters in poor countries.[2/]

> [2/] Hagman, G. Prevention Better than Cure (Stockholm, Sweden: Swedish Red Cross, 1984).

Figure 2 - LATIN AMERICA AND THE CARIBBEAN: SELECTED NATURAL HAZARD EVENTS (1983-1989)[a/]

Country	Year	Event type	Number of fatalities	Affected population[b/] (thousands)	Economic losses (million US$)	International assistance[c/] (million US$)
Antigua & Barbuda	83	Drought	0	75.0	- -	0.44
Argentina	83	Floods	0	5,580.0	1,000.0	1.74
Bolivia	83	Floods	250	50.0	48.4	1.85
	83	Drought	0	1,583.0	417.2	71.41
	84	Drought	0	1,500.0	500.0	0.53
Brazil	83	Floods	143	3,330.0	12.0	0.18
	83	Drought	0	20,000.0	- -	9.48
	84	Floods	27	250.0	1,000.0	0.10
	85	Floods	100	600.0	200.0	- -
	88	Floods	289	58.6	1,000.0	0.65
Chile	85	Earthquake	180	980.0	1,500.0	9.98
Colombia	83	Earthquake	250	35.0	410.9	3.76
	85	Volcano	21,800	7.7	1,000.0	22.65

	88	Hurricane Joan	26	100.0	50.0	- -
Ecuador	83	Floods	307	700.0	232.1	12.68
	87	Earthquake	300	150.0	- -	11.30
El Salvador	86	Earthquake	1,100	500.0	1,030.0	308.68
Eastern Caribbean Islands[d/]	89	Hurricane Hugo	21	50.0	- -	11.67
Haiti	88	Hurricane Gilbert	54	870.0	91.3	3.32
Jamaica	86	Floods	54	40.0	76.0	3.41
	88	Hurricane Gilbert	49	810.0	1,000.0	102.41
Mexico	85	Earthquake	8,776	100.0	4,000.0	21.70
Nicaragua	88	Hurricane Joan	120	300.0	400.0	- -
Paraguay	83	Floods	0	100.0	82.0	0.56
Peru	83	Floods	364	700.0	988.8	83.81
	83	Drought	0	620.0	151.8	18.05
Venezuela	87	Landslide	96	15.0	0.8	0.03

[a/] Information for all columns but International assistance was obtained from the United States Agency for International Development/Office of Foreign Disaster, Disaster History, Significant Data on Major Disasters Worldwide, 1900-Present, August 1990 (Washington, D.C.: USAID/OFDA, 1990). Damage estimates may be preliminary and therefore, other sources may show different figures.

[b/] Excluding fatalities.

[c/] Information obtained from United States Agency for International Development/Office of Foreign Disaster Assistance, OFDA Annual Report FY 1983, 1984, 1985, 1986, 1987, 1988, and 1989 (Washington, D.C.: USAID/OFDA, 1983-1989). Disaster assistance figures do not include contributions from international reconstruction loans and grants.

[d/] Information obtained from a preliminary report from the United States Agency for International Development/Office of Foreign Disaster Assistance (USAID/OFDA), "After-Action Report of the Hurricane Hugo OFDA Disaster Relief Team" (Washington, DC: OFDA, 1990).

- - Information not available.

Until quite recently, in fact, many practitioners believed that development efforts themselves would spontaneously provide solutions to problems posed by natural hazards. In 1972 the United Nations Conference on the Human Environment in Stockholm declared:

> Environmental deficiencies generated by the conditions of underdevelopment and natural disasters pose grave problems and can best be remedied by accelerated development through the transfer of financial and technological assistance as a supplement to the domestic effort of the developing countries.

In the intervening eighteen years enormous amounts of financial aid and sustained technical assistance have been provided, but far from reducing the effects of natural disasters, development has contributed to disaster vulnerability in areas where the presence of hazards was not properly assessed.

While the link between natural disasters and development has been demonstrated repeatedly, governments and lending agencies do not yet systematically integrate the consideration of natural hazards into project preparation. Past losses and the vulnerability of infrastructure have reached such levels that in some areas development assistance consists almost entirely of disaster relief and rehabilitation. When loan proceeds are routinely programmed for reconstruction, little remains for investment in new infrastructure or economic production. Thus, recurrent disaster relief and reconstruction needs have brought about a reassessment of economic development programs in Bolivia, Colombia, Ecuador, El Salvador, Guatemala, Honduras, Nicaragua, Peru, the Paraguay River Basin, and several Caribbean island countries.

There is a growing awareness that natural hazard management is a pivotal issue of development theory and practice. The United Nations has declared the 1990s the "International Decade for Natural Disaster Reduction" (IDNDR) and calls on developing countries to participate actively in reducing disaster vulnerability. The OAS has endorsed the IDNDR and made natural hazard management a priority technical assistance area.

PREVENTION VERSUS RECONSTRUCTION

A key element to be addressed in this decade is the distribution of resources between disaster prevention and post-disaster efforts. Prevention, which includes structural measures (e.g., making structures more hazard-resistant) and non-structural measures (e.g., land-use restrictions), is a cost-effective means of reducing the toll on life and property. Post-disaster relief and reconstruction measures are important for humanitarian reasons, and may include improvements that are designed to prevent or mitigate future disasters. This is increasingly the case in projects funded by development financing organizations. Nevertheless, post-disaster measures are disproportionately costly for each life saved and each building reconstructed. Moreover, preventive measures in developing countries can reduce the human tragedy and the incalculable costs of lost jobs and production associated with natural disasters.

It is useful in this regard to distinguish between hazard management and disaster management. Both include the complete array of pre-event and post-event measures, but they differ in their focus. Disaster management is concerned with specific events that destroy lives and property to such an extent that international assistance is often needed. Hazard management addresses the potentially detrimental effects of all natural hazardous events, whether or not they result in a disaster; it is the more inclusive of the two terms, seeking to incorporate consideration of natural hazards in all development actions, regardless of the severity of the impact. It thus concentrates more on the analysis of hazards, the assessment of the risk they present, and the prevention and mitigation of their impact, while disaster management tends to concentrate more on preparedness, alert, rescue, relief, rehabilitation, and reconstruction.

Despite the clear economic and humanitarian advantages of prevention, it is relief and reconstruction measures that typically enjoy political appeal and financial support. Donor nations quickly offer sophisticated equipment and highly trained personnel for search and rescue missions. Politicians of a stricken nation gain more support from consoling disaster victims than from requesting taxes for the undramatic measures that would have avoided the disaster. Short-term efforts to address immediate needs usually take precedence over long-term disaster recovery and prevention activities, particularly given the visibility attached to the relief phase of disaster by the mass media. It is not surprising, therefore, to find that of all funds spent on natural hazard management in the region, more than 90 percent goes to saving lives during disasters and replacing lost investment; less than 10 percent goes to prevention before disasters.

The situation is similar with respect to science and technology. Increasingly, investment is directed toward prediction, monitoring, and alert technologies as opposed to basic information on the location, severity, and probability of events-the data that provide the basis for prevention measures. A sound balance must be sought between obtaining additional scientific information and applying existing information to institute mitigation measures resting chiefly on economic and political organization and process.

THE MESSAGE OF THIS BOOK

From the seven years of experience the Organization of American States through its Department of Regional Development and Environment (OAS/DRDE) has had in assisting its member states with natural hazard management and reduction of vulnerability to natural disasters, several related principles have emerged:

> ***The impact of natural hazards can be reduced.*** The information and methods exist to minimize the effects of even the most sudden and forceful of hazardous events and prevent them from causing a disaster. While in some cases the event itself cannot be avoided, construction measures and location decisions can save lives and prevent damage. In other cases, such as flooding, the integration of hazard mitigation measures into development planning and investment projects may make it possible to avoid the event altogether.
>
> ***Hazard mitigation pays high social and economic dividends in a region with a history of natural disasters.*** Mitigation measures should be seen as a basic investment, fundamental to all development projects in high-risk areas, and not as a luxury that may or may not be affordable. The vulnerability of many areas of Latin America and the Caribbean to hurricanes, earthquakes, volcanic eruptions, flooding, or drought is widely recognized. Planners should not ask themselves whether these events will occur, but what may happen when they do.
>
> ***Hazard management is most effective in the context of integrated development planning.*** Traditional single-sector planning cannot maximize the benefits of mitigation techniques and may, in fact, increase the risk exposure of people and their property. Because the traditional development project often represents an isolated intervention into complex and long-standing natural and socioeconomic processes, an advance in one sector may not be accompanied by needed change in another. When natural events subsequently exert pressure, the fruits of the project may be lost to a disaster caused by the deterioration of the natural and human environment related, in turn, to the project itself.

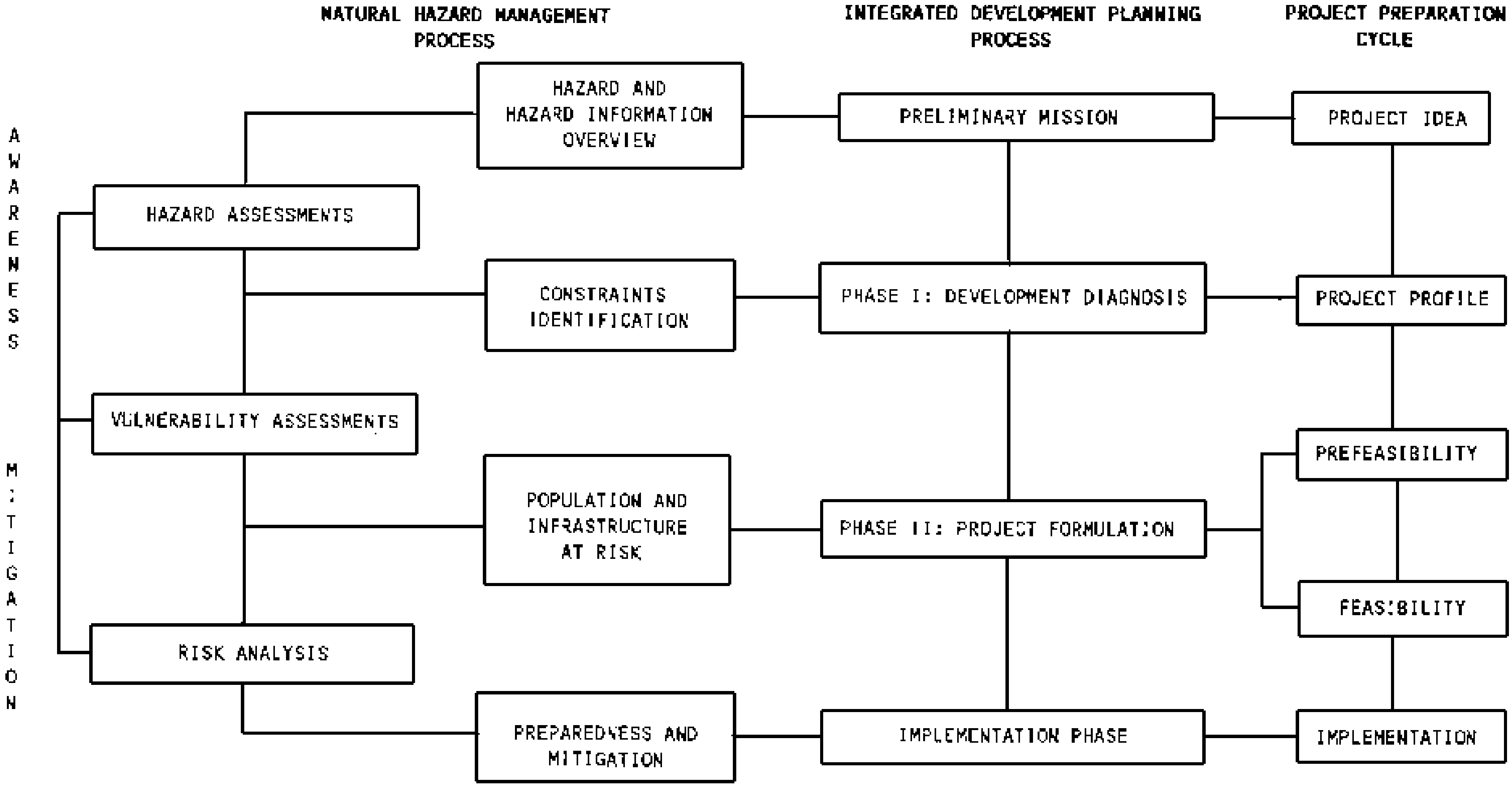
Integrated development planning, in contrast, means a multisectoral approach. It accounts both for a change in associated sectors that share a defined physical space and for the changing relationships between sectors as the result of an intervention. Underlying the integrated approach is the assumption that change is organic and that an initiative in one sector affects the region as a whole. In its development work the OAS applies this philosophy by preparing packages of interrelated projects that reflect a balance between investment in infrastructure, productive activities, service provision, and resource management.

Natural hazard considerations should be introduced at the earliest possible stage in the development process. If a site lies in a fault zone subject to earthquakes, that should be known before it is planned for urban development. If an area considered for an irrigation project is subject to flooding, that should be taken into consideration in the formulation of the project. As natural hazard risk is identified earlier in the planning process, fewer undesirable projects will be carried forward simply on their own momentum. Mitigation measures should be introduced early, and non-structural mitigation, the most cost-effective mechanism, requires particularly early recognition of the need for land-use restrictions. Like an environmental impact statement conducted on a project already formulated, an after-the-fact natural hazard evaluation has much less value than an evaluation conducted in time to influence the original formulation of the project.

One of the roles of development assistance agencies such as the OAS is the identification and preliminary formulation of investment projects which later may be funded by international lending agencies for more advanced study and implementation. It is important that development assistance agencies incorporate hazard considerations into their part of the development process since it becomes progressively more difficult to do so in later stages.

Use Common Sense. People know the kinds of hazards that occur in their home areas. They may not know how to quantify these dangers or the best ways to mitigate them, but they understand something must be done about them.

This book is a guide to natural hazard management in the context of integrated development planning based on the accumulated experience of the OAS. It is in no sense comprehensive, but rather is confined to the experiences of the recent past in development planning in this hemisphere. Readers should also be aware that it focuses on broad strategies and methodologies, rather than specific instructions for all possible particular cases. But it is about what has proved useful in actual field work.


NATURAL HAZARD MANAGEMENT PROCESS
INTEGRATED DEVELOPMENT PLANNING PROCESS
PROJECT PREPARATION CYCLE
AWARENESS
MITIGATION
HAZARD AND HAZARD INFORMATION OVERVIEW
PRELIMINARY MISSION
PROJECT IDEA
HAZARD ASSESSMENTS
CONSTRAINTS IDENTIFICATION
PHASE I: DEVELOPMENT DIAGNOSIS
PROJECT PROFILE
VULNERABILITY ASSESSMENTS
PREFEASIBILITY
POPULATION AND INFRASTRUCTURE AT RISK
PHASE II: PROJECT FORMULATION
FEASIBILITY
RISK ANALYSIS
PREPAREDNESS AND MITIGATION
IMPLEMENTATION PHASE
IMPLEMENTATION

What are natural hazards?

A widely accepted definition characterizes natural hazards as "those elements of the physical environment, harmful to man and caused by forces extraneous to him."[1/] More specifically, in this document, the term "natural hazard" refers to all atmospheric, hydrologic, geologic (especially seismic and volcanic), and wildfire phenomena that, because of their location, severity, and frequency, have the potential to affect humans, their structures, or their activities adversely. The qualifier "natural" eliminates such exclusively manmade phenomena as war, pollution, and chemical contamination. Hazards to human beings not necessarily related to the physical environment, such as infectious disease, are also excluded from consideration here. Figure 3 presents a simplified list of natural hazards, and the boxes on the following pages briefly summarize the nature of geologic hazards, flooding, tsunamis, hurricanes, and hazards in arid and semi-arid areas.

[1/] Burton, I., Robert W. Kates and Gilbert F. White. The Environment as Hazard (New York: Oxford University Press, 1978).

1. How natural are natural hazards?

Notwithstanding the term "natural," a natural hazard has an element of human involvement. A **physical event**, such as a volcanic eruption, that does not affect human beings is a **natural phenomenon** but not a natural hazard. A natural phenomenon that occurs in a populated area is a **hazardous event**. A hazardous event that causes unacceptably large numbers of fatalities and/or overwhelming property damage is a **natural disaster**. In areas where there are no human interests, natural phenomena do not constitute hazards nor do they result in disasters. This definition is thus at odds with the perception of natural hazards as unavoidable havoc wreaked by the unrestrained forces of nature. It shifts the burden of cause from purely natural processes to the concurrent presence of human activities and natural events.

Although humans can do little or nothing to change the incidence or intensity of most natural phenomena, they have an important role to play in ensuring that natural events are not converted into disasters by their own actions. It is important to understand that **human intervention can increase the frequency and severity of natural hazards**. For example, when the toe of a landslide is removed to make room for a settlement, the earth can move again and bury the settlement. **Human intervention may also cause natural hazards where none existed before.** Volcanoes erupt periodically, but it is not until the rich soils formed on their ejecta are occupied by farms and human settlements that they are considered hazardous. Finally, **human intervention reduces the mitigating effect of natural**

ecosystems. Destruction of coral reefs, which removes the shore's first line of defense against ocean currents and storm surges, is a clear example of an intervention that diminishes the ability of an ecosystem to protect itself. An extreme case of destructive human intervention into an ecosystem is desertification, which, by its very definition, is a human-induced "natural" hazard.

Figure 3 - POTENTIALLY HAZARDOUS NATURAL PHENOMENA

ATMOSPHERIC

Hailstorms
Hurricanes
Lightning
Tornadoes
Tropical storms

SEISMIC

Fault ruptures
Ground shaking
Lateral spreading
Liquefaction
Tsunamis
Seiches

OTHER GEOLOGIC/HYDROLOGIC

Debris avalanches
Expansive soils
Landslides
Rock falls
Submarine slides
Subsidence

HYDROLOGIC

Coastal flooding
Desertification
Salinization
Drought
Erosion and sedimentation
River flooding
Storm surges

VOLCANIC

Tephra (ash, cinders, lapilli)
Gases
Lava flows
Mudflows
Projectiles and lateral blasts
Pyroclastic flows

WILDFIRE

- Brush
- Forest
- Grass
- Savannah

Earthquakes

Earthquakes are caused by the sudden release of slowly accumulated strain energy along a fault in the earth's crust. Earthquakes and volcanoes occur most commonly at the collision zone between tectonic plates. Earthquakes represent a particularly severe threat due to the irregular time intervals between events, lack of adequate forecasting, and the hazards associated with these:

- Ground shaking is a direct hazard to any structure located near the earthquake's center. Structural failure takes many human lives in densely populated areas.

- Faulting, or breaches of the surface material, occurs as the separation of bedrock along lines of weakness.

- Landslides occur because of ground shaking in areas having relatively steep topography and poor slope stability.

- Liquefaction of gently sloping unconsolidated material can be triggered by ground shaking. Flows and lateral spreads (liquefaction phenomena) are among the most destructive geologic hazards.

- Subsidence or surface depressions result from the settling of loose or unconsolidated sediment. Subsidence occurs in waterlogged soils, fill, alluvium, and other materials that are prone to settle.

- Tsunamis or seismic sea waves, usually generated by seismic activity under the ocean floor, cause flooding in coastal areas and can affect areas thousands of kilometers from the earthquake center.

Volcanoes

Volcanoes are perforations in the earth's crust through which molten rock and gases escape to the surface. Volcanic hazards stem from two classes of eruptions:

- Explosive eruptions which originate in the rapid dissolution and expansion of gas from the molten rock as it nears the earth's surface. Explosions pose a risk by scattering rock blocks, fragments, and lava at varying distances from the source.

- Effusive eruptions where material flow rather than explosions is the major hazard. Flows vary in nature (mud, ash, lava) and quantity and may originate from multiple sources. Flows are governed by gravity, surrounding topography, and material viscosity.

Hazards associated with volcanic eruptions include lava flows, falling ash and projectiles, mudflows, and toxic gases. Volcanic activity may also trigger other natural hazardous events including local tsunamis, deformation of the landscape, floods when lakes are breached or when streams and rivers are dammed, and tremor-provoked landslides.

Landslides

The term landslide includes slides, falls, and flows of unconsolidated materials. Landslides can be triggered by earthquakes, volcanic eruptions, soil saturated by heavy rains or groundwater rise, and river undercutting. Earthquake shaking of saturated soils creates particularly dangerous conditions. Although landslides are highly localized, they can be particularly hazardous due to their frequency of occurrence. Classes of landslide include:

- Rockfalls, which are characterized by free-falling rocks from overlying cliffs. These often collect at the cliff base in the form of talus slopes which may pose an additional risk.

- Slides and avalanches, a displacement of overburden due to shear failure along a structural feature. If the displacement occurs in surface material without total deformation it is called a slump.

- Flows and lateral spreads, which occur in recent unconsolidated material associated with a shallow water table. Although associated with gentle topography, these liquefaction phenomena can travel significant distances from their origin.

The impact of these events depends on the specific nature of the landslide. Rockfalls are obvious dangers to life and property but, in general, they pose only a localized threat due to their limited areal influence. In contrast, slides, avalanches, flows, and lateral spreads, often having great areal extent, can result in massive loss of lives and property. Mudflows, associated with volcanic eruptions, can travel at great speed from their point of origin and are one of the most destructive volcanic hazards.

Flooding

Two types of flooding can be distinguished: (1) land-borne floods, or river flooding, caused by excessive run-off brought on by heavy rains, and (2) sea-borne floods, or coastal flooding, caused by storm surges, often exacerbated by storm run-off from the upper watershed. Tsunamis are a special type of sea-borne flood.

a. Coastal flooding

Storm surges are an abnormal rise in sea water level associated with hurricanes and other storms at sea. Surges result from strong on-shore winds and/or intense low pressure cells and ocean storms. Water level is controlled by wind, atmospheric pressure, existing astronomical tide, waves and swell, local coastal topography and bathymetry, and the storm's proximity to the coast.

Most often, destruction by storm surge is attributable to:

- Wave impact and the physical shock on objects associated with the passing of the wave front.

- Hydrostatic/dynamic forces and the effects of water lifting and carrying objects. The most significant damage often results from the direct impact of waves on fixed structures. Indirect impacts include flooding and undermining of major infrastructure such as highways and railroads.

Flooding of deltas and other low-lying coastal areas is exacerbated by the influence of tidal action, storm waves, and frequent channel shifts.

b. River flooding

Land-borne floods occur when the capacity of stream channels to conduct water is exceeded and water overflows banks. Floods are natural phenomena, and may be expected to occur at irregular intervals on all stream and rivers. Settlement of floodplain areas is a major cause of flood damage.

Tsunamis

Tsunamis are long-period waves generated by disturbances such as earthquakes, volcanic activity, and undersea landslides. The crests of these waves can exceed heights of 25 meters on reaching shallow water. The unique characteristics of tsunamis (wave lengths commonly exceeding 100 km, deep-ocean velocities of up to 700 km/hour, and small crest heights in deep water) make their detection and monitoring difficult. Characteristics of coastal flooding caused by tsunamis are the same as those of storm surges.

Hurricanes

Hurricanes are tropical depressions which develop into severe storms characterized by winds directed inward in a spiraling pattern toward the center. They are generated over warm ocean water at low latitudes and are particularly dangerous due to their destructive potential, large zone of influence, spontaneous generation, and erratic movement. Phenomena which are associated with hurricanes are:

- Winds exceeding 64 knots (74 mi/hr or 119 km/hr), the definition of hurricane force. Damage results from the wind's direct impact on fixed structures and from wind-borne objects.

- Heavy rainfall which commonly precedes and follows hurricanes for up to several days. The quantity of rainfall is dependent on the amount of moisture in the air, the speed of the hurricane's movement, and its size. On land, heavy rainfall can saturate soils and cause flooding because of excess runoff (land-borne flooding); it can cause landslides because of added weight and lubrication of surface material; and/or it can damage crops by weakening support for the roots.

- Storm surge (explained above), which, especially when combined with high tides, can easily flood low-lying areas that are not protected.

All this is the key to developing effective vulnerability reduction measures: **if human activities can cause or aggravate the destructive effects of natural phenomena, they can also eliminate or reduce them.**

2. The environment, natural hazards, and sustainable development

The work of the OAS/DRDE is focused upon helping countries plan spatial development and prepare compatible investment projects at a prefeasibility level. In a general sense, these tasks may be called "environmental planning"; they consist of diagnosing the needs of an area and identifying the resources available to it, then using this information to formulate an integrated development strategy composed of sectoral investment projects. This process uses methods of systems analysis and conflict management to arrive at an equitable distribution of costs and benefits, and in doing so it links the quality of human life to environmental quality. In the planning work, then, the environment-the structure and function of the ecosystems that surround and support human life-represents the conceptual framework. In the context of economic development, the environment is that composite of goods, services, and constraints offered by surrounding ecosystems. An ecosystem is a coherent set of interlocking relationships between and among living things and their environments. For example, a forest is an ecosystem that offers goods, including trees that provide lumber, fuel, and fruit. The forest may also provide services in the form of water storage and flood control, wildlife habitat, nutrient storage, and recreation. The forest, however, like any physical resource, also has its constraints. It requires a fixed period of time in which to reproduce itself, and it is vulnerable to wildfires and blights. These vulnerabilities, or natural hazards, constrain the development potential of the forest ecosystem.

Hazards in Arid and Semi-Arid Areas

a. Desertification

Desertification, or resource degradation in arid lands that creates desert conditions, results from interrelated and interdependent sets of actions, usually brought on by drought combined with human and animal population pressure. Droughts are prolonged dry periods in natural climatic cycles. The cycles of dry and wet periods pose serious problems for pastoralists and farmers who gamble on these cycles. During wet periods, the sizes of herds are increased and cultivation is extended into drier areas. Later, drought destroys human activities which have been extended beyond the limits of a region's carrying capacity.

Overgrazing is a frequent practice in dry lands and is the single activity that most contributes to desertification. Dry-land farming refers to rain-fed agriculture in semiarid regions where water is the principal factor limiting crop production. Grains and cereals are the most frequently grown crops. The nature of dry-land farming makes it a hazardous practice which can only succeed if special conservation measures such as stubble mulching, summer fallow, strip cropping, and clean tillage are followed. Desertified dry lands in Latin America can usually be attributed to some combination of exploitative land management and natural climate fluctuations.

b. Erosion and Sedimentation

Soil erosion and the resulting sedimentation constitute major natural hazards that produce social and economic losses of great consequence. Erosion occurs in all climatic conditions, but is discussed as an arid zone hazard because together with salinization, it is a major proximate cause of desertification. Erosion by water or wind occurs on any sloping land regardless of its use. Land uses which increase the risk of soil erosion include overgrazing, burning and/or exploitation of forests, certain agricultural practices, roads and trails, and urban development. Soil erosion has three major effects: loss of support and nutrients necessary for plant growth; downstream damage from sediments generated by erosion; and depletion of water storage capacity, because of soil loss and sedimentation of streams and reservoirs, which results in reduced natural stream flow regulation.

Stream and reservoir sedimentation is often the root of many water management problems. Sediment movement and subsequent deposition in reservoirs and river beds reduces the useful lives of water storage reservoirs, aggravates flood water damage, impedes navigation, degrades water quality, damages crops and infrastructure, and results in excessive wear of turbines and pumps.

c. Salinization

Saline water is common in dry regions, and soils derived from chemically weathered marine deposits (such as shale) are often saline. Usually, however, saline soils have received salts transported by water from other locations. Salinization most often occurs on irrigated land as the result of poor water control, and the primary source of salts impacting soils is surface and/or ground water. Salts accumulate because of flooding of low-tying lands, evaporation from depressions having no outlets, and the rise of ground water close to soil surfaces. Salinization results in a decline in soil fertility or even a total loss of land for agricultural purposes. In certain instances, farm land abandoned because of salinity problems may be subjected to water and wind erosion and become desertified.

Inexpensive water usually results in over-watering. In dry regions, salt-bearing ground water is frequently the major water resource. The failure to properly price water from irrigation projects can create a great demand for Such projects and result in misuse of available water, causing waterlogging and salinization.

A survey of environmental constraints, whether focused on urban, rural, or wildland ecosystems, includes (1) the nature and severity of resource degradation; (2) the underlying causes of the degradation, which include the impact of both natural phenomena and human use; and (3) the range of feasible economic, social, institutional, policy, and financial interventions designed to retard or alleviate degradation. In this sense, too, natural hazards must be considered an integral aspect of the development planning process.

Recent development literature sometimes makes a distinction between "environmental projects" and "development projects." "Environmental projects" include objectives such as sanitation, reforestation, and flood control, while "development projects" may focus on potable water supplies, forestry, and irrigation. But the project-by-project approach is clearly an ineffective means of promoting socioeconomic well-being. Development projects, if they are to be sustainable, must incorporate sound environmental management. By definition, this means that they must be designed to improve the quality of life and to protect or restore environmental quality at the same time and must also ensure that resources will not be degraded and that the threat of natural hazards will not be exacerbated. In short, good natural hazard management is good development project management.

Indeed, in high-risk areas, sustainable development is only possible to the degree that development planning decisions, in both the public and private sectors, address the destructive potential of natural hazards. This approach is particularly relevant in post-disaster situations, when tremendous pressures are brought to bear on local, national, and international agencies to replace, frequently on the same site, destroyed facilities. It is at such times that the pressing need for natural hazard and risk assessment information and its incorporation into the development planning process become most evident.

To address hazard management, specific action must be incorporated into the various stages of the integrated development planning study: first, an assessment of the presence and effect of natural events on the goods and services provided by natural resources in the plan area; second, estimates of the potential impact of natural events on development activities, and third, the inclusion of measures to reduce vulnerability in the proposed development activities. Within this framework, "lifeline" networks should be identified: components or critical segments of production facilities, infrastructure, and support systems for human settlements, which should be as nearly invulnerable as possible and be recognized as priority elements for rehabilitation following a disaster.

Reducing the impact of natural hazards

Experiences both in and out of Latin American and the Caribbean show that the record of hazard mitigation is improving. The installation of warning systems in several Caribbean countries has reduced the loss of human life due to hurricanes. Prohibition of permanent settlement in floodplains, enforced by selective insurance coverage, has significantly reduced flood damage in many vulnerable areas.

In the field of landslide mitigation, a study in the State of New York (U.S.A.) showed that improved procedures from 1969 to 1975 reduced the cost of repairing landslide damage to highways by over 90 percent.[2/] Experience of the city of Los Angeles, California, indicates that adequate grading and soil analysis ordinances can reduce landslide losses by 97 percent.[3/]

> [2/] Hays, W.W. (ed.) Facing Geologic and Hydrologic Hazards. Earth-Science Considerations. Geological Survey Professional Paper 1240-B (Washington, D.C.: U.S. Government Printing Office, 1981).
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> [3/] Petak, W.J. and A.A. Atkisson. Natural Hazard Risk Assessment and Public Policy: Anticipating the Unexpected (New York: Springer-Verlag, 1982).

A study in the San Fernando Valley, California, after the 1971 earthquake showed that of 568 older school buildings that did not satisfy the requirements of the Field Act (a law stipulating design standards), 50 were so badly damaged that they had to be demolished. But all of the 500 school buildings that met seismic-resistance standards suffered no structural damage.[4/] The Loma Prieta earthquake in 1989 was the costliest natural disaster in U.S. history, but provisions in local zoning and building codes kept it from being even worse. In the San Francisco Bay area post-1960 structures swayed but stayed intact, while older buildings did not fare nearly as well. Unreinforced masonry structures suffered the worst damage. Buildings on solid ground were less likely to sustain damage than those constructed on landfill or soft mountain slopes.[5/]

> [4/] Bolt, Bruce A. Earthquakes (New York: W.H. Freeman and Company, 1988).
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> [5/] King, John. "In the Wake of the Quake" in Planning, December, 1989 (Chicago, Illinois: APA, 1989).

Mitigation techniques can also lengthen the warning period before a volcanic eruption, making possible the safe evacuation of the population at risk. Sensitive monitoring devices can now detect increasing volcanic activity months in advance of an eruption. Still more sophisticated assessment, monitoring, and alert systems are becoming available for volcanic eruption, hurricane, tsunami, and earthquake hazards.

Sectoral hazard assessments conducted by the OAS of, among others, energy in Costa Rica and agriculture in Ecuador, have demonstrated the savings in capital and continued production that can be realized with very modest investments in the mitigation of natural hazard threats through vulnerability reduction and better sectoral planning.

However, much remains be done. The overall record of hazard management in Latin America and the Caribbean is unimpressive for a number of reasons among them lack of awareness of the issue, lack of political incentive, and a sense of fatalism about "natural" disasters. But techniques are becoming available, experiences are being analyzed and transmitted, the developing countries have demonstrated their interest, and the lending agencies are discussing their support. If these favorable tendencies can be encouraged, significant reduction of the devastating effects of hazards on development in Latin America and the Caribbean is within reach.

Part two: Guidelines for incorporating natural hazard considerations into development planning and project formulation

As has been said, it is the fundamental premise of this document that natural hazards information should be included routinely in development planning and investment project preparation, and that it makes financial and economic sense to build appropriate mitigation measures into investment projects themselves. These efforts, of course, consume financial and technical resources. Therefore, investment project preparation must include a method of estimating the costs and benefits of investing in mitigation measures in order to compare the value of losses that might be caused by natural hazards with the costs of their mitigation. The earlier calculations are made, the better.

The guidelines set forth here synthesize the experience of the OAS in assisting member states to build hazard mitigation measures into development planning and project formulation. The guidelines are divided into the following components:

- Factors that influence susceptibility to vulnerability reduction
- Hazard mitigation strategies for development planning
- Hazard mitigation strategies for investment project formulation
- Strategies for specific hazards
- Strategies for selected economic sectors
- Tools and techniques for natural hazard assessment
- Strategies for development assistance agencies

Susceptibility to vulnerability reduction

1. The nature of the hazard

Rapid Onset vs. Slow Onset

The speed of onset of a hazard is an important variable since it conditions warning time. At one extreme earthquakes, landslides, and flash floods give virtually no warning. Less extreme are tsunamis, which typically have warning periods of minutes or hours, and hurricanes and floods, where the likelihood of occurrence is known for several hours or days in advance. Volcanoes can erupt suddenly and surprisingly, but usually give indications of an eruption weeks or months in advance. (Colombia's Volcán Ruiz gave warnings for more than a year before its destructive eruption in 1985.) Other hazards such as drought, desertification, and subsidence act slowly over a period of months or years. Hazards such as erosion/sedimentation have varying lead times: damage may occur suddenly as the result of a storm or may develop over many years.

Controllable Events vs. Immutable Events

For some types of hazards the actual dimensions of the occurrence may be altered if appropriate measures are taken. For others, no known technology can effectively alter the occurrence itself. For example, channelizing a stream bed can reduce the areal extent of inundations, but nothing will moderate the ground shaking produced by an earthquake.

Frequency vs. Severity

Where flooding occurs every year or every few years, the hazard becomes part of the landscape, and projects are sited and designed with this constraint in mind. Conversely, in an area where a tsunami may strike any time in the next 50 or 100 years, it is difficult to stimulate interest in vulnerability reduction measures even though the damage may be catastrophic. With so long a time horizon, investment in capital intensive measures may not be economically viable. Rare or low-probability events of great severity are the most difficult to mitigate, and vulnerability reduction may demand risk-aversion measures beyond those justified by economic analysis.

Mitigation Measures to Withstand Impact vs. Mitigation Measures to Avoid Impact

Earthquake-resistant construction and floodproofing of buildings are examples of measures that can increase the capacity of facilities to withstand the impact of a natural hazard. Measures such as zoning ordinances, insurance, and tax incentives, which direct uses away from hazard-prone areas, lead to impact avoidance.

2. The nature of the study area

The high density of population and expensive infrastructure of cities makes them more susceptible to the impacts of natural events. Mitigation measures are both more critically needed and more amenable to economic justification than in less-developed areas. Urban areas are likely to have or are able to establish the institutional arrangements necessary for hazard management.

For small towns and villages non-structural mitigation measures may be the only affordable alternative. Such settlements rely on the government to only a limited extent for warning of an impending hazard or assistance in dealing with it. Thus organizing the local community to cope with hazards is a special aspect of hazard management.

The physical characteristics of the land, land-use patterns, susceptibility to particular hazards, income level, and cultural characteristics similarly condition the options of an area in dealing with natural hazards.

3. The participants in the drama

Among the "actors" involved in the process of hazard management are planning agencies, line ministries, emergency preparedness and response centers, the scientific and engineering community, local communities, technical assistance agencies, development finance agencies, and non-governmental organizations, not to mention the equally diverse list of private-sector players. Each has its own interests and approach. These varied and sometimes conflicting viewpoints can add to the constraints of planning and putting into operation a hazard management program, but having advance knowledge of the difficulties each may present can help the practitioner deal with them.

Planning agencies are often unfamiliar with natural hazard information, or how to use it in development planning.

Line ministries similarly have little familiarity with natural hazard information or with the techniques of adapting it for use in planning. Projects for the development of road, energy, telecommunications, irrigation systems, etc. often lack hazard mitigation consideration. Furthermore, ministries tend to have little experience in collaborating with each other to identify the interrelationships between projects or to define common information requirements so that information that suits the needs of many users can be collected cooperatively.

The ***emergency preparedness community*** has tended to view its role exclusively as preparing for and reacting to emergencies and has therefore neglected linking preparedness to long-term mitigation issues. Furthermore, emergency centers have paid insufficient attention to the vulnerability of their own infrastructure. When these lifeline facilities are wiped out, disaster victims have nowhere to turn. Emergency preparedness policies are beginning to change. For example, international emergency relief organizations such as the International League of Red Cross and the Red Crescent Societies have stated that they will devote more effort in developing countries to prevention.

The ***scientific and engineering community*** often sets its agenda for research and monitoring on the basis of its own scientific interests without giving due consideration to the needs of vulnerability reduction or emergency preparedness. For example, a volcano may be selected for monitoring because of its scientific research value rather than its proximity to population centers. Valuable information on hazards is often published in scientific journals in abstruse language. The scientific community should ensure that data are translated into a form suitable for use by hazard management practitioners.

Local communities are jarringly aware of the impact of natural hazards. But they usually have little opportunity to participate in the preparation of large infrastructure and production projects that impinge on them, and even less in setting agendas for natural hazard assessment and vulnerability reduction.

Technical cooperation agencies do not normally include natural hazard assessment and vulnerability reduction activities as a standard part of their project preparation process. "Hazard impact statements" that, like environmental impact statements, are conducted after the project is formulated are not adequate. Hazard considerations must be introduced earlier in the process so that projects are prepared with these constraints in mind.

Development financing agencies engage actively in post-disaster reconstruction measures, yet do not insist on hazard assessment, mitigation, and vulnerability reduction measures in their ordinary (non-disaster-related) development loans, and are reluctant to incorporate such considerations into project evaluation.

Other institutional considerations: Knowledge of and experience with hazard management techniques are rare commodities in most agencies in Latin America and the Caribbean. Thus, if a technical cooperation agency proposes to incorporate these ideas into planning and project formulation, it invariably has to overcome the skepticism of the relevant local personnel. This adds to the cost of formulating a project, but the extra cost can pay high dividends.

Greater consideration should be given to the private sector, as is pointed out by Andrew Natsios in "Disaster Mitigation and Economic Incentives."[1/] Natsios, following George Schultze, claims that policy-makers can change social behavior more effectively by changing the incentives of the marketplace, i.e., the public use of private interest, than by regulation. For example, casualty insurance companies could offer a large premium differential for earthquake- and hurricane-resistant construction. He suggests that governments should specify the desired outcome of policy, but leave the method of achieving that outcome to the economic actors.

> [1/] Natsios, Andrew S. "Disaster Mitigation and Economic Incentives" in Colloquium on the Environment and Natural Disaster Management (Washington, D.C.: The World Bank, June 27-28, 1990).

At the national level, giving a single entity total responsibility for hazard management tends to cause other agencies to see it as an adversary. Instead, each agency that formulates projects as part of its standard activities should appreciate the importance of introducing hazard considerations into the process of project formulation. Planning agencies should take an advocacy position on hazard management and on introducing non-structural mitigation strategies early in the planning process. Such agencies should have personnel trained for these functions.

Similarly, at the project level responsibility for mitigating the impact of natural hazards does not lie with a single individual or component but is an overall responsibility of the project, requiring the cooperation of all components.

Post-disaster reconstruction activities often lack support for hazard assessments intended to ensure that the impact of the next event is less destructive. The problem lies with both the lender and the recipient: the stricken country rarely includes this item in its request, but when it does, the lending agencies often reject it. Reconstruction projects, especially when they are very large, are often managed by newly created implementation agencies. This results in a drain of the already limited supply of technical personnel from the existing agencies and complicates coordination between long-term development and short-term rehabilitation.

Hazard mitigation strategies for development planning

For purposes of this discussion, development planning is considered the process by which governments produce plans to guide economic, social, and spatial development over a period of time. The hazard management process consists of a number of activities carried out before, during, and after a hazardous event in order to reduce loss of life and destruction of property. Natural hazard management has often been conducted independently of development planning. A distinctive feature of OAS technical assistance is the integration of the two processes.

The natural hazard management process can be divided into pre-event measures, actions during and immediately following an event, and post-disaster measures. In approximate chronological order, these are as follows:

1. Pre-event Measures:
    a. Mitigation of Natural Hazards:
        - Data Collection and Analysis
        - Vulnerability Reduction

    b. Preparation for Natural Disasters:
        - Prediction
        - Emergency preparedness (including monitoring, alert, evacuation)
        - Education and Training

2. Measures During and Immediately after Natural Disasters:
    a. Rescue
    b. Relief

3. Post-disaster Measures
    a. Rehabilitation
    b. Reconstruction

Of these, the mitigation mechanisms are most cost effective in reducing loss of life and property and most compatible with the development planning process. The data collection effort refers to data on the hazards themselves, vulnerability, and risk. The mitigation mechanisms are described briefly below.

Natural Hazard Assessments

Studies that assess hazards provide information on the probable location and severity of dangerous natural phenomena and the likelihood of their occurring within a specific time period in a given area. These studies rely heavily on available scientific information, including geologic, geomorphic, and soil maps; climate and hydrological data; and topographic maps, aerial photographs, and satellite imagery. Historical information, both written reports and oral accounts from long-term residents, also helps characterize potential hazardous events. Ideally, a natural hazard assessment promotes an awareness of the issue in a developing region, evaluates the threat of natural hazards, identifies the additional information needed for a definitive evaluation, and recommends appropriate means of obtaining it.

Vulnerability Assessments

Vulnerability studies estimate the degree of loss or damage that would result from the occurrence of a natural phenomenon of given severity. The elements analyzed include human populations; capital facilities and resources such as settlements, lifelines, production facilities, public assembly facilities, and cultural patrimony; and economic activities and the normal functioning of settlements. Vulnerability can be estimated for selected geographic areas, e.g., areas with the greatest development potential or already developed areas in hazardous zones. The techniques employed include lifeline (or critical facilities) mapping and sectoral vulnerability analyses for sectors such as energy, transport, agriculture, tourism, and housing. In Latin America and the Caribbean vulnerability to natural hazards is rarely considered in evaluating an investment even though vulnerability to other risks, such as fluctuating market prices and raw-material costs, is taken into account as standard practice.

Risk Assessments

Information from the analysis of an area's hazards and its vulnerability to them is integrated in an analysis of risk, which is an estimate of the probability of expected loss for a given hazardous event. Formal risk analyses are time-consuming and costly, but shortcut methods are available which give adequate results for project evaluation. Once risks are assessed, planners have the basis for incorporating mitigation measures into the design of investment projects and for comparing project versus no-project costs and benefits.

Vulnerability Reduction

Risk from natural hazards can be substantially reduced by the introduction of mitigation measures, both structural and non-structural. Mitigation measures are discussed in detail in the section Hazard Mitigation Strategies for Project Preparation.

1. Incorporating mitigation measures into an integrated development planning study

Integrated development planning is a multidisciplinary, multisectoral approach to planning. Issues in the relevant economic and social sectors are brought together and analyzed vis-a-vis the needs of the population and the problems and opportunities of the associated natural resource base. A key element of this process is the generation of investment projects, defined as an investment of capital to create assets capable of generating a stream of benefits over time. A project may be independent or part of a package of projects comprising an integrated development effort. The process of generating projects is called the project cycle. This process proceeds from the establishment of development policies and strategies, the identification of project ideas, and the preparation of project profiles through prefeasibility and feasibility analyses (and, for large projects, design studies) to final project approval, financing, implementation, and operation.

While the process is more or less standardized, each agency develops its own version. The development planning process evolved by the OAS Department of Regional Development consists of four stages: Preliminary Mission, Phase I (development diagnosis), Phase II (project formulation and preparation of an action plan), and implementation. Because the process is cyclical, activities relating to more than one stage can take place at the same time. The main elements of the process are shown in Figure 4, and a synthesis of the activities and products of each stage is shown in Figure 5. A comprehensive set of guidelines for executing a study following this process is given in *Regional Development Planning: Guidelines and Case Studies from OAS Experience.*

This presentation of the procedures of an integrated study features the incorporation of hazard management considerations at each stage. The relationships of the integrated development planning process, the hazard management process, and the project cycle are summarized in Figure 6.

Generally, planners depend on the science and engineering community to provide the required information for natural hazard assessments. If the information available is adequate, the planner may decide to make an assessment. If it is not adequate, the planner usually decides that the time and cost of generating more would be excessive, and the assessment is not made. While the information available on hurricanes and geologic hazards is often adequate for a preliminary evaluation, the information on desertification, flooding, and landslide hazards rarely is. The OAS has developed fast, low-cost methodologies that make these evaluations possible in the context of a development study. The differences in treating the various hazards in each stage of the process are highlighted in the following discussion.

Preliminary Mission: Designing the Study

The first step in the process of technical assistance for an integrated development planning study is to send a "preliminary mission" to consult with officials in the interested country. Experience has shown that this joint effort of OAS staff and local planners and decision-makers is frequently the most critical event in the entire study. They take action to:

- Determine whether the study area is affected by one or more natural hazards. For example, the National Environmental Study of Uruguay conducted by the OAS with financial support from the Inter-American Development Bank determined in the preliminary mission that natural hazards were an important environmental problem, and consequently an assessment of all significant hazards, to be conducted by reviewing existing information, was programmed for Phase I.

- Identify the information available for judging the threat posed by those hazards in the study area: history of hazardous events; disaster and damage reports; assessments of hazards, vulnerability, risk; maps and reports on natural resources and hazards; topographic maps, aerial photographs, satellite imagery.

- Determine whether the available data are sufficient to evaluate the threat of hazards. If they are not, determine what additional data collection, hazard assessment, remote sensing, or specialized equipment will be needed for the next stage of the study. For example, in preliminary missions in Dominica, Saint Lucia, and St. Vincent and the Grenadines, landslides were determined to be a serious problem, and landslide assessments were included in the work plan for Phase I.

- Determine whether the studies required would serve more than one sector or project. If so, establish coordination.

- Establish coordination with the national institution responsible for disaster planning.

- Prepare an integrated work plan for Phase I that specifies the hazard work to be done, the expertise needed, and the time and cost requirements.

Figure 4 - KEY ELEMENTS IN THE PROCESS OF OAS ASSISTANCE FOR INTEGRATED REGIONAL DEVELOPMENT PLANNING

Source: OAS. Integrated Regional Development Planning: Guidelines and Case Studies from OAS Experience. (Washington, D.C.: OAS, 1984).

Phase I: Development Diagnosis

In Phase I, the team analyzes the study region and arrives at detailed estimates of development potentials and problems of the region and selected target areas. From this analysis a multisectoral development strategy and a set of project profiles are prepared for review by government decision-makers. Phase I also includes a detailed assessment of natural hazards and the elements at risk in highly vulnerable areas which facilitates the early introduction of non-structural mitigation measures. During this phase the team will:

- Prepare a base map.

- Determine the goods, services, and hazards of the region's ecosystems. Identify cause-and-effect relationships between natural events and between natural events and human activity. In the hilly Chixoy region of Guatemala, for example, it was found that inappropriate road construction methods were causing landslides and that landslides, in turn, were the main problem of road maintenance. In Ecuador, the discovery that most of the infrastructure planned for the Manabí Water Development Project was located in one of the country's most active earthquake zones prompted a major reorientation of the project.

- Evaluate socioeconomic conditions and institutional capacity. Determine the important linkages between the study region and neighboring regions.

- Delineate target areas of high development potential, followed by more detailed natural resource and socioeconomic studies of these areas.

- In planning the development of multinational river basins or border areas where a natural disaster could precipitate an international dispute, make an overall hazard assessment as part of the resource evaluation. Examples of such studies include those for the development of the San Miguel-Putumayo River Basin, conducted in support of the Colombia-Ecuador Joint Commission of the Amazon Cooperation Project, and for the Dominican Republic and Haiti

Frontier Development Projects.

- Conduct assessments of natural hazards determined to be a significant threat in the study region. For hurricanes and geologic hazards, the existing information will probably suffice; if the information on geologic hazards is inadequate, an outside agency should be asked to conduct an analysis. For flooding, landslides, and desertification, the planning team itself should be able to supplement the existing information and prepare analyses. The studies of the Honduran departments of Atlántida and Islas de la Bahía included flood hazard assessment as part of the coastal area development plan and landslide hazard assessments for some of the inland areas.

- Conduct vulnerability studies for specific hazards and economic sectors. Prepare lifeline maps, hazard zoning studies, and multiple hazard maps as required. The study of the vulnerability of the Ecuadorian agriculture sector to natural hazards and of ways to reduce the vulnerability of lifelines in St. Kitts and Nevis, for example, both generated project ideas which could be studied at the prefeasibility level in Phase II. The study of the Paraguayan Chaco included flood and desertification assessments and multiple-hazard zoning. The execution of these hazard-related activities did not distort the time or cost of the development diagnosis.

- Identify hazard-prone areas where intensive use should be avoided.

- Prepare a development strategy, including non-structural mitigation measures as appropriate.

- Identify project ideas and prepare project profiles that address the problems and opportunities and that are compatible with political, economic, and institutional constraints and with the resources and time frame of the study.

- Identify structural mitigation measures that should be incorporated into existing facilities and proposed projects.

- Prepare an integrated work plan for the next stage that includes hazard considerations.

Figure 5 - SYNTHESIS OF THE OAS INTEGRATED DEVELOPMENT PLANNING PROCESS

COMPONENTS	**STUDY DESIGN**	**STUDY EXECUTION**		**IMPLEMENTATION OF THE RECOMMENDATIONS**
		PHASE I	**PHASE II**	
		Development Diagnosis	**Project Formulation and Preparation of Action Plan**	
Activities:	Receipt and analysis of request for cooperation	Diagnosis of the region	Project formulation (pre-feasibility or feasibility) and evaluation	Assistance for specific programs and projects

Preliminary Mission	- sectoral analysis	- production sectors (agriculture, forestry, agroindustry, industry, fishing, mining)	Assistance in incorporating proposed investments into the national budget
- pre-diagnosis	- spatial analysis	- support services (marketing, credit, extension)	Advisory services for private sector actions
- cooperation agreement preparation	- institutional analysis	- social development (housing, education, labor training, health)	Support to executing agencies
	- environmental analysis	- infrastructure (energy, transportation, communications)	Support in the inter-institutional coordination
	- synthesis: needs, problems, potentials, constraints	- urban services	
	Relation to national plans, strategies and priorities	- natural resource management	
	Development strategies	Action plan preparation	
	- formulation and analysis of alternatives	- formulation of project packages	
	- identification of project ideas, preparation of project profiles	- determination of policies for priority areas and sectors	
		- enabling and incentive actions	
		- investment timetable	
		- evaluation of funding sources	

			- institutional development and training	
			- promotion	
Products:	Signed agreement	Interim Report (Phase I)	Final Report	Execution by government of
	- definition of the study products	- diagnosis of the region	- development strategy	- final design studies
	- financial commitments of participants	- preliminary development strategy	- action plan	- project implementation
	- preliminary workplan	- identified projects	- formulated projects	- changes in legislation and regulations
			- supporting actions	
				Improved operational capability of institutions
Time Frame:	3 to 6 months	9 to 12 months	12 to 18 months	Variable

Source: OAS. Primer on Natural Hazard Management in Integrated Development Planning. (Washington, D.C.: In Press)

Figure 6 - INTEGRATED DEVELOPMENT PLANNING PROCESS, NATURAL HAZARD MANAGEMENT, AND THE PROJECT CYCLE

Source: OAS. Primer on Natural Hazard Management in Integrated Development Planning (Washington, D.C.: In Press).

Phase II: Project Formulation and Action Plan Preparation

At the end of Phase I a development strategy and a set of project profiles are submitted to the government. Phase II begins after the government decides which projects merit further study. The team now makes prefeasibility and feasibility analyses of the projects selected. Refined estimates are made of benefits (income stream, increases in production, generation of employment, etc.) and costs (construction, operation and maintenance, depletion of resources, pollution effects, etc.). Valuative criteria are applied, including net present value, internal rate of return, cost-benefit ratio, and repayment possibilities. Finally, the team assembles packages of investment projects for priority areas and prepares an action plan. More detail on this phase is given in the section on Hazard Mitigation Strategies for Development Projects, but broadly speaking the team must:

- Examine the human activities that could contribute to natural hazards (e.g., irrigation, plowing in the dry season, and animal husbandry could cause or exacerbate desertification) and the social and cultural factors that could influence project vulnerability during and after implementation.

- Determine the levels of technology, credit, knowledge, information, marketing, etc., that it is realistic to expect will be available to the users of the land, and ensure that the projects formulated are based on these levels.

- Prepare site-specific vulnerability and risk assessments and appropriate vulnerability reduction measures for all projects being formulated. For example, the multimillion-dollar program for the development of the metropolitan area of Tegucigalpa, Honduras, featured landslide mitigation components. Flood alert and control projects were central elements in the comprehensive Water Resource Management and Flood Disaster Reconstruction Project for Alagoas, Brazil.

- Mitigate the undesirable effects of the projects, avoid development in susceptible areas, recommend adjustments to existing land use and restrictions for future land use.

- Examine carefully the compatibility of all projects and proposals.

- Define the specific instruments of policy and management required for the implementation of the overall strategy and the individual projects; design appropriate monitoring programs.

Implementing the Study Recommendations

The fourth stage of the development planning process helps implement the proposals by preparing the institutional, financial, and technical mechanisms necessary for successful execution and operation. Efforts made to consider hazards in previous stages will be lost unless mitigation measures are closely adhered to during the projects' execution. Either the planning agency or the implementing agency should:

- Ensure that suitable hazard management mechanisms have been included in all investment projects; provide for monitoring of construction to ensure compliance with regulations, and for ongoing monitoring to ensure long-term compliance with project design.

- Ensure that national disaster management organizations have access to the information generated by the study. Point out hazardous situations for which the study did not propose vulnerability reduction measures.

- Arrange for the continuing collection of hazard data and the updating of information of planning and emergency preparedness agencies.

- Prepare legislation mandating zoning codes and restrictions, building and grading regulations, and any other legal mechanisms required.

- Include adequate financing for hazard mitigation measures.

- Involve the private sector in the vulnerability reduction program.

- For community-based vulnerability reduction programs, establish national training and hazard awareness programs for town and village residents, a feature of OAS technical assistance programs for Saint Lucia and Grenada.

- Generate broad-based political support through the media, training programs, and contacts with community organizations. Use products of the studies (photos, maps, charts, etc.) for mass communication. Use personnel who participated in the studies in public meetings to promote the concept of vulnerability reduction.

- Accelerate the implementation of projects that include hazard mitigation considerations; if budget cutbacks occur, reduce the number of projects rather than dropping the hazard mitigation components.

2. Advantages of integrated development planning for hazard management

Even though integrated development planning and hazard management are usually treated in Latin America and the Caribbean as parallel processes that intermix little with each other, it is clear that they should be able to operate more effectively in coordination, since their goals are the same-the protection of investment and improved human well-being-and they deal with similar units of space. Some of the advantages of such coordination are the following:

- There is a greater possibility that vulnerability reduction measures will be implemented if they are a part of development package. The possibility increases if they are part of specific development projects rather than stand-alone disaster mitigation proposals. Furthermore, including vulnerability reduction components in a development project can improve the cost-benefit of the overall project if risk considerations are included in the evaluation. A dramatic example is the case study on vulnerability reduction for the energy sector in Costa Rica.

- Joint activities will result in a more efficient generation and use of data. For example, geographic information systems created for hazard management purposes can serve more general planning needs.

- The cost of vulnerability reduction is less when it is a feature of the original project formulation than when it is incorporated later as a modification of the project or an "add-on" in response to a "hazard impact analysis." It is even more costly when it is treated as a separate "hazard project," independent of the original development project, because of the duplication in personnel, information, and equipment.

- Exchanging information between planning and emergency preparedness agencies strengthens the work of the former and alerts the latter to elements whose vulnerability will not be reduced by the proposed development activities. In the Jamaica study of the vulnerability of the tourism sector to natural hazards, for example, solutions were proposed for most of the problems identified, but no economically viable solutions were found for others. The industry and the national emergency preparedness agency were so warned.

- With its comprehensive view of data needs and availability, the planning community can help set the research agenda of the science and engineering community. For example, when a planning team determines that a volcano with short-term periodicity located close to a population center is not being monitored, it can recommend a change in the priorities of the agency responsible.

- Incorporating vulnerability reduction into development projects builds in resiliency for the segment of the population least able to demand vulnerability reduction as an independent activity. A clear example of this situation was the landslide mitigation components of the metropolitan Tegucigalpa study: the principal beneficiaries were the thousands of the city's poor living in the most hazard-prone areas.

Hazard mitigation strategies for project formulation

Building natural hazard mitigation measures into investment projects consumes financial and technical resources. Therefore, hazard assessments should include an estimate of the damage the project might suffer over its lifetime and a method for estimating the costs and benefits of mitigation measures. Having this information, the planner can compare the costs of mitigation with the losses that might be incurred if hazards are not taken into account.

With the right information it is theoretically possible to achieve an optimum level of risk management, balancing the cost of mitigation against the value of the elements at risk and the probability of a hazardous event. But to reach such an ideal state, changes in the current institutional environment are needed:

- Governments and development assistance agencies must have access to information on natural hazards.

- National and regional planning institutions and sectoral agencies must undertake the necessary natural hazard assessments and formulate policies for non-structural mitigation.

- These policies, in turn, must become a part of the process of identification and preparation of investment projects.

- Donors or lenders must undertake their own review of individual investments from the natural hazard perspective.

- There must be a strong private insurance sector to optimize risk management and efficiency and spread the costs of unavoidable risks across the entire society.

The priority that governments afford natural hazard mitigation is not very high, judging by the increasing losses to major investment projects from storms, earthquakes, floods, and landslides that could have been greatly reduced. There are a number of explanations for this:

- Governments believe that the risk is limited and that the potential savings from mitigation are low.

- Political and financial pressures make it unappealing to take expensive steps now to avoid losses in the future.

- If losses occur, international agencies frequently provide assistance.

- People are resigned: after repeated events, they tend to accept the inevitability of natural hazards, and they lack knowledge about non-structural mitigation.

- The burden of analysis, institution-building, and implementation discourages the effort.

- The political, financial, and social costs of hazard assessment and mitigation may not always be less than the benefits.

- There are some methodological problems in cost-benefit analysis, including the fact that not all costs or benefits related to disasters are quantifiable.

- The costs fall on public institutions that cannot recapture directly the benefit of preventing losses in the future.

For similar reasons international development assistance agencies sometimes neglect natural hazards that may affect projects for which they have provided funds or assistance.

1. Incorporating mitigation measures into investment projects

The preparation of investment projects entails six steps: project idea, project profile, prefeasibility analysis, feasibility analysis, engineering design, and implementation. Some institutions require that hazard considerations be built into the last stages of project preparation, usually at the point of engineering design. While such an approach is preferable to not thinking about them at all, it must be emphasized that the earlier hazard considerations are introduced, the more easily they are handled.

As was said in the previous section, Phase II of the development planning process is dedicated mainly to the preparation of prefeasibility and feasibility analyses of investment projects. The following factors can be incorporated relatively easily in the course of these analyses and would improve an evaluation of the project's risk:

- The incidence of natural hazard risks in the study area.

- The incidence of natural hazard risks in the project's market areas.

- The vulnerability of the supply and cost of project inputs to natural hazards.

- The vulnerability of the project's output prices to natural hazards.

- The vulnerability of project-related physical structures and production processes to natural hazards.

- The effectiveness and cost of alternative natural hazard mitigation measures.

The principal components of a study in which natural hazard considerations should be included are listed in the box below.

Structural and non-structural measures can mitigate the effects of natural hazard events. **Structural**

mitigation includes physical measures and standards such as building codes, materials specifications, and performance standards for the construction of new buildings; the retrofitting of existing structures to make them more a hazard-resistant; and protective devices such as dikes. **Non-structural mitigation** measures typically concentrate on identifying hazard-prone areas and limiting their use. Examples include land-use zoning, the selection of building sites, tax incentives, insurance programs, relocation of residents to remove them from the path of a hazard, and the establishment of warning systems. Figure 7 gives a variety of approaches for reducing the effects of natural hazards.

A strong case can be made for emphasizing non-structural measures in developing countries. All structural measures have a direct cost that must be added to the costs of the project being considered. Given the prevailing reluctance to include hazard considerations in projects, the added cost would certainly be a constraint. This does not mean that non-structural mitigation measures will have no cost, but that in an area subject to flooding, for example, the economic and social costs of measures such as zoning restrictions and crop insurance are likely to be much lower than those of a large-scale flood control system. Moreover, not every mitigation measure should be adopted, only those for which the benefits exceed the costs.

Experience in the region indicates that the activities that have been most affected by natural hazards are large-scale development projects-precisely the kind that could have been oriented differently by the use of appropriate non-structural mitigation measures.

To summarize, in the prefeasibility study, when the technical and economic viability of the project is assessed, the appraisal of mitigation measures should be included. In the feasibility study, when the final appraisal of project alternatives is made, the project options that are best with respect to mitigation measures should be selected. Final economic appraisals should incorporate risk considerations, and the final project design should include optimal structural and non-structural mitigation measures.

2. Methods for evaluating natural hazard risk

A number of issues are involved in deciding whether to consider natural hazard risk in development planning and project formulation, and if so, how to do it.

First, many governments and international financing agencies are unconvinced that natural hazard risk is a proper consideration for project evaluation. The merits of that viewpoint will be examined.

Second, decision-makers are always faced with competing and conflicting objectives, of which reducing the risk of natural hazards is only one. A technique called multicriteria analysis offers a way to decide on the weights to be given to the various objectives, even before projects are identified and formulated.

PRINCIPAL COMPONENTS OF A FEASIBILITY STUDY IN WHICH TO CONSIDER NATURAL HAZARD INFORMATION

Market Study

a. Determination of market areas
b. Product's supply and demand analysis
c. Price analysis
d. Commercialization strategies

Determination of Size and Location of the Project

a. Current and expected demand
b. Technical-economic constraints on size
c. Geographical and seasonal availability of production inputs
d. Geographical and seasonal cost of inputs
e. Market proximity
f. Transportation and communication scenarios
g. Existing legal and financial incentives

Project Engineering

a. Selection of production technology
b. Specification of equipment
c. Infrastructure and building design and location
d. Production process flexibility
e. Operation schedule

Investment Calculations

a. Capital investments
b. Equipment and buildings
c. Land and natural resources
d. Engineering and administration of implementation

Cash-Flow Analysis

a. Inputs and other materials
b. Energy and fuels
c. Insurance and taxes
d. Revenues from sales

Financing Assessment

a. Financing sources
b. Financing conditions

Figure 7 - EXAMPLES OF APPROACHES FOR REDUCING THE EFFECTS OF NATURAL HAZARDS

Preparing Development Studies and Plans

- Community-facility inventories and plans
- Economic development plans
- Investment project evaluations
- Land-subdivision layouts
- Land-use and transportation inventories and plans
- Public-safety plans
- Redevelopment plans (pre-disaster and post-disaster)
- Utility inventories and plans

Siting, Designing, and Constructing Safe Structures

- Reconstruction after disaster
- Reconstruction or relocation of community facilities
- Reconstruction or relocation of utilities
- Repair of dams
- Site-specific investigations and hazard evaluations
- Strengthening or retrofitting buildings
- Siting and design of critical facilities

Discouraging New or Removing Existing Development

- Disclosure of hazards to real-property buyers
- Financial incentives and disincentives
- Lenders' and insurers' development policies
- Location of infrastructure
- Posted warnings of potential hazards
- Public acquisitions of hazardous areas
- Public information and education
- Public records of hazards
- Removal of unsafe structures

Regulating Development

- Building and grading ordinances
- Design and construction regulations
- Engineering, geologic, hydrologic, and seismologic reports
- Hazard-zone investigations and regulations
- Land-use zoning and setback requirements
- Subdivision ordinances

Preparing for and Responding to Disasters

- Anticipating damage to critical facilities
- Damage inspection, repair, and recovery procedures
- Disaster training exercises
- Emergency response plans
- Event prediction and response plans
- Event preparedness plans
- Monitoring and warning systems

Personal preparedness actions

Source: Kockelman, W.J. U.S. Geological Survey.

Third, a project may provoke the passionate support or opposition of particular interest groups. A way must be found to resolve these conflicts to the reasonable satisfaction of all parties if the mix of projects ultimately selected is to be in the best interest of society as a whole.

Finally, once these issues have been resolved, objective methods are needed for evaluating natural hazard risk as an element of overall investment project evaluation. A number of economic appraisal methods are available for this purpose.

Attitudes Toward Risks from Natural Hazards

Should risk be considered in analyzing public sector projects? The private investor tends to avoid risky propositions, but it has been argued that governments should take a risk-neutral stance. Given that the benefits and costs of public projects are spread over a large number of individuals in the society, the element of risk facing each one is negligible. Since risks are widely shared, the argument goes, governments should be indifferent between a high-risk and a low-risk project provided that the two have the same expected net present value.

Compare two multipurpose dam proposals, both with a project life of 100 years. Dam A will be built on geologically stable ground; Dam B will be built on land that has a 70 percent probability of undergoing an earthquake of magnitude 7.5 Richter by 2010. If future risk is not considered, Dam B has a much higher net present value and the country is inclined to select it. But including the correct factors of risk causes its expected net present value to plummet below that of Dam A. It is wiser for the country to select Dam A.

From the point of view of the international bank providing the financing, the government will be obligated to repay the loan whichever dam it builds. Yet the banks are trying to inculcate fiscal responsibility in the planning and execution of their loan agreements. The bank is indifferent between Dams A and B with regard to loan repayment, but should logically prefer Dam A because it is the more fiscally responsible alternative. Banking institutions, however, may place a higher priority on macroeconomic and political factors-specifically, a government's ability and/or willingness to repay loans-than on evaluating each project loan in terms of realistic cost-recovery criteria.

The OAS, through its participation in the Committee of International Development Institutions on the Environment (CIDIE) together with other organizations concerned with the impact of natural hazards on development projects, is fostering a change in this attitude.

Establishing Evaluation Criteria and Priorities

Multicriteria analysis, or multiple conflicting objectives analysis, is a technique for explicitly incorporating societal goals and priorities into the selection of projects. It has been used in environmental assessments and has been gaining increasing acceptance as a means of addressing this complex issue. The analysis entails the establishment of a set of objectives and a sub-set of attributes representing alternative social, economic, political, environmental, and other societal goals which are to be fulfilled by specific projects. The relevant societal groups (government, interest groups, community leaders, etc.) participate in establishing the objectives and attributes and placing discriminatory weights on them.

Projects can then be evaluated in terms of their capacity to fulfill the stated goals. Both single-project analysis and project comparisons can be performed. Natural hazard vulnerability criteria can be introduced into the analysis along with the other goals.

It is important to remember that it is not planners but high-level decision makers who will ultimately rule on public investment options. The value of multicriteria analysis, in contrast to traditional project selection methods, is that it forces decision-makers to state their evaluation criteria explicitly. For economic or political reasons, most decision-makers can be expected to give low vulnerability a high priority in project selection.

Multicriteria analysis can be applied throughout the project cycle, from identification of a project idea to feasibility study, but since it is effective in the identification of more desirable projects or project components, its use at the beginning stages of project planning maximizes its benefits.

Conflict Resolution

The construction of a dam for flood control and energy generation may be in the interest of industry and municipal governments, but may be perceived by local farmers as reducing available agricultural land. This is but one example of the many situations in which opposing factions can take perfectly defensible but intractable positions on an environmental issue. The concept of "negative environmental impact," it turns out, can be defined as a conflict between interest groups over the use of a natural good or service. Thus negative environmental impacts can be seen as activities of one sector or sub-sector that cause problems for another. Since development actions are always legitimate in the eyes of their sponsors, the result is a conflict requiring management. Obviously, the sooner a conflict is identified and made manageable, the better. Obvious also is that "sooner" means in the policy and project formulation stages instead of after funds and prestige have been invested in projects.

Sectoral agencies and their planning efforts are not organized either to identify or to manage such conflicts. Many funding institutions are also unable to do so: so much time, effort, and prestige have already been invested in the projects they receive that any attempt to change them is difficult. Furthermore, to work efficiently within their mandates, the institutions generally prefer comparatively large projects in which interest groups that lack political and economic power are seldom fully represented. A process of "environmental planning" that seeks equitable solutions to development problems and at the same time identifies and resolves the conflicts brought on by development is a requisite part of the development process.

Economic Evaluation Techniques

Occasionally a project with natural hazard risk components works its way past this formidable array of impediments. There are a number of methods available for evaluating the hazard components in the economic analysis of the project. One set of these methods can be applied when little hazard information is available; a second set is appropriate when information on probability distributions can be obtained. All the methods can be used in comparing different projects or comparing alternatives within a project.

The methods used when limited information is available can be applied at project profile, prefeasibility, or feasibility levels of analysis. Those using probabilistic information are usually applied in feasibility studies, but may also be used at the prefeasibility stage. In all cases the methods should be applied as early as possible in the project cycle.

(1) Decision Criteria with Limited Information

Four methods of risk evaluation compensate for a lack of information: cut-off period, discount rate adjustment, game theory, and sensitivity analysis.

Cut-off period. This is the crudest procedure for incorporating natural hazard risk into economic analysis. It is used primarily by private investment agencies with a primary interest in capital return. To be economically feasible under the cut-off-period method, a project must accrue benefits that exceed its cost in relatively few years. For very risky projects, such as those at high risk of flooding or landslides, the cut-off period might be set as low as two to three years. The logic of the cut-off-period rule is that, because of the uncertainty of costs and benefits beyond the cut-off date, they should be ignored in determining project feasibility. To determine the length of the cut-off period, a rough idea of the riskiness of the project should be sought during the prefeasibility analysis. The method is appropriate when three conditions are present: (1) few records concerning natural hazard risk are available; (2) the likely hazards are of fast rather than slow onset, and (3) the magnitude of potential disasters is great.

Discount rate adjustment. Adding a risk premium to the discount rate is another *ad hoc* way to reflect uncertainty in project analysis. A variation of this is to add a premium to the discount rate for the benefits accruing to the project as a result of mitigation, and subtract a premium for the costs, a procedure consistent with the fact that hazards decrease benefits and increase costs. Introducing these premiums into the calculations of feasibility has the effect of giving less weight to increasingly uncertain costs and benefits in the future. This is consistent with the conventional expectation that an investor will require higher rates of return for riskier investments. The analyst using this method must determine an arbitrary risk premium to add to the discount rate. The same kind of hazard information used for the cut-off method is applicable here, and the method is applicable to both slow- and rapid-onset hazards. Again, this information should be available by the prefeasibility stage of planning.

Game-theory approaches. Two strategies from game theory are applicable to the task of introducing risk assessment into the economic appraisal of projects: the "maximin-gain" and the "minimax-regret." Both can be applied at the earliest stages of project formulation, as the necessary minimum information on historical hazardous events and damage becomes available. From this information, it is possible to estimate the comparative benefits of equivalent project alternatives, given varying severities of a hazardous event. The game-theory approaches are best suited to short-term, high-impact hazards for which most/least-damage scenarios can be produced.

Given the possible net benefits accrued under different hazard conditions, the maximin-gain approach seeks the project alternative that will give the highest net return in the worst-case scenario; the selection of a particular project alternative is based entirely on security and is thus very conservative. The minimax-regret takes a different approach by considering the sum of the losses that each project alternative might incur given the probabilities of hazardous events occurring. The alternative with the smallest sum of possible losses when all scenarios are considered is the one that would be selected.

Sensitivity analysis. Using this method, an analyst tests the effect of changes in the values of key project parameters (e.g., halving the income from admission fees or doubling the maintenance cost) on net costs and benefits. To assess the impact of natural hazards, values are changed according to previous hazard information, damage reports, etc., so that the effects of a possible natural event on the economic feasibility of the project can be quantified. With this type of analysis it is possible to determine how much a key parameter can change before the project becomes economically unfeasible. The analysis can also be used to test the effect of mitigation measures.

(2) Decision Criteria with Probabilistic Information

A more rigorous analysis of risk can be made if probabilistic distributions of the key variables (such as net present value, NPV) are available. These distributions can be based on historical information or on the estimates of experts, and ideally include probabilistic information on natural events. NPV probability distributions can be estimated by holding constant a number of variables and repeatedly sampling values for other variables to calculate a large number of possible NPV values, which are then used to approximate the probability distribution of the NPV.

Once the NPV probability distributions for the proposed projects have been prepared, the mean value of the distributions can be compared. However, considering only the average NPV ignores the relative riskiness of the project. To make better use of the risk information in a probability distribution, two methods are available: **mean-variance analysis** and **safety-first analysis.**

As the name implies, mean-variance analysis considers not only the mean economic indicator (NPV) for each project, but also the degree of dispersion (or variance) around the mean. As an example, consider three agricultural development projects being evaluated for a flood-susceptible area. Projects A and C have been designed without flood mitigation measures, while Project B foresees the construction and protection of retention basins, stream channelization, and terracing. The probability distributions and expected net present values for the three projects are shown in Figure 8.

Projects A and B both have an expected NPV of US$5 million. However, Project A is vulnerable to floods, and thus could have an NPV of 0. Project B is less susceptible to flood damage, and has a NPV range of US$3 million to US$7 million. Since the mean NPV for the projects is the same but the capital costs of Project B are higher, society might choose Project A. Conversely, society may decide it cannot afford to invest in a large project that might yield no benefits at all in flood years and so choose project B. The comparison of Projects B and C is less evident. Project C has an expected NPV of US$8 million - US$3 million more than Project A - but its variance or variability of returns is also greater. The trade-off between higher expected net returns and greater risk or lower expected NPV and lower risk will have to be carefully considered by the decision-maker.

Safety-first analysis differs from mean-variance analysis in that it focuses on the lower tail of the distribution, seeking to maximize expected NPV with the proviso that it does not fall below a critical level.

Figure 8 - MEAN-VARIANCE ANALYSIS

Source: OAS. Primer on Natural Hazard Management in Integrated Development Planning. (Washington, D.C.: OAS, in Press).

For example, the criterion used to select between projects could be stated as follows: "Choose the project with the highest expected NPV, as long as the probability of its falling below US$1 million is less than 5 percent."

A more detailed explanation of each of these methods is given in the *Primer on Natural Hazard Management in Integrated Development Planning.*

Strategies for specific hazards

The natural hazards of principal concern to development practitioners in the region are:

- Hurricanes
- Drought and desertification
- Geologic hazards (earthquakes, volcanic eruptions, tsunamis)
- Floods
- Landslides

While hazards often materialize as discrete events, their occurrence may also overlap. For example, hurricanes and tsunamis may produce floods; earthquakes may trigger landslides; and erosion and sedimentation are frequently the result of flooding, desertification, or unsound land management practices rather than hazards in their own right. The natural hazards listed above are of greatest concern to development agencies, not only because they cause the most harm to human life and property, but also because they may be exacerbated by development practices. But the most important thing about these hazards is that means of reducing their impact are now available.

At the start of a development study, the planner should attempt to determine from the information available whether any particular hazard constitutes a problem in the study area. In the absence of sufficient information for these preliminary decisions, the planner usually decides by default: the hazard in question will not be considered.

Because of the availability of new techniques in hazard assessment, it is no longer necessary to make these default determinations. The information required to evaluate a natural hazard can often be obtained as a part of the planning process and it is possible to make hazard assessments part of the study without incurring unreasonable costs or sacrificing other aspects.

The availability of information determines the strategy for treating a natural hazard in a development study. The crucial question is: is the existing information sufficient to determine whether the hazard poses a significant threat in the study area? If not, additional information must be generated, fast enough and cheaply enough to be commensurate with the rest of the study. For **hurricanes, desertification, and geologic hazards, the available information is generally adequate; for flooding and landslides, it is not** (see box below).

1. Hurricanes

In the Caribbean island countries hurricanes cause more damage and disturb the lives of more people than any other natural hazard. In Mexico and Central America they are second only to earthquakes. From 1960 to 1989 hurricanes killed 28,000 people, disturbed the lives of 6 million people, and destroyed property worth US$16 billion in the Greater Caribbean Basin (excluding the United States and U.S. possessions). Small countries are particularly vulnerable to hurricanes, since they can be affected over their entire area, and major infrastructure and economic activities may be crippled in a single event.

More significant, however, is the record of reducing this impact. Hurricane intensity has not abated. Thus, with population density increasing, the number of deaths would be expected to increase over time. In fact, it has decreased. In 1930 three people were affected by hurricanes for each person killed. By 1989 that ratio had risen to 100,000 to one. The ratio of dollar value of damage to people killed rose from 5,000 to 20,000,000 in the same period. These reduced death rates are due almost entirely to improved warning systems and preparation. Some progress has been made toward reducing damage, but that is a more difficult issue.

A hurricane is defined as a large non-frontal tropical depression or cyclone with wind speeds that exceed 119 km/hr (a tropical storm has wind speeds of 63 to 119 km/hr). The hurricane season of the Greater Caribbean Basin is June through November, although 84 percent occur in August and September. Hurricanes cause damage by their high winds, heavy rainfall, and storm surge. Winds up to about 162 km/hr cause moderate damage such as blowing out windows. Above that velocity winds begin to cause structural damage. Heavy rainfall can cause river flooding, putting at risk all structures and transportation facilities in valleys, and can also trigger landslides.

Storm surge is a rise in sea level due to on-shore winds and low barometric pressure. Storm surges of 7.5 meters above mean sea level have been recorded, and a surge of over 3 meters is not uncommon for a large hurricane. Storm surges present the greatest threat to coastal communities. Ninety percent of hurricane fatalities are due to drowning caused by storm surges. If heavy rain accompanies a storm surge, and the hurricane landfall occurs at a peak high tide, the consequences can be catastrophic. The excess water inland creates fluvial flooding, and the simultaneous increase in sea level blocks the seaward flow of rivers, leaving nowhere for the water to go.

STRATEGIES FOR INCORPORATING NATURAL HAZARD CONSIDERATIONS INTO DEVELOPMENT PLANNING STUDIES BASED ON INFORMATION AVAILABILITY

Hurricanes. If hurricanes are found to be a threat, the study can go directly to local-level vulnerability reduction strategies. Mitigation actions using established structural and non-structural techniques can be undertaken as soon as it is established that the project falls within the hurricane-prone belt because there is currently no practical way to relate mitigation strategies to different hurricane intensities.

- The section on hurricanes discusses how to prepare for storms so as to reduce the damage they cause, with emphasis on procedures for small towns and villages.

Desertification. The information available on desertification for the region is very general, but it can be augmented for a study area easily and at low cost to the level needed for policy orientation and project identification and formulation. Desertification potential must be refined in the context of a development study precisely because the degree of that potential is directly related to the impact of development activities on natural conditions.

- The section on desertification gives the desertification potential for each political subdivision (state, department, province) subject to the hazard and tells how to prepare a desertification analysis using only four universally available parameters.

Geologic Hazards. The information available on seismic, volcanic, and tsunami hazards is sufficient to determine in the preliminary mission whether they constitute a significant threat in the study area. But vulnerability reduction is a site-specific matter, with emphasis on micro-level zonation and determination of severity and probability characteristics. These determinations require relatively elaborate and expensive techniques that are suitable only for feasibility and engineering design studies.

- The appendix lists the political subdivisions subject to seismic and tsunami hazards and gives the location and brief history of all active volcanoes in Latin American and the Caribbean. The lists are sufficient to determine whether these hazards pose a significant threat in a study area.

Flooding and Landslides. The information available on flooding and landslide hazards is generally spotty or nonexistent, but with a combination of historical event studies and new mapping techniques, these hazards can be evaluated at costs and scales appropriate to the corresponding stage of a development study.

- The section on floods describes a technique for quick mapping of flood-prone areas at scales up to 1:50,000 by interpretation of satellite imagery.

- The section on landslides describes alternative methods, depending on the source materials available, for mapping landslide threat.

To assess risk as a step in the process of preparing a hurricane hazard mitigation plan, a planner first determines whether the study area lies within the belt of commonly occurring hurricanes. If it is located in "Hurricane Alley" (see Figure 9), the planner studies records of past storms and land uses and correlates them with probable future land use and population changes. Most cities in the West Indies are in low coastal zones threatened by storm surge, and population movement to these high-risk zones greatly increases vulnerability. The economic sectors most affected by hurricanes are agriculture and tourism. Bananas, one of the most important Caribbean crops, are particularly vulnerable. The tourism sector in the Caribbean is notorious for its apparent disregard of hurricane risk. Not only does a hotel built with insufficient setback risk damage by wave action and storm surge, the building also interferes with the normal processes of beach and dune formation and thus reduces the effectiveness of a natural protection system.

Figure 9 - OCCURRENCE OF TROPICAL STORMS AND CYCLONES IN THE WESTERN HEMISPHERE [1/]

[1/] Wind strength of Beaufort 8 and above

Source: Munchener Ruck. Mapa Mundial de los Riesgos de la Naturaleza. (Munich, Federal Republic of Germany, Munchener Ruckversicherungs: 1988)

Once the risks are defined and quantified, planners and engineers can design appropriate mitigation mechanisms. Obviously, these are most cost-effective when implemented as part of the original plan or construction. Examples of effective mitigation measures include avoiding areas that can be affected by storm surge or flooding, the application of building standards designed for hurricane-force winds, or the planting of windbreaks to protect crops. Retrofitting buildings to make them more resistant is a more costly but sometimes viable option, but once a project is built in a flood-prone area it may not be feasible to move it to safer ground.

In the past three decades the ability to forecast and monitor these storms has increased greatly, which has had a dramatic effect on saving lives. The time and location of landfall and the resulting damage can be estimated. The U.S. National Hurricane Center uses this information to issue track prediction and intensity forecasts every six hours for tropical storms and hurricanes in the Atlantic/Caribbean region. The U.S. Oceanographic and Atmospheric Administration (NOAA) has developed the model Sea Lake Overland Surge from Hurricanes (SLOSH) to simulate the effects of a hurricane as it approaches land. This makes it possible to determine which areas should be abandoned and to plan evacuation routes. Tailored to specific areas, operational SLOSH is available in the United States and Puerto Rico and is being developed in the Virgin Islands. It can be expanded to other Caribbean and Central American countries.

At the national level non-structural mitigation strategies include campaigns to create a public awareness of warning services and protective measures, since informed citizens are more likely to check the condition of their roofs and other structures at risk. Good examples of such campaigns can be seen in The Bahamas, Barbados, and Jamaica. Taxation of investment in high-risk land is a potentially important strategy that has not been tried widely. Insurance can also be structured to encourage sound land use and structural mitigation actions. Among the important structural strategies are codes that control the design and construction of buildings and, in public works, the construction of breakwaters, diversion canals, and storm surge gates and the planting of tree lines to serve as windbreaks.

All these approaches may be effective in the largest urban settings where communications are good and institutional arrangements are firmly in place. But national emergency preparedness offices usually do not have the resources to function effectively in areas of low population density when faced with widespread catastrophes such as hurricanes. An alternative is to prepare small towns and villages to respond to emergencies by their own means. The approach followed by the OAS in collaboration with the Pan Caribbean Disaster Preparedness and Prevention Project (PCDPPP) in several Eastern Caribbean countries involves training local disaster managers and community leaders of both urban and rural settlements in organizing disaster risk assessment and mitigation in their communities. A training manual and accompanying video produced for this purpose are available. The focus is on lifeline networks (transportation, communications, water, electricity, and sanitation) and critical facilities (health and education facilities, police and fire stations, community facilities, and emergency shelters). Combining the disaster preparedness efforts of the PCDPPP program with disaster prevention through the integrated development planning of the OAS clearly illustrates the interface of disasters and development.

The process of preparing community leaders to cope with hurricanes consists of six steps:

- Preparing an inventory of lifeline networks and critical facilities.

- Learning the operation of these networks and facilities and their potential for disruption by hurricanes.

- Checking the vulnerability of the lifelines and facilities through field inspection and investigation.

- Establishing an effective working relationship with the agencies and companies that manage the infrastructure and services of the community.

- Developing an understanding of the total risk to the community.

- Formulating a mitigation strategy.

Communities can use the OAS-PCDPPP training manual and video to train themselves, but often they find it more effective to have outside help. The best approach is to set up a unit for local training in the national government which then travels regularly to each small community first to train the local leadership and then to give updates and practice sessions.

2. Drought and desertification

Droughts are prolonged dry periods in natural climate cycles. In arid and semi-arid regions, dry periods that are much drier than average and wet periods that are much wetter are common, and these variations cause serious problems. When the wet period is unusually wet, pastoralists increase the size of their herds and farmers extend their cultivation into areas normally too dry for agriculture. Then when a dry period comes, these expansions must be cut back. If the uses that exceed carrying capacity are not cut back, the vegetative cover can die, and the unprotected soil is subject to rapid erosion, one of the indicators of desertification.

Desertification is the spread of desert-like conditions induced by human activities with consequent decrease in biomass production. It is manifested by loss of productive soils, water and wind erosion, creation and movement of dunes, waterlogging, reduced quantity and quality of surface and subsurface water, and rapid depletion of vegetative cover. Figure 10 classifies the status of desertification by country and subdivision (province, department, state) in South America and Mexico.

Desertification is a result of many interrelated phenomena, with human-induced erosion and salinization often exacerbating natural drought. Soil erosion by moving water occurs on any sloping land but can be accelerated by overgrazing, deforestation, certain agricultural practices, road construction, and urban development. Erosion by wind can take place on flat land lacking vegetative cover. Erosion results in loss of soil nutrients, downstream damage by the deposition of sediments generated by the erosion, and depletion of water storage capacity.

Salinization most often occurs on irrigated land as the result of poor water control. Salts accumulate because of flooding of low-lying lands, evaporation from depressions having no outlets, and the rising of groundwater close to the soil surface.

Many of the problems associated with desertification can be circumvented by sound planning. This requires information about physical conditions and the social-cultural context of the planning area. If the area has the potential for desertification (i.e., if it is in one of the areas shown in Figure 10), a desertification hazard assessment should be undertaken at the very outset of a development planning study.

The OAS has developed a simple, quick method for conducting such an assessment that can be applied in the earliest stages of development planning. This method uses only four variables-precipitation, soil texture, slope, and the ratio of precipitation to evapotranspiration. Wind and other descriptors can also be important in some regions, but the four variables selected are those for which data are most readily available. The method defines a maximum of 16 mappable units, as shown in Figure 11. Each unit has a set of characteristics that indicate suitable and unsuitable land uses or management practices and the kinds of problems that misuse can cause. The resulting desertification hazard map can be used to design and evaluate development projects according to the conditions of water scarcity and the potential for desertification. Relying on data that are almost universally available, the approach can be used in the preliminary mission to make a first approximation of the hazard, which can be refined in Phase I.

Other approaches are available. For example, an OAS study of the Paraguayan Chaco delineated four degrees of severity of desertification risk based on characteristics of bioclimate, terrain, and human pressure, and used these units to prescribe appropriate soil management methods and precautions to be incorporated into the proposed irrigation and animal husbandry projects.[2/]

> [2/] Gobierno de la República del Paraguay y Departamento de Desarrollo Regional de la Secretaria General de la Organización de los Estados Americanos. Desarrollo Regional Integrado del Chaco Paraguayo (Asunción, Paraguay: Marzo, 1985).

The following are some mitigation measures for overgrazing, dry-land farming, and salinization. Addressing the problem of overgrazing starts with recognizing the needs of the pastoralists. Reducing the number of stock and introducing improvements such as fencing and watering points can help. Ameliorative range management techniques must meet the particular requirements of the area, taking into consideration the most appropriate treatment for flood-plains and sandy hills, the kinds of animals that are most suitable to the area, and the social structure and cultural context. Pastoralists are more willing to accept management alternatives that are relatively less capital-intensive even though they may take longer to be beneficial.

The difficulties of dry-land agriculture include low and unreliable rainfall, hot and dry winds, dependence on extensive rather than intensive farming, a restricted choice of crops, soils that are highly susceptible to wind erosion, and crop yields that are seldom sufficient to justify major investment in chemicals or erosion control measures. Thus the prospects for mitigating problems of dry-land farming are not as favorable as those for range lands. Major dry-land farming problems are erosion by wind and water and loss of fertility owing to the removal of nutrients by crops.

Fertility can be restored with fertilizer-expensive over the short term, but the long-term alternative is severe loss of production. Coarse, sandy soils and soils on steeply sloping land are the most difficult to improve.

Mitigation of soil erosion problems can draw on an array of well-known soil and water conservation practices such as the use of drought-resistant plants, fallow periods and mulches, the installation of water-retaining terraces, wide spacing of plants in and between rows, special practices such as minimum tillage and zero tillage, and leaving crop residues in place after harvesting. With some experimentation it is usually possible to find a set of management practices that the farmer will accept and that will result in greater profits for him within a few years.

Figure 10 - AREAS OF POTENTIAL DESERTIFICATION IN SOUTH AMERICA AND MEXICO[a/]

COUNTRY	Hyperarid region	STATUS OF DESERTIFICATION			
		Slight	Moderate	Severe	Very severe
ARGENTINA		Catamarca	Chubut	Catamarca	La Pampa
		Chaco	La Pampa	Córdoba	
		Chubut	Mendoza	Jujuy	
		Formosa	Neuquén	La Pampa	
		Jujuy	Río Negro	La Rioja	
		La Rioja		Mendoza	
		Mendoza		Salta	
		Neuquén		San Juan	
		Río Negro		San Luis	
		Salta		Santiago del Estero	
		San Juan			
		Santa Cruz			
		Santiago del Estero			
BOLIVIA		Cochabamba		Cochabamba	
		Chuquisaca		Chuquisaca	
		La Paz		La Paz	
		Oruro		Potosí	
		Potosí		Tarija	
		Santa Cruz			
		Tarija			
BRAZIL			Alagoas		
			Bahía		
			Ceará		
			Paraíba		
			Pernambuco		
			Piauí		
			Río Grande do Norte		
			Sergipe		
COLOMBIA			Atlántico		
			Guajira		Magdalena
CHILE	Antofagasta	Antofagasta	Aconcagua	Antofagasta	

	Atacama	Atacama	Coquimbo	Atacama	
	Tarapacá	Tarapacá	Valparaíso		
ECUADOR		Esmeraldas			
		Guayas			
		Manabí			
MEXICO	Sonora	Baja California Norte	Baja California Norte	Aguascalientes	Chihuahua
		Baja California Sur	Nuevo León	Baja California Norte	
		Sonora	Sinaloa	Chihuahua	
			Sonora	Coahuila	
				Durango	
				Guanajuato	
				Guerrero	
				Hidalgo	
				Michoacán	
				Nuevo León	
				Oaxaca	
				Puebla	
				Querétaro	
				San Luis Potosí	
				Sinaloa	
				Sonora	
				Tamaulipas	
				Zacatecas	
PARAGUAY		Boquerón			
		Chaco			
		Nueva Asunción			
PERU	Ancash	Ancash		Arequipa	
	Arequipa	Arequipa		Ayacucho	
	Ica	Ayacucho		Moquegua	
	La Libertad	Cajamarca		Puno	
	Lima	Huancavelica		Tacna	
	Moquegua	Ica			
	Tacna	La Libertad			

		Lambayeque			
		Lima			
		Moquegua			
		Piura			
		Puno			
		Tacna			
		Tumbes			
VENEZUELA			Falcón		
			Zulia		

[a/] Area is defined as the largest political subdivision of the country: province in Argentina, Chile, and Ecuador; department in Bolivia, Colombia, Paraguay, and Peru; and state in Brazil, Mexico, and Venezuela. The fact that an area appears with a specific status of desertification does not necessarily imply that the entire area is affected. Moreover, an area can have more than one status when different portions are affected to different degrees.

Source: Adapted from: Dregne, H.E. Desertification of Arid Lands (New York, New York: Harwood Academic Publishers GmbH, 1983).

Figure 11 - DESERTIFICATION TYPES

Precipitation Class (mm)	**P/PET class[a/]**	**Texture class (% Sand)**	**Slope class (% Slope)**	**Desertification Unit**
More than 1500	-	More than 50	More than 10	1
			Less than 10	2
		Less than 50	More than 10	3
			Less than 10	4
Less than 1500	1.0 or greater	More than 50	More than 10	5
			Less than 10	6
		Less than 50	More than 10	7
			Less than 10	8
	0.76-0.99	More than 50	More than 10	9
			Less than 10	10
		Less than 50	More than 10	11
			Less than 10	12
	0.01-0.75	More than 50	More than 10	13
			Less than 10	14

		Less than 50	More than 10	15
			Less than 10	16

[a] Ratio of precipitation to potential evapotranspiration.

Source: Organization of American States. Primer on Natural Hazard Management in Integrated Development Planning (Washington, D.C.: In Press).

Salinization can be mitigated with currently available technology. Leaching is a practical way to remove excess salts from soils, but requires good drainage. Essentially, what is needed is properly designed and managed irrigation systems. This involves, at a minimum, consideration of the peculiarities of the natural soil situation (e.g., chemical composition of ground water, salinity of soils up to the water table, conditions of natural drainage), deep drainage installations to carry off excess water, and avoidance of over-watering. Over-watering is a common consequence of the propensity to undercharge for water; it can result in such heavy use of it as to result in waterlogging and salinization.

3. Geologic hazards

The most damaging geologic hazards are earthquakes, volcanic eruptions, and tsunamis (large sea waves, erroneously called tidal waves, which are usually caused by earthquakes). Landslides, which can be triggered by earthquakes and other mechanisms, are discussed in Section 5 of this chapter.

Geologic hazards are characterized by (1) very rapid onset; (2) geographically limited impact (the phenomena occur in limited and clearly defined zones in Latin America and the Caribbean); (3) lack of predictability except in the most general sense; and (4) extreme destructiveness (in spite of their relative rarity, earthquakes in urban areas, pyroclastic flows and mudflows caused by volcanic eruptions, and flooding due to tsunamis are some of the most damaging and feared natural hazards).

This combination of characteristics makes the non-structural strategy of avoidance the best way to cope with geologic hazards. As has been emphasized, the avoidance strategy requires information about the threat of the hazards as early as possible in the development planning process. The information requirements are very general early in the process, becoming more explicit with each successive stage so as to provide answers to the following questions in order:

- Does the hazard pose a threat in the study area?

- Is the danger great enough to merit mitigation?

- What kind of mitigation mechanisms are appropriate?

- What are the costs and benefits of a particular mitigation measure, in terms of both economics and quality of life?

Scientific data to answer the first question exist for the principal geologic hazards in most of Latin America and the Caribbean, but up to now they have not been readily accessible. One of the services of the OAS has been to compile this information in a form suitable for use by planners. This section summarizes that information for earthquakes, volcanic eruptions, and tsunamis.

Earthquakes

Two kinds of information are needed to evaluate earthquake threat: the potential severity of an earthquake and the likelihood that a damaging earthquake will occur during a specific time frame. When either type of information is not available, a partial evaluation can be made with the information that does exist.

Potential severity is usually defined historically; that is, the largest earthquake determined to have occurred in an area is taken as the maximum that is likely to occur there again. A map of Earthquake Intensities of South America has been prepared that delineates zones according to the Modified Mercalli Intensity (MMI) scale, a 12-unit scale of increasing shaking intensity. MMI VI, for example, is defined as follows: "Felt by all; many frightened and run outdoors; falling plaster and chimneys; damage small."[3/] At MMI X, roughly equivalent to magnitude 7 on the Richter scale, "Most masonry and frame structures destroyed; ground cracked; rails bent; landslides." Taking MMI VI as a cut-off, on the assumption that mitigation measures would be difficult to justify economically at or below this level, mitigation measures should be considered for areas of MMI VII and above.

> [3/] Centro Regional de Sismología para América del Sur (CERESIS). Mapa de Intensidades Máximas de América del Sur (Santiago, Chile: CERESIS, 1985).

The threat is serious. Figure 12 shows twelve locations in Central and South America where there is a probability of 50 percent or greater that an earthquake with magnitude of 7+ will occur in the next 20 years. Damaging quakes in Costa Rica and Ecuador are almost a certainty during that time (probabilities of over 90 percent). Table A-1 (see Appendix A for Tables A-1 to A-6) gives the MMI rating of all departments (provinces, states) in South America having an MMI of VI or greater. Table A-2 gives the conditional probability of a large or great earthquake occurring on the west coast of South America in the next five, ten, or 20 years, again at the departmental level, as well as the maximum likely seismic intensity of such a quake. Tables A-3 and A-4 give comparable information for Central America. The *Primer on Natural Hazard Management in Integrated Development Planning* gives similar data for Mexico and the Caribbean.

This is, of course, very preliminary information, but if, for example, a study area has an 80 percent probability of being struck by an MMI X earthquake in the next 20 years, the planner recognizes that reality as something that cannot be ignored.

OAS work with geologic hazards has been confined largely to pre-event planning and non-structural mitigation measures. The study for the integrated development of the San Miguel-Putumayo river basin on the Colombia-Ecuador border, for example, included a comprehensive examination of all natural hazards that could affect the projects identified. Active fault zones-the locus of potential earthquakes and unstable ground unsuitable for locating infrastructure-were one of the elements studied.

The principal earthquake hazards are ground shaking, fault rupture, and propensity to liquefaction (see the section below on landslides). Once it is recognized that an area is prone to earthquakes, it is important to prepare maps of high-risk areas delineating zones subject to the particular hazards. Some hazard and risk mapping has been completed in Latin America and Caribbean countries, but in general it is not very reliable or useful to engineers, government officials, or planners for site-specific engineering design work. Some national and regional projects have begun to incorporate recent scientific and technological advances into seismic hazard and risk mapping, and are producing work of much higher quality. The availability of existing information, and more particularly the quality of that information, must be determined for areas under seismic threat and supplemented as necessary.

The science of earthquake engineering has devised building techniques and materials that resist all but the strongest earth shaking. Building codes stipulate the application of these structures. Retrofitting may provide important economic benefits for large buildings and public infrastructure. It is also of great importance in saving lives of millions who live in non-engineered mud constructions. Basic do-it-yourself techniques can prolong resistance to shaking of these structures long enough to allow people to escape before collapse. With regard to fault rupture, the best way to cope with this hazard is to avoid the narrow zones prone to movement along faults.

Volcanic Eruptions

The principal volcanic hazards are pyroclastic flows, mudflows (or lahars), ash falls, projectiles, and lava flows. These hazards usually do not constitute a serious problem more than 30 km from the source, although in exceptional cases, a lahar or an ash fall can cause serious damage as much as 60 km away. Table A-5 characterizes all "active" volcanoes in Latin America and the Caribbean. Because some of the most terrible eruptions have come from volcanoes that had been regarded as dormant, an active volcano is defined as one that has erupted in the past 10,000 years (the Holocene Epoch of geologic time). The degree of threat is gauged by periodicity, with short-term periodicity (interval between eruptions of less than 100 years) posing a greater threat than long-term periodicity. The information given for each volcano includes location, periodicity, date of last eruption, a measure of the size or "bigness" of the largest historic eruption, and the hazards associated with its eruptions.

Figure 12 - TOP SEISMIC HAZARD SITES: AREAS IN LATIN AMERICA WITH GREATER THAN 50 PERCENT PROBABILITY OF AN EARTHQUAKE OF MAGNITUDE 7+ DURING 1989-2009

Location	Magnitude (Richter)	Probability (Percent)
Ometepec, Mexico	7.3	74
Central Oaxaca, Mexico	7.8	(72)[a/]
Eastern Oaxaca, Mexico	7.8	70
Western Oaxaca, Mexico	7.4	64
Colima, Mexico	7.5	66
Central Guerrero, Mexico	7.8	(52)[a/]
Southeastern Guatemala	7.5	79
Central Guatemala	7.9	50
Nicoya, Costa Rica	7.4	93
Papagayo, Costa Rica	7.5	55
Jama, Ecuador	7.7	90
Southern Valparaíso, Chile	7.5	61

[a/] Probability values in parentheses reflect less reliable estimates.

Source: Nishenko, S. P. Circum-Pacific Seismic Potential 1989-1999. National Earthquake Information Center, U.S. Geological Survey, Open File Report 89-86 (Reston, Virginia: U.S. Geological Survey, 1989).

If a study area lies within 30 km of a volcano with short-term periodicity, a volcanic hazard zonation map showing the likelihood of occurrence and severity of each hazard in the vicinity of the volcano should be prepared as part of the planning process. Few mitigation measures other than avoidance are effective in resisting volcanic hazards such as lava flows or pyroclastic flows. Steeply sloping roofs help to reduce damage from heavy ash falls.

Tsunamis

These awesome seismic sea waves are caused by large-scale sudden movement of the sea floor, usually due to earthquakes. In Latin America they are a significant threat only on the west coast of South America, where every off-shore earthquake over a magnitude 7.5 is potentially tsunamigenic. While they occur in the Caribbean, they are so infrequent and cause so little damage, mitigation is difficult to justify economically. Even where tsunamis pose a significant threat, mitigation is feasible only for urban concentrations. The construction of sea walls along low-lying stretches of coast, planting tree belts between the shoreline and built-up areas, and zoning restrictions provide some measure of help, but effective warning and evacuation systems are the most reliable defense against this intractable hazard.

Table A-6 gives estimates of the potential tsunami threat for the west coast of South America, showing the potential wave height for population centers from Colombia to Chile that face tsunami hazards. Comparable information is available for Mexico and Central America.

4. Floods

Floods are usually described in terms of their statistical frequency. For example, the flat land bordering a stream that is inundated at a time of high water is called a "100-year floodplain" if it is subject to a 1 percent probability of being flooded in a given year. Commonly, any risk this great or greater is considered significant.

Development practices may unwittingly increase the risk of flooding by increasing the amount of water that must be carried off, or decreasing the area available to absorb it. Drainage and irrigation ditches, as well as water diversions, can alter the discharge into floodplains and a channel's capacity to carry the discharge. Deforestation or logging practices will reduce a forest's water absorption capacity, thus increasing runoff. Large dams will affect the river channel both upstream and downstream: the reservoir acts as a sediment trap, and the sediment-free stream below the dam scours the channel. Urbanization of a floodplain or adjacent areas increases runoff because it reduces the amount of surface area available to absorb rainfall. In short, integrated development planning must examine the potential effect on flooding of any proposed change and must identify mitigation measures that would avoid or minimize flooding for inclusion in investment projects.

First, however, the planning study must establish river flow patterns and propensity to flood. This has commonly been accomplished by gauging rivers and streams, thus directly measuring flood levels and recurrence intervals over a period of many years to determine the statistical probability of given flood events. Without a record of at least twenty years such assessments are difficult, but in many countries stream-gauging records are insufficient or absent. In this situation hazard assessments based on remote sensing data, damage reports, and field observations can be used to map flood-prone areas that are likely to be inundated by a flood of a specified interval.

Remote Sensing Techniques for Floodplain Mapping

Integrated regional development planning studies do not traditionally include original flood hazard assessments but rather depend on available information. If such information is needed but not available, an assessment should be undertaken as part of the study. If time and budget constraints preclude a detailed, large-scale assessment, a floodplain map and a flood hazard assessment can be prepared through the photo-optical method, using Landsat data and whatever information can be found.

Floods and engineering structures on a floodplain cause changes in the river channel, sedimentation patterns, and flood boundaries. A flood often leaves its imprint, or "signature," on the surface in the form of soil moisture anomalies, ponded areas, soil scours, stressed vegetation, and debris lines for days or even weeks after the flood waters have receded. Because satellite imagery can provide a record of these changes and imprints, up-to-date imagery can be compared with previously collected data to determine alterations during specific time periods. Similarly, the inundated area can be compared with a map of the area under pre-flood conditions.

It should be noted that the delineation of flood-plains through remote-sensing data cannot, by itself, be directly related to probabilities of recurrence. However, when these data are used in conjunction with other information such as precipitation records and history of flooding, the delineated floodplain can be related to an event's likelihood of occurrence. This method can reveal the degree to which an area is flood prone and yield information useful for a flood hazard assessment.

As an example, the Government of Paraguay requested the OAS to delineate the floodplain and flood hazards along the Pilcomayo River because of its recurrent flooding. The study team found Landsat data showing the river in normal and flooded conditions, which, after processing and interpretation, made it possible to plot the floodplain boundaries and hazardous zones rapidly and confidently. From imagery taken at three points in time, the analysts were able to identify areas of sediment deposit (Figure 13) and changes in the course of the river (Figure 14). Since this was a preliminary analysis, the map was produced without field checking, thus lowering the cost. The 1:500,000-scale map of about 60,000 sq km was produced in one month at a cost of US$3,800.

Dynamic features of flooding that can cause changes, e.g., changes in the channel of the river itself or floodplain boundaries, can be monitored through repetitive coverage of any area by earth observation satellites. Further, the spatial distribution of the features that have changed can be readily mapped by techniques of temporal analysis developed since the launch of Landsat 1 in 1972.[4/] Slides of full scenes and subscenes can be projected at any scale. The slides can be projected onto a base map, thematic maps, and enlarged satellite single-band prints to define hazard-prone areas for further analysis.

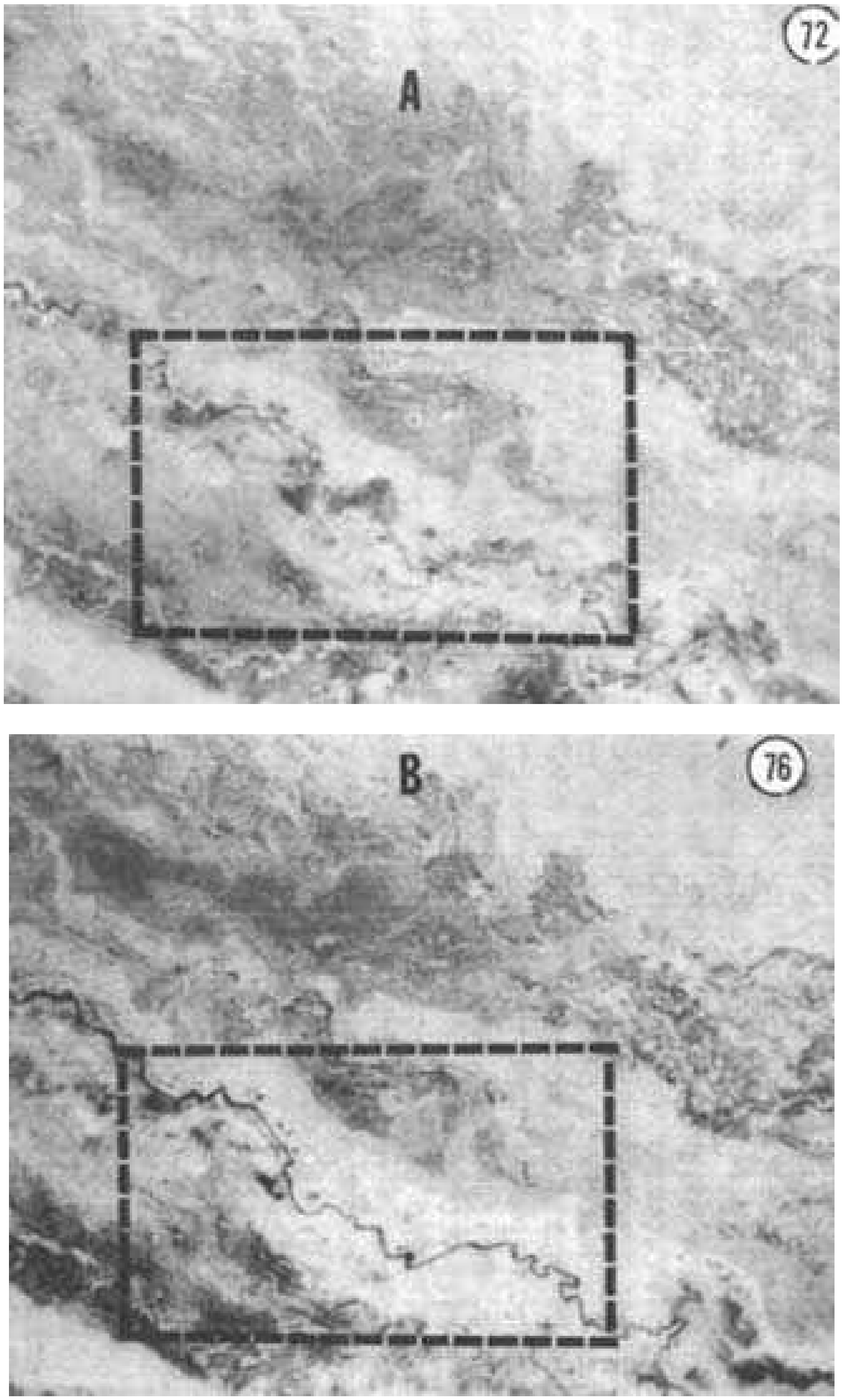
[4/] Deutsch, M. "Optical Processing of ERTS Data for Determining Extent of the 1973 Mississippi River Flood" in. R.C. Williams and W.D. Carter (eds.). ERTS 1 - A New Window on Our Planet, U.S. Geological Survey Professional Paper 929 (Reston, Virginia: U.S. Geological Survey, 1976): pp. 209-213.

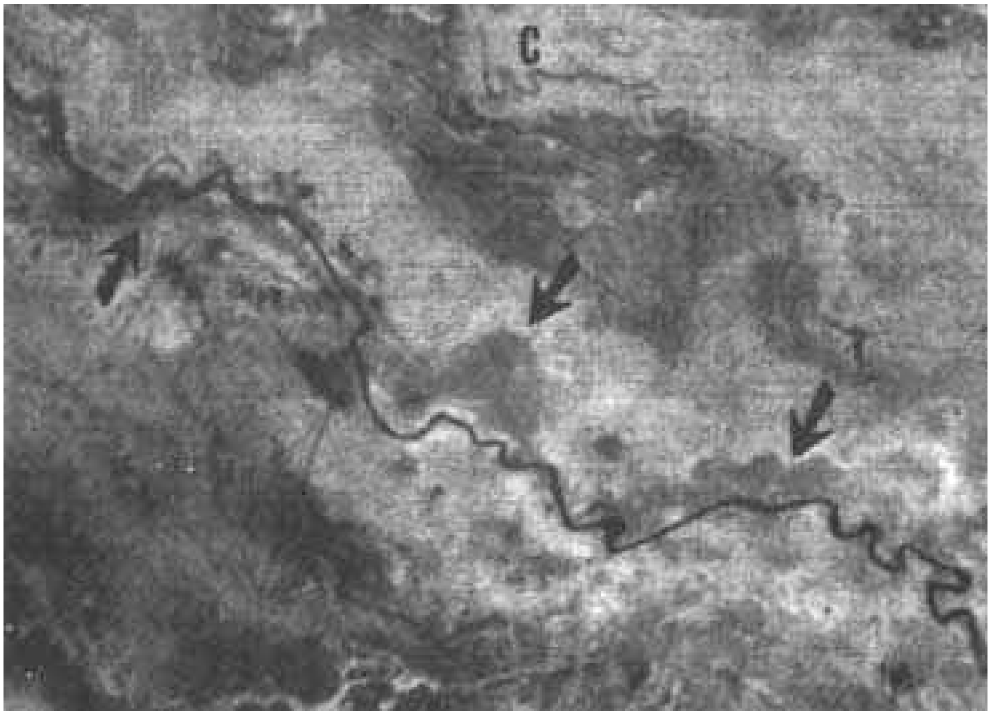
Deutsch, M. and Ruggles, F.H. "Optical Data Processing and Projected Applications of the ERTS-1 Imagery Covering the 1973 Mississippi River Valley Floods" in Water Resources

Bulletin, Vol. 10, No. 5 (1974): pp. 1023-1039.

Deutsch, M., Kruus, J., Hansen, P., and Ferguson, H. "Flood Applications of Satellite Imagery" in M. Deutsch, D. Wiesnet, and R. Rango (eds.). Satellite Hydrology, American Water Resources Association Proceedings from the Fifth Annual W.T. Pecora Memorial Symposium on Remote-Sensing (Sioux Falls, South Dakota: 10-15 June 1979): pp. 292-301.

Figure 13 - USE OF SATELLITE IMAGERY TO DETECT SEDIMENT DEPOSITION





Legend:

A. LANDSAT-1 MSS band-5 negative.
Subscene (path 245/row 76) covering a portion of the Pilcomayo River basin.

Collected September 1, 1972.

B. LANDSAT-2 MSS band-5 negative.

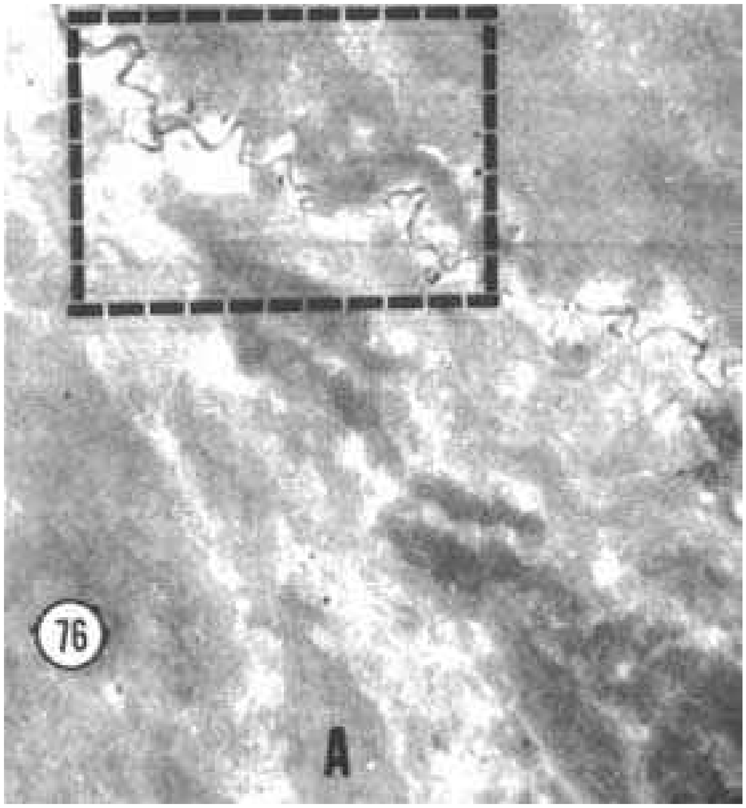
Subscene (path 245/row 76) covering the same portion of the Pilcomayo River basin as in "A" above.

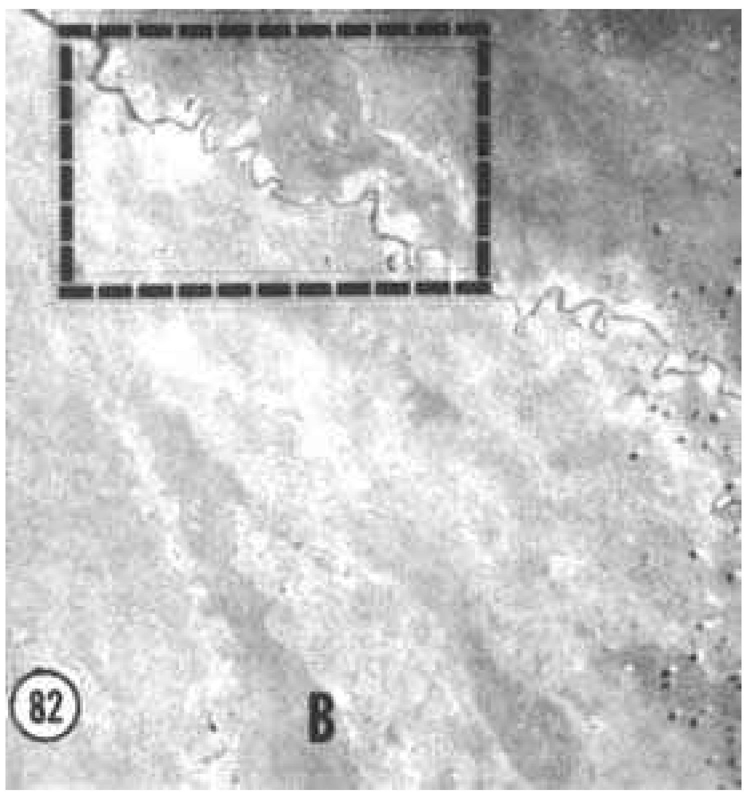
Collected March 29, 1976.

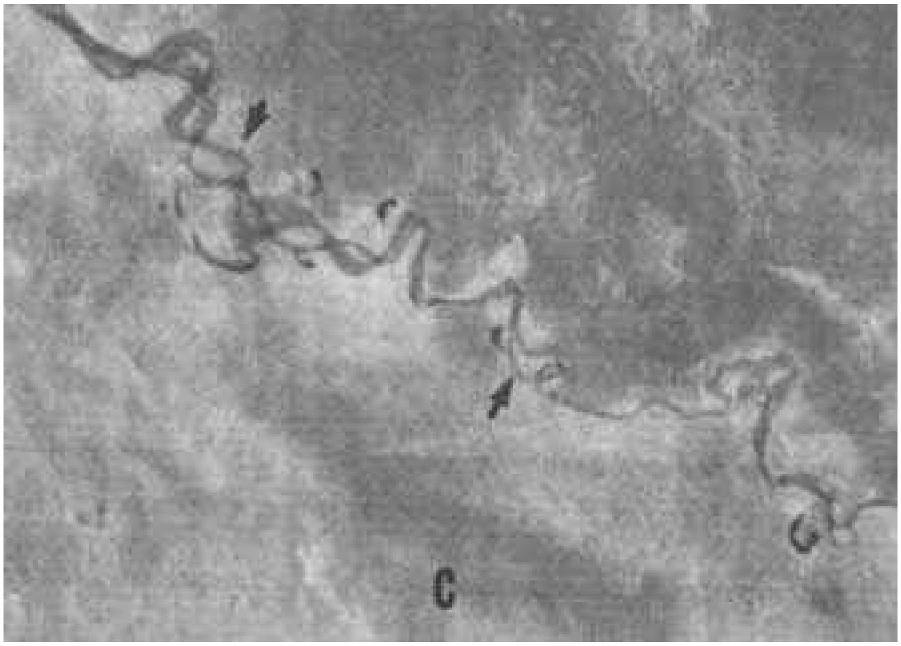
C. Temporal composite of subscenes A and B.
The arrows show the areas of sediment deposition in the interval between 1972 and 1976.

Source: OAS. Primer on Natural Hazard Management in Integrated Development Planning. (Washington, D.C.: In Press)

Figure 14 - USE OF SATELLITE IMAGERY TO DETECT RIVER COURSE CHANGE


76
A


82
B



Legend:

A. LANDSAT-2 MSS band-7 subscence showing a reach of the Pilcomayo River.

Collected March 30, 1976.

B. LANDSAT-4 MSS band-7 subscence showing the same reach of the Pilcomayo River as in "A" above.

Collected October 12, 1982.

C. Temporal composite of subscenes A and B.
The arrows show the change in the course of the Pilcomayo River between 1976 and 1982.

Source: OAS. Primer on Natural Hazard Management in Integrated Development Planning. (Washington, D.C.: In Press)

While data prices vary from source to source and country to country, the cost of data acquisition, analysis, and preparation of analog products usually ranges from about four to 20 U.S. cents per square kilometer. A remote-sensing specialist familiar with photo-optical or computer-enhanced multispectral analysis systems, in collaboration with other planning studies and with regional complementary information and logistical support, would be able to carry out a flood hazard assessment and prepare a flood plain map covering 30,000 to 90,000 square kilometers, at a scale of up to 1:50,000, in approximately one month.

5. Landslides

The term "landslide" conjures up an image of a great mass of rock and dirt roaring down a mountainside, uprooting huge trees, burying whole villages, pushing before it a howling wind that flattens every structure. This is a fair description of an avalanche, one type of the earth mass movements grouped popularly as landslides, but there are several others. Many are less dramatic but nevertheless cause much damage.

For the purpose of hazard management, three general types of earth mass movement merit consideration: (1) slides and avalanches, (2) flows and lateral spreads (liquefaction phenomena), and (3) rockfalls. Slides and avalanches are very rapid movement of colluvial material on over-steepened slopes under conditions of high moisture. They occur commonly to frequently, and each event can cause moderate to great damage, so that collectively they cause very great damage. Liquefaction refers to rapid, fluid movement of unconsolidated material on gently sloping to nearly flat land. These earth movements occur commonly and can cause great to very great damage. Rockfalls are free-falling or tumbling rocks from cliffs and steep slopes. Each event may cause limited damage, but because they are so frequent, cumulatively they cause great damage and loss of life.

Landslides are often triggered by earthquakes but can also be set off by volcanic eruptions, heavy rains, groundwater rise, undercutting by streams, and other mechanisms; consequently, they occur more widely than earthquakes.

The best strategies for mitigating landslide hazards are to avoid construction in hazardous areas and to avoid land uses that provoke mass movement. To build these strategies into development planning requires information on the likely occurrence of landslides. Such information should be compiled only for areas of intensive present or planned land use, since mitigation is not needed in areas of non-intensive use such as extensive grazing or park land.

A map showing landslide potential is suitable for making recommendations on land use intensity, but the more explicit information afforded by a landslide zonation map is required for land use management. Methods of preparing both these types of landslide hazard assessments are discussed briefly below.

The best indicator of landslide potential is the evidence of past landslides. The location, size, and structure of past landslides can be interpreted from remotely-sensed imagery (aerial photography and satellite imagery). A map showing the aerial distribution of landslides can be compiled, and zones of differing landslide potential can be interpreted. Since the map is based simply on frequency of occurrence and not on causal factors, it has limited predictive power.

Slides and avalanches are associated with steep slopes, certain types and structures of bedrock, and particular hydrological conditions. Maps of these characteristics can be prepared, and a landslide zonation map can be compiled by overlaying these causal factors. Much of the required data such as bedrock geology and topography may already be available. The rest can be compiled-again using remote-sensing imagery. The geology, slope, and hydrology data can be overlaid to compile a map on which each unit is a combination of the three natural characteristics. Development activities (e.g., the conversion of forest to grasslands or crops, which increases soil moisture) can increase susceptibility to landslides, and the map units of natural characteristics can be adjusted to show the effects of these human activities. Each of the resulting units can then be characterized as to landslide potential, to provide the basis for preparing a landslide hazard zoning map.

The same process can be followed in evaluating the potential liquefaction, except that for this type of mass earth movement the critical factors are the presence of unconsolidated Holocene sediments (sands and silts less than 10,000 years old) and less than 30-foot depth to the water table.

An example is the landslide hazard assessment prepared by the OAS at the request of Dominica.[5/] The study found that the volcanic origin of the country, resulting in steep slopes and unstable bedrock, and the abundant rainfall together create conditions which readily generate landslides. A full 2 percent of the land area of the country is disturbed by existing landslides, of which the most abundant type is debris flows. The landslide analysis team first delineated all past landslides on black-and-white 1:20,000 aerial photographs and prepared a landslide map at a scale of 1:50,000. Next a map of surface geology was compiled from existing information and overlaid on the landslide map to determine which bedrock units were associated with existing landslides. Six of the eight bedrock units were found to be so associated. Next a map of slope classes was compiled, again from existing information. Four classes were defined that corresponded to present land uses. Hydrologic factors were examined, but no correlation between rainfall distribution or vegetation zones with landslides could be established. Finally, the bedrock and slope units were combined, the composite units were compared with the landslide map, and the proportion of each bedrock-slope unit subject to landslide disturbance was determined.

> [5/] Organization of American States. Landslide Hazard on Dominica, West Indies (Washington, D.C.: OAS, February 1987).

The landslide hazard map was used to locate areas unsuitable for development. Surprisingly, it also showed that an active landslide area could dam a tributary of the Trois Pitons river, threatening the lives of the downstream population. The map of the 290 sq mi country was compiled in six weeks at a total cost of US$13,000.

The important message here is that by using modern remote-sensing techniques a landslide hazard zoning map-which greatly enhances the ability of planners to make intelligent choices about future land use-can be compiled in one or two months at only the costs of technician time and the acquisition of the imagery.

As wise as the strategy of avoiding hazardous areas may be, it is not always possible to follow it. The poor commonly establish squatter settlements on the slide-prone steeply sloping areas surrounding many Latin American urban centers. Landslide mitigation mechanisms tend to be very expensive under these circumstances. At a minimum, squatters should be helped to avoid settling on previous slides, and care should be taken to avoid cutting off the toe of a steep slope to increase the area of a settlement. These areas are most susceptible to sliding in heavy rains, at which time preparatory measures should be taken to deal with large slides that may occur.

Liquefaction can be prevented by ground stabilization techniques or accommodated through appropriate engineering design, but both are expensive.

As with all mitigation measures, these proposals hold only within the constraints of cost-benefit analysis. Avoidance mechanisms will almost invariably yield high cost-benefit ratios. The results for other mechanisms are not as predictable.

Strategies for selected economic sectors

The managers of public and private sectoral agencies share a concern about the vulnerability of their sectors to hazardous events: What hazards threaten which services? Where are the weak links? How much damage might be done? How would the damage affect sector investment, income, employment, and foreign exchange earnings? What is the impact of losing x service in y city for z days? What investment in mitigation would resolve that problem? What is the cost-benefit of that investment? In the experience of the OAS the sectors that can benefit most from vulnerability assessments are energy, transport, tourism, and agriculture, since these sectors typify problems of disaster impact faced by developing countries.

Presented below are case studies of hazard assessments for the energy sector, the tourism sector, and the agriculture sector. The section ends with some strategies for conducting such assessments for selected economic sectors.

1. Energy in Costa Rica

In 1989 the Costa Rican Sectoral Directorate of Energy asked the OAS to assist in analyzing the vulnerability of the energy sector to natural hazards. The study first defined the nature of possible impacts. These included:

- Loss of infrastructure; associated investment losses

- Loss of income to the sector from forgone energy sales

- Effect on the production of goods and services; associated losses of employment income

- Loss of foreign exchange

- Negative impact on the quality of life

It was clear that the study would have to cover not only the main energy subsectors, but also the service and production sectors that could affect or be affected by the supply of energy. Thus it included the electric power system, the hydrocarbon system, railroads, roads, telecommunications, the metropolitan aqueduct, and the major economic production facilities. Existing information was analyzed for earthquakes, volcanic eruptions, landslides, hurricanes, flooding, drought, and erosion.

To evaluate the vulnerability of each facility, the study used two methods simultaneously: field examination and the preparation of a geographic information system which could overlay each hazard with each energy and service system. Figure 15 shows one of the GIS overlays: landslide threats to transmission lines. Matrices prepared to show impacts were rated as follows:

- No impact
- Potential threat, major or minor
- Confirmed threat, major or minor

Figure 15 - COSTA RICA: ENERGY SECTOR VULNERABILITY TO LANDSLIDE HAZARDS

Source: Adapted from Departamento de Desarrollo Regional/Organización de los Estados Americanos (OEA), and Dirección Sectorial de Energía/Ministerio de Recursos Naturales, Energía y Minas de Costa Rica (MIRENEM). Amenazas Naturales y la Infraestructura Energética de Costa Rica (San José, Costa Rica: Unpublished report, 1989).

A rapid examination of the threats yielded a number of serious problems. The confirmed major impacts caused by each hazard in each sector are shown in Figure 16. The most important problems were studied in greater detail and actions to deal with them were recommended. Some examples follow.

- The worst event would be a strong earthquake or volcanic eruption that breached Arenal dam or crippled the Arenal and Corobici hydroelectric plants, cutting off half of the hydropower in the country. The probability of such an event is low, but the magnitude of the catastrophe is so great it has to be planned for. The report recommended contingency plans for emergency generation and the establishment of new power plants outside the Arenal system.

- Two critical substations and two transmission lines are threatened by earthquakes, landslides, volcanic eruptions, flooding, and severe windstorms. The multiple hazards make the probability of occurrence moderate, and the loss of any of these components would cut off power from the Arenal system to the central region. The report recommended building a alternate transmission line that would bypass the four components.

- Landslides periodically damage one segment of the railroad that carries heavy petroleum derivatives from the refinery on the Atlantic Coast to a critical substation in San Jose. Since having the substation out of commission for a long time would be a major catastrophe for the region and rerouting the railroad would be too expensive, the report recommended equipping a West Coast port with facilities for handling a substitute supply which could be trucked to San Jose.

Figure 16 - NUMBER OF CONFIRMED MAJOR IMPACTS OF NATURAL HAZARDS ON ENERGY FACILITIES IN COSTA RICA

	Electric Power Subsector				Oil and Gas Subsector[a/]		Transport Sector	
	Hydropower plants	Thermal plants	Transmission lines	Substations	Refinery	Pipelines	Railroads	Roads
Earthquakes	- -	- -	- -	15	- -	1	- -	3
Landslides[b/]	- -	- -	15	8	- -	4	6	15
Hurricanes								

Flooding	- -	1	4	4	- -	- -	4	-
Wind	- -	- -	4	2	1	- -	4	-
River flooding	1	1	4	2	- -	- -	7	1
Erosion	- -	- -	- -	- -	- -	- -	2	- -

a/ No confirmed major impacts on port or substations

b/ Caused by earthquakes, volcanic eruptions, flooding, hurricanes

Source: Adapted from Departamento de Desarrollo Regional/Organización de los Estados Americanos (OEA), and Dirección Sectorial de Energía/Ministerio de Recursos Naturales, Energía y Minas de Costa Rica (MIRENEM). Amenazas Naturales y la Infraestructura Energética de Costa Rica (San José, Costa Rica: Unpublished report, 1989).

The Government found the recommendations valid and is now seeking financing for feasibility studies of the most critical ones. It is noteworthy that so many serious problems could be identified in a three-month study and, more importantly, that many were amenable to mitigation by relatively modest investments.

2. Tourism in Jamaica

The geographic and climatic setting of the Caribbean and the siting of tourism projects on or near the beaches combine to make Caribbean tourism especially vulnerable to disruption from natural disasters. In the island countries hurricanes are the most damaging hazard, but land-based flooding, landslides, earthquakes, and wildfires also exact a toll.

Direct damage caused by Hurricane Gilbert to property and equipment of the Jamaican tourism industry amounted about US$85 million. The indirect damage was much greater. In foreign exchange alone the cost from September to December 1988 was US$90 million-a particularly painful loss since the foreign exchange was needed to finance recovery programs. The temporary closing of hotels for repairs meant fewer visitors to the island, causing other indirect effects such as loss of income for the national airline and reduction in employment and the purchase of local goods and services.

The vulnerability of the tourism industry is not confined to its own capital stock, as was demonstrated by the Jamaican experience. Damage to roads, utilities, airports, harbors, and shopping centers also affected the industry. Conscious of the need to minimize damage from future events, the Government of Jamaica requested OAS technical cooperation in preparing an assessment of the vulnerability of the tourism sector to natural hazards and recommending mitigation actions.

The assessment disclosed that much of the damage to tourism facilities, as to other buildings, was due to lack of attention to detail in construction and maintenance, particularly in roof construction. Roof sheeting was poorly interlocked. Tie-downs of roof structures were inadequate. Nail heads were rusted off. Timber strength was reduced by termites, and metal strength by corrosion. Much glass was needlessly blown out because of faulty installation and poor design criteria, but also because windows were not protected from flying debris. Drains clogged with debris caused excessive surface runoff, resulting in erosion and scouring around buildings. Local water shortages developed because the lack of back-up generators prevented pumping. Although a major contributor to the damage, faulty building practices and maintenance deficiencies are easy to correct: it was calculated that proper attention to these matters would have increased the cost of construction less than 1 percent.

Long-term mitigation measures were also identified. The study recommended the protection of beach vegetation, sand dunes, mangroves, and coral reefs, all of which help to protect the land from wave and wind action. New construction sites should be evaluated for susceptibility to hazards. Setback distance from the shore should be enforced, and the quality of sewage outfall should be maintained to protect live coral formations.

In short, the preliminary study, conducted in one month, identified a number of possible actions that would substantially reduce the impact of future hurricanes and other natural hazards. The preliminary analysis indicated that many of these actions would have a high cost-benefit ratio. Subsequently, Jamaica requested IDB financing to undertake feasibility analyses of these proposals and to implement them. The ultimate objective of this work is for the tourism sector to arrive at a "practical and effective loss reduction strategy and program in response to the risks posed by natural disasters to the industry."

3. Agriculture in Ecuador

In Ecuador, as in most Latin American and Caribbean countries, agriculture is one of the most important sources of income, employment, investments, and foreign exchange earnings. However, it is perhaps the most vulnerable and least protected sector in terms of infrastructure and institutional support to cope with natural hazards. In the floods caused by the El Niño phenomenon in 1982-83, for example, the agricultural sector suffered 48 percent of the US$232 million in damage. Furthermore, besides generating inflationary pressures on domestic prices, the disaster had a significant impact on the balance of payments due to the loss of export crops and the need to import basic food products to compensate for domestic production losses.[6/]

> [6/] United Nations Economic Commission for Latin America and the Caribbean (ECLAC). Ecuador: Evaluation of the Effects of the 1982/83 Floods on Economic and Social Development (New York: ECLAC, 1983).

In 1990, the Ministry of Agriculture asked the OAS to assist in evaluating the vulnerability of the agricultural sector to natural hazards and identifying appropriate mitigation strategies to reduce it to acceptable levels. These strategies would be identified as project ideas or project profiles, some of which would be selected by local officials to be further studied and evaluated to determine their economic and technical viability.

The study, conducted at the national level, first defined 14 of the most important crops, grouped in three categories: basic food crops, strategic crops, and export crops. Key infrastructure support elements for the production, processing, storage, transportation, and distribution of agricultural products were also defined and geographically located. This information was overlaid in a geographic information system (GIS; see next section) with information on drought, erosion, floods, landslides, volcanic eruptions, and seismic hazards.

By relating province-level socioeconomic data to potential affected areas, the study was able to determine the impacts of natural events in terms of sectoral income, employment, investments, foreign exchange earnings, and national food security. On the basis of these criteria, 49 different situations were selected as the most critical. It was found, for example, that erosion hazards in Carchi Province would affect in the medium to long run 11,750 ha of the potato-growing area, which accounts for more than 43 percent of the national production and for 40 percent and 80 percent, respectively, of the employment and income produced by the sector in the province.

The most serious problems according to each of the five criteria were identified, and policy options that would achieve the best gains were established. It was determined, for example, that policies oriented to avoid unemployment should seek to mitigate flood hazards in Guayas Province and erosion hazards in Tungurahua Province. To protect foreign exchange earnings, the most effective actions would be to protect banana production in El Oro Province against drought hazards and to mitigate flood hazards in Guayas Province, especially in areas used for coffee and banana production.

Possible mitigation strategies were also identified as part of the study, and planned or on-going programs and projects in the Ministry of Agriculture and other institutions were identified as suitable for carrying out some of these mitigation strategies and more detailed studies. A report describing the major findings and recommendations was prepared and submitted to the Government for review. Based on these recommendations, a US$317,000 technical cooperation proposal for hazard mitigation activities within the sector has been prepared by the Government and is to be presented to outside agencies for financing.

4. Strategies derived from the case studies

The following observations are common to many sectors. Of course, many additional strategies apply to individual sector studies.

Sectors are useful units of analysis for examining hazard assessment and vulnerability reduction issues.

Sectors are recognizable and legitimate program subjects. Banks make loans on the basis of sectors. A sectoral approach fits the organizational structure of both international finance agencies and national governments. The knowledge and experience of most technical professionals is built around a sectoral approach. Information for the development diagnosis (Phase I of an integrated development planning study) is collected and analyzed on a sectoral basis. Sectoral studies need not be restricted to economic sectors: urban and rural sectors and the poor also make valid units of study.

Vulnerability reduction measures can be cost-effective, either as stand-alone projects or, more commonly, as component elements of overall sector development programs. Including such measures can improve the cost-benefit ratio of investment projects.

Sector vulnerability studies are a new approach which can be considered for inclusion in development diagnosis (Phase I) studies. Initial national-level studies allow for a quick and low-cost assessment of policies and projects at a profile level that can be examined in greater detail later.

Sectoral studies reveal previously unrecognized linkages between disasters and development. Often a sector is unaware of its role in the lifeline or critical facilities network. In many cases it has no strategy for dealing with abnormal situations resulting from any exogenous event. The complex interrelationships among the components of some sectors make it difficult to cope with the impact of a natural event. This is particularly true when the sector is more concerned with one set of components, such as the production or generation of power, than with another set such as transmission, distribution, and storage. Furthermore, sectors usually do not have an adequate understanding of the effect a curtailment of service can have on other sectors.

A sector may have to select between competing objectives to arrive at a vulnerability reduction strategy.

Criteria that define those competing objectives include investment in the sector, income stream, export earnings, employment, and sector security. The cost of a component may be disproportionate to the impact of its loss as measured by one of these criteria.

Tools and techniques for natural hazard assessment

1. Geographic information systems

An increasing number of planning agencies throughout the region are attempting to undertake natural hazard mitigation activities through development planning studies. However, while the expertise and baseline data in the form of maps, documents, and statistics may exist, a systematic approach is often lacking. The volume of information needed for natural hazards management, particularly in the context of integrated development planning, exceeds the capacity of manual methods and makes the use of computerized techniques compelling.

Geographic information systems (GIS) can play a crucial role in this process, serving as a tool to collect, organize, analyze and present data. A GIS is a systematic means of combining various bits of information about a unit of geographic space. The concept is analogous to a panel of post-office boxes, each representing a specified area. As each element of information about a particular attribute (soil, rainfall, population) that applies to the area is identified, it can be placed into the corresponding box. Since there is theoretically no limit to the amount of information that can be entered into each box, huge volumes of data can be compiled in an orderly manner, generating a collection of mapped information which reveals spatial relationships between the different attributes, e.g., hazardous events, natural resources, and socioeconomic phenomena, and can thus help planners assess the impact of natural events on existing and proposed development activities.

The use of GIS offers a number of advantages:

- It can be surprisingly cheap; very expensive equipment and highly specialized technicians can be avoided by proper selection of a system and its application. The main constraint is not typically a lack of funds but rather a lack of trained personnel.

- It can multiply the productivity of a technician.

- It can give higher quality results than can be obtained manually, regardless of the costs involved. It can facilitate decision-making and improve coordination among agencies when efficiency is at a premium.

The information to be assembled in a GIS for hazards management will be determined by the level of application (national, regional, or local) and by what it is to be used for: natural hazard assessments, vulnerability assessments, disaster preparedness and response, or post-disaster relief and reconstruction activities. In general, there are three different categories of information:

- Natural hazards information, which denotes the presence and effect of natural phenomena. This information should ideally include the location, severity, frequency, and probability of occurrence of a hazardous event. Location is the easiest for planners to find; the rest can often be obtained from sectoral agencies, natural hazard research and monitoring centers, and, increasingly, integrated development planning studies.

- Information on natural ecosystems (e.g., slopes and slope stability, river flow capacity, vegetation cover), which provides the basis for estimating the effect natural hazards can have on the goods and services these systems offer and also determines the factors or conditions that create, modify, accelerate, and/or retard the occurrence of a natural event.

- Information on population and infrastructure, which is the basis for quantifying the impact natural events can have on existing and planned development activities. Large-scale data describing lifeline infrastructure and human settlements, for example, are critical elements for preparing vulnerability assessments and for initiating disaster preparedness and response activities.

Most of these data are readily available throughout the region.

The GIS can be used for hazards management at different levels of development planning. At the national level, it can provide a general familiarity with the study area, giving planners a reference to the overall hazard situation. At the regional level, it can be used in hazard assessments for resource analysis and project identification. And at the local level, it can be used to formulate investment projects and specific mitigation strategies. The following section demonstrates its versatility.

Applications at the National Level

At the national level, planners can use GIS to categorize land with regard to natural hazards and determine whether, and to what extent, natural phenomena pose a significant danger. At this level, location is usually enough for a first estimation of the overall hazard situation. Examples of categories include:

- Hazard-free areas apt for development activities.

- Areas prone to severe natural hazards where most development should be avoided.

- Hazardous areas where development has already taken place and measures to reduce vulnerability are needed.

- Areas where further hazard evaluations are required.

In hazard-prone areas, GIS can be used to overlay hazard information with socioeconomic or infrastructure data-on population density, location of urban areas, ports, airports, roads, electricity network-for a preliminary quantitative assessment of people and property at risk. This can provide the necessary elements for the identification of structural and/or non-structural mitigation measures, which can be incorporated as a component in integrated sectoral development projects or as part of a national strategy to lessen vulnerability.

The identification of existing critical facilities, infrastructure, and population in high-risk areas is also the first step in the vulnerability assessment for disaster preparedness and response.

Applications at the Regional Level

At the regional level, GIS can be used for a more detailed study to identify the development potential and hazard-related constraints of selected areas. Typically, national-level information is complemented at the regional level with more comprehensive mapped and tabular data including, for example:

- Hazard assessments, including use of remote sensing information (i.e., aerial photographs and satellite imagery).

- Maps showing floodplain boundaries, landslide areas, seismic zones, tsunami-susceptible areas, etc.

- Soils, topography, land use, water resources, lifeline network, and density of population and structures.

With this type of information, it is possible to make a more intensive analysis relating natural hazards to planned or existing development activities. As with national-level exercises, the vulnerability of existing critical segments of production facilities, infrastructure, and human settlements can be determined, to give disaster mitigation and preparedness their proper priority in development activities.

Some examples of GIS applications at the regional level are:

- Identification of investment projects and preparation of project profiles showing where hazard mitigation measures (flood protections, earthquake resistant structures, etc.) must be taken into account in the design.

- Preparation of hazard mitigation projects to reduce risk on currently occupied land.

- Guidance on land use and intensity.

These and other applications can take advantage of the flexibility of scale in a GIS: small to medium scale for resource inventory and project identification; medium scale for project profile and prefeasibility studies; and large scale for feasibility studies, hazard zone mapping, and urban hazard mitigation studies. Information originally entered for one purpose at a particular scale can be used for another at a different scale.

GIS capabilities can also be used at this level to generate hazard information not readily available. If applied to information about slope, precipitation, and the carrying capacity of rivers, for example, GIS could determine maximum flood levels and threshold levels of precipitation. Similarly, landslide inventories can be combined with data on slope, bedrock, and hydrology to provide the likelihood of a future landslide. Such syntheses can help planners determine where to construct a future dam or reservoir in order to prevent flood-induced damage, or where heavy capital investments or construction should be avoided and/or less landslide-susceptible activities implemented.

Applications at the Local Level

At the local level, planners can use a GIS to formulate projects at the prefeasibility and feasibility levels and to locate vulnerable lifeline network elements for the implementation of emergency preparedness and response activities. The presence of hazards should affect the site selection, engineering design, and economic feasibility of investment projects.

Lifeline networks are the critical elements of an area, which should be made as little vulnerable to damage as possible or be recognized as priority elements for rehabilitation or reconstruction following a disaster. In Latin America and the Caribbean, few planners will find already-prepared individual or aggregated lifeline network maps. Where none exists, a GIS can be used to prepare one. Some components typically included are:

- Ports and airports (primary and secondary, international, national, and regional, both public and private)

- Hospitals, health centers, medical posts

- Police stations, fire stations

- Schools, universities, auditoriums, convention centers

- Energy infrastructure and supply system, including pipelines and transmission lines

- Road network (highways, primary and secondary roads, bridges, underpasses, railroads)

- Emergency management facilities

- Telecommunications transmission and relay installations

Once the lifeline network map has been prepared, it can be further combined with hazard information for an initial determination of the most vulnerable segments and the identification of mitigation measures and disaster preparedness activities.

Guidelines for GIS Acquisition

As enticing as it may look, a GIS is not always applicable to a given situation, and it may not necessarily pay for itself. Planners need to make a meticulous evaluation of their GIS needs in terms of specific objectives and applications before deciding to acquire a system. Among the basic questions that have to be answered are:

- What planning activities will be supported by the proposed GIS?

- How many and what kinds of decisions is it intended to support?

- How will it improve planning activities and the decision-making process?

- How much information, time, and training are going to be needed to obtain the desired results? Is it feasible?

- How will the GIS be converted into local instructions? What difficulties can be anticipated among local administrators and decision-makers?

If this investigation reaches positive conclusions, the logical next step is to determine what kind of system should be acquired and the type of hardware and software to be used. In general, experience in the region shows that PC-based GIS are the most practical for planning teams analyzing natural hazard issues in integrated development projects. Although they may not produce maps of cartographic quality or of sufficient detail for engineering design they are capable of generating maps of varying scales and tabular information suitable for repeated analysis, project design, and decision-making, and are most affordable and relatively simple to operate.

Among PC-based GIS, however, there are still a myriad of possibilities among hardware and software combinations. Again, the system to choose should be simple and must, of course, fit the budget and technical constraints of the agency. Sophisticated (and expensive) systems require more technical skills, may be more difficult to maintain and repair locally, and, especially for the purposes of map analysis for hazards management, their added capabilities may not be worth the additional cost. Given the financial and technical constraints that prevail in the region, it is wise to start with a modest system and later expand it as the agency's needs dictate.

2. Remote sensing in natural hazard assessments

Remote sensing refers to the process of recording information from sensors mounted either on aircraft or on satellites. The technique is applicable to natural hazards management because nearly all geologic, hydrologic, and atmospheric phenomena are recurring events or processes that leave evidence of their previous occurrence. Revealing the location of previous occurrences and/or distinguishing the conditions under which they are likely to occur makes it possible to identify areas of potential exposure to natural hazards so that measures to reduce the social and economic impact of potential disasters can be introduced into the planning process.

Aerial remote sensing is useful to natural hazard management for focusing on priority areas, verifying small-scale data interpretations, and providing information about features that are too small for detection by satellite imagery. Among the available airborne systems, the most useful for natural hazard assessments and integrated development planning are aerial photography, airborne radars, and thermal infrared (IR) scanners. Each has its advantages and limitations:

- Aerial photography provides the closest approximation of what the human eye sees. The film can be black and white (the least expensive medium), conventional color, or color infrared. Its use is limited by the available light and the weather, but it shows considerably more detail than radar at the same scale.

- Airborne radars are active sensors that produce their own illumination and whose images appear as black-and-white photography. They usually require an interpreter. Radar can be used at any time in any weather, and an area can be surveyed much more rapidly and distance can be measured more accurately with radar than with photography.

- Thermal IR scanners use a semiconductor detector sensitive to the thermal infrared part of the spectrum to produce imagery that defines the thermal pattern of the terrain. The capability of thermal imaging is unsurpassed, but because the airborne system can only be used at lower altitudes (under 3,000 m), it covers smaller areas than either radar or aerial photography. In addition, its recording technique produces inherent distortions in the final built-up image scene.

Despite their usefulness, extensive aerial surveys are not often undertaken since they commonly exceed the budget constraints of a planning study and may provide more information than necessary, particularly during the early stages.

Remote sensing from satellite vehicles has become increasingly important since the successful launch of Landsat 1 in 1972. It provides the synoptic view required by the broad scale of integrated development planning studies.

Given the range of tools available for aerial and satellite remote sensing, their applications vary according to the advantages and limitations of each. Their use in assessments of each of the major natural hazards is discussed in the following paragraphs.

Floods

The most obvious evidence of a major flood potential, outside of historical evidence, is identification of floodplain or flood-prone areas, which are generally recognizable on remote sensing imagery. The most valuable application of remote sensing to flood hazard assessments, then, is in the mapping of areas susceptible to flooding, and satellite sensor coverage of a planning study area is the practical tool for floodplain definition because of cost and time factors. Such mapping may permit the delineation of potentially flood-prone areas where the defined flood level exceeds an acceptable degree of loss. When no floods have occurred during the period of the sensor operation, indirect indicators of flood susceptibility may be used to determine such levels.

But cloud cover or heavy haze will conceal large parts of tropical humid ecosystems from satellite imagery. In some instances the heavy tropical vegetation masks many of the geomorphic features so obvious in drier climates. In this case the use of available radar imagery from space or previously acquired from an aircraft survey is desirable. The radar imagery can satisfactorily penetrate the clouded sky and define many floodplain features. Moisture on the ground noticeably affects the radar return and, together with the textural variations emphasized by the sensor, makes radar a suitable alternative for flood and floodplain mapping.

Hurricanes

Areas of potential inundation along coasts and inland can be predicted using topographic maps with scales as large as 1:12,500. When such maps are not available, remote sensing techniques can be used. In areas with a distinct wet and dry season, information for the wet season can be obtained from high-resolution satellite imagery to identify both the moisture-saturated areas susceptible to flooding and the higher and drier ground for potential evacuation areas.

If imagery of areas inundated by floods, hurricanes, or other storms is obtained with any sensor immediately after the event, it should be used regardless of its resolution, since its delineation of problem areas will be more exact than any interpretations of higher-resolution data from a non-flood period.

Earthquakes

In most areas of earthquake activity some seismic information is usually available, although it may not be sufficient for planning purposes. Remote sensing techniques and resulting data interpretation can play a role in providing the additional information needed.

Airborne radar has been successfully used to locate fault zones, to identify unconsolidated deposits - upon which most of the destruction occurs - and to delineate areas where an earthquake can trigger landslides. Conventional aerial photography, in black and white or color, would also work well.

Color IR composites from satellite imagery, at scales up to about 1:100,000, can also be used to define active surface fault zones. Radar would be better, but the available coverage is extremely limited and the cost of contracting airborne radar is usually prohibitive. Satellite imagery from Landsat is the most practical data source, simply because of its availability, and provides sufficient resolution for regional planning studies.

Volcanic Eruptions and Related Hazards

Prediction of a volcano's behavior is extremely difficult, and the best evidence for the frequency and severity of activity is the history of eruptions. The interpretation of remote sensing data can lead to a recognition of past catastrophic events associated with recently active volcanoes. This information can be supplemented with the available historical data.

The varied nature and sizes of volcanic hazards require the use of various types of sensors from both satellites and aircraft. The relatively small area involved with volcanoes should encourage the use of aerial photography in their analysis. Black-and-white aerial coverage at scales between 1:25,000 and 1:60,000 is usually adequate to recognize and map geomorphic evidence of recent activity and associated hazards. Color and color IR photography may be useful in determining the possible effects of volcanic activity on nearby vegetation, but the slower film speed, lower resolution, and high cost diminish much of any advantage they provide.

The airborne thermal IR scanner is probably the most valuable tool in surveying the geothermal state of a volcano. The heat within a volcano and underlying it and its movement are amenable to detection, and many volcanoes thought to be extinct may have to be reclassified if aerial IR surveys discover any abnormally high IR emissions from either the summit craters or the flanks. However, because of the rapid decrease in resolution with increasing altitude (about 2 m per 1,000 m), the surveys need to be made at altitudes under 2,000 m.

Landslides

In an area with a potential landslide hazard there is usually some evidence of previous occurrences, if not some historical record. Usually the scars of the larger slides are evident, and although smaller slide features may not be individually discernible, the overall rough appearance of a particular slope can suggest that mass movement occurred.

The spatial resolution required for the recognition of most large landslide features is about 10 m.[7/] This precludes the use of most satellite-borne sensor imagery, although large block landslides can be detected on Landsat. Recognition depends to a great extent on the ability and experience of the interpreter and is enhanced by the availability of stereoscopic coverage, which can be expensive to acquire.

> [7/] Richards, P. B. The Utility of Landsat-D and Other Satellite Imaging Systems in Disaster Management, Final Report. NASA Goddard Space Flight Center Disaster Management Workshop, NASA DPR S-70677 (Washington, D.C.: Naval Research Laboratory, March 29-30, 1982).

The best sensor system for detecting both large and (to the extent that they can be found at all) small landslides is aerial photography, and photographic scales as small as 1:60,000 can be used. Black-and-white panchromatic or IR films are adequate in most cases, but color IR may prove better in some instances, since it eliminates much of the haze found in the humid tropics.

Other possibly applicable techniques include thermal IR scanners and radars. The thermal IR scanner is particularly helpful in locating seepage areas that lubricate slides, but its use is usually ruled out by the low altitude required for reasonable spatial resolution, the large number of flight lines required for the large area involved, and the geometric distortions inherent in the system. Radar can be marginally useful because of its ability to define some larger textures related to landslides, and it may be the only sensor that can provide interpretable information in some cloud-prone environments.

Desertification

Both spaceborne and airborne remote sensing provide valuable tools for evaluating areas subject to desertification. Film transparencies, photographs, and digital data can be used to locate, assess, and monitor the deterioration of natural conditions in a given area. Information about these conditions can be obtained from direct measurements or inferred from indicators.

Large-scale aerial photography provides a great amount of detail for desertification studies. Systematic reconnaissance flights can be used for environmental monitoring and resource assessment. Radar sensors and IR scanners may be used to monitor soil moisture and other desertification indicators. However, acquisition of this type of data is costly and time-consuming. The use of satellite imagery is recommended during the first stages of a detailed desertification study, since it offers an overview of the entire region.

As for any other natural-hazard-related study, the data from aerial and space remote sensing must be combined with data collected on the ground. Together, these can provide the basis for the assessment.

3. Special mapping techniques

The use of mapping to synthesize data on natural hazards and to combine these with socioeconomic data facilitates analysis and improves communications among participants in the hazard management process and between planners and decision-makers. Two important techniques are multiple hazard mapping and critical facilities mapping. The discussion below treats the preparation of these maps, their applications, and the benefits of combining them.

Multiple Hazard Mapping

Valuable information on individual natural hazards in a study area may appear on maps with varying scales, coverage, and detail, but these disparate maps are difficult to use in risk analyses or in deciding on suitable mitigation measures. Information from several of them can be combined in a single map to give a composite picture of the magnitude, frequency, and area of effect of all the natural hazards (see Figure 17).

The multiple hazard map (MHM; also called a composite, synthesis, or overlay map) is an excellent tool for fomenting an awareness of natural hazards and for analyzing vulnerability and risk, especially when combined with the mapping of critical facilities. Its benefits include the following:

- Characteristics of the natural phenomena and their possible impacts can be synthesized from different sources and placed on a single map.

- It can call attention to hazards that may trigger others (as earthquakes or volcanic eruptions trigger landslides) or exacerbate their effects.

- A more precise view of the effects of natural phenomena on a particular area can be obtained. Common mitigation techniques can be recommended for the same portion of the study area.

- Sub-areas requiring more information, additional assessments, or specific hazard-reduction techniques can be identified.

- Land-use decisions can be based on all hazard considerations simultaneously.

Figure 17 - NATURAL HAZARDS MAP OF THE PARAGUAYAN CHACO

Source: Adapted from OEA. Proyecto de Desarrollo Urbano Paraguayo. Mapa de Riesgos Naturales del Chaco Paraguayo, Area de Programa 4-C. (Washington, D.C.: Organization of American States, 1985).

The use of a multiple hazard map also has several implications in emergency preparedness planning:

- It provides a more equitable basis for allocating disaster planning funds.

- It stimulates the use of more efficient, integrated emergency preparedness response and recovery procedures.

- It promotes the creation of cooperative agreements to involve all relevant agencies and interested groups.

The base map upon which to place all the information is the first consideration. It is usually selected during the preliminary mission. If at all possible, it is best to use an existing map or controlled photograph rather than go through the difficult and time-consuming process of creating a base map from scratch.

The scale used for an MHM depends on the hazard information to be shown, and the scale of the base map. If a choice of scales is available, then the following factors should be considered:

- Number of hazards to be shown.
- Hazard elements to be shown.
- Range of relative severity of hazards to be shown.
- Area to be covered.
- Proposed uses of the map.

Much hazard information will be in forms other than maps, and not readily understandable by laymen. It must be "translated" for planners and decision-makers and placed on maps. The information should explain how a hazard may adversely affect life, property, or socioeconomic activities, and must therefore include location, likelihood of occurrence (return period), and severity. If some of this information is missing, the planning team must decide whether it is feasible to fill the gaps. Development and investment decisions made in the absence of these data should be noted.

Despite the importance of multiple hazard maps in the integrated development planning process, planners and decision-makers must remember that the credibility, accuracy, and content of an MHM are no better than the individual hazard information from which it was compiled. Furthermore, since it contains no new information - it is merely a clearer presentation of information previously compiled - the clarity and simplicity of the map is the key to its utility.

Critical Facilities Mapping

The term "critical facilities" means all man-made structures or other improvements whose function, size, service area, or uniqueness gives them the potential to cause serious bodily harm, extensive property damage, or disruption of vital socioeconomic activities if they are destroyed or damaged or if their services are repeatedly interrupted.

The primary purpose of a critical facilities map (CFM) is to convey clearly and accurately to planners and decision-makers the location, capacity, and service area of critical facilities. An extensive number of such facilities can be presented at the same time. Also, when combined with a multiple hazard map, a CFM can show which areas require more information, which ones require different hazard reduction techniques, and which need immediate attention when a hazardous event occurs. Some of the benefits of a CFM are:

- The lack of redundancy or the uniqueness of service of facilities is discovered.

- Facilities that may require upgrading and expansion are identified.

- The impact of potential development on existing infrastructure can be assessed before a project is implemented.

- Any need for more (or better) hazard assessment becomes apparent.

Combining Critical Facilities Maps and Multiple Hazard Maps

There are many advantages to making a CFM, comparing or combining it with a MHM, and integrating both into the development planning process. For example, if a critical facility is found to be in a hazardous area planners and decision-makers are alerted to the fact that in the future it may confront serious problems. Its equipment, use and condition can then be analyzed to evaluate its vulnerability.

If appropriate techniques to reduce any vulnerability are incorporated into each stage of the planning process, social and economic disasters can be avoided or substantially lessened. New critical facilities can be made less vulnerable by avoiding hazardous areas, designing for resistance, or operating with minimal exposure. Strategies for existing critical facilities include relocation, strengthening, retrofitting, adding redundancy, revising operations, and adopting emergency preparedness, response, and recovery programs.

The benefits obtained by combining a CFM and an MHM include:

- Project planners and decision-makers are made aware of hazards to existing and proposed critical facilities prior to project implementation.

- The extent to which new development can be affected by the failure or disruption of existing critical facilities as a consequence of a natural event can be determined.

- More realistic benefit-cost ratios for new development are possible.

- Sub-areas requiring different assessments, emergency preparedness, immediate recovery, or specific vulnerability reduction techniques can be identified.

The combination of CFM and MHM can be used by agencies concerned with land-use planning, preparedness and disaster response, utility services including energy, transportation, and communication, and national security and community safety. It is also important when preparing investment projects for national and international bank lending. A discussion of the various uses follows.

Land-Use Planning. Land-use planning is one of the most efficient ways of avoiding or reducing the density of development in hazardous areas. In one seismic-prone California (U.S.A.) county, all the potential earthquake hazards - liquefaction, lurching, lateral spreading, differential settlement, ground displacement, landslides, and flooding due to dike failure - were combined on an MHM and three zones were marked out to indicate different degrees of need for detailed site investigations. Urban settlements, transportation, utilities, and emergency facilities were then superimposed. This graphic presentation made citizens, as well as planners and decision-makers, aware of the potential damage in the varying hazard zones. In addition, large-scale maps can show potential hazards in relation to property boundaries.

Development Regulations. Sometimes critical facilities and hazards information are shown on a map selected for regulatory purposes. For example, a 1972 California law provides for public safety by restricting development in surface fault rupture zones. Reproducible copies of pertinent maps showing numerous critical facilities have been provided to each affected county and city.

Disclosure in Land Title Transfers. Often a combination CFM-MHM map is used for orientation of purchasers of land. Local authorities could require lenders or sellers of real property to let the prospective borrower or buyer know whether the property is located in a hazard-prone area. To facilitate compliance with these laws, local boards of real estate agents can prepare street-index maps showing the hazard zones.

Public Awareness. Often a prerequisite to obtaining support for integrated development planning and hazard reduction is public awareness of not only the hazards but those critical facilities that will be affected. As an example, more than 1,100 miles of Pacific Ocean coastline in California were mapped into three hazard zones reflecting a combination of coastal erosion, wave-cut cliffs, slumping, bluff retraction, landslides, creep, rockfalls, and storm waves.[8/] The purpose of such studies is to help planners, investors, and decision-makers make more educated decisions about building, buying, and living in hazard-prone areas.

[8/] Griggs, G., and L. Savoy (eds.). Living with the California Coast (Durham, North Carolina: Duke University Press, 1985).

Emergency Preparedness Planning. Maps can be prepared to show the critical facilities-highways, airports, railroads, docks, communication lines, water-supply and waste-disposal systems, and electrical power, natural gas, and petroleum lines-that would require a major emergency response from a damaging natural event. The telecommunications map, for example, could assess telephone-system performance after a postulated earthquake. Similarly, maps for water-supply and waste-disposal facilities can show the location and estimates of damage to facilities. Most of the lifelines susceptible to significant damage that require a major response effort can be identified and measures planned.

Site Selection. Often the likelihood, location, and severity of natural hazards are used as criteria in selecting a site for a critical facility. For example, one study, which identified areas warranting further study for use as disposal sites for hazardous wastes, recommended that these disposal sites and facilities be located so as not to adversely affect human health and safety, air and water quality, wildlife, critical environmental resources, and urbanized areas.[9/] Sites that may be subject to inundation, washout, faulting, liquefaction, landsliding, or accelerated erosion were deemed unacceptable.

[9/] Perkins, J.B. Identification of Possible Class I Site Areas, Solid Waste Management Plan. Technical Memorandum 7 (Berkeley, California: Association of Bay Area Governments, 1978).

Likewise, the location and assessment of natural hazards have been key determinants in the selection of sites for offshore structures, electrical power generating stations, hydroelectric dams, water pipes, liquefied natural gas terminals, schools, and other critical facilities.

Strategies for development assistance agencies[10]/

10/ This section is largely extracted from a previous OAS document, "Incorporating Natural Hazard Assessment and Mitigation into Project Preparation," published by the Committee of International Development Institutions on the Environment (CIDIE) in 1989.

The different categories of development assistance agencies (technical cooperation agencies, bilateral and multilateral lending and donor agencies) each have a potential role in supporting the assessment and mitigation of natural hazards. Technical cooperation agencies such as the OAS support institution-building, research, planning, and project formulation as requested. Their financial impact and their political or technical leverage are limited. But their contribution to natural hazard assessment and mitigation in regional and sectoral planning, project identification, and prefeasibility studies is important.

Bilateral agencies such as AID, CIDA, and the members of the OECD Development Assistance Committee provide funds for projects as well as for technical cooperation. Most bilateral funds are concessional, and financial returns are less important to these agencies than to the development banks. They can exert considerable leverage over projects they fund.

The multilateral development banks, mainly the World Bank and the regional development banks, fund development projects but are also increasingly involved in sector policies, institutional strengthening, program lending, and structural adjustment. The dominant factors that shape their lending programs are the financial and economic soundness of an investment and the creditworthiness of the borrowing institutions. Within these parameters they can significantly influence hazard mitigation issues.

The conditions for increasing national and international attention to disaster mitigation issues may be stated as follows:

- The more developed a country's planning institutions and processes, the more easily natural hazards assessment and mitigation issues can be adopted.

- The more experience a country has gained in assessing specific hazards, often following a major disaster, the more likely it will be to request assistance for continuing such assessments.

- The more scientific, engineering, and prevention-related information available to countries and to donors, the easier it will be to apply natural hazards assessment and mitigation to individual programs and projects.

- The more experience governments and donors have concerning the kinds of mitigation measures that are most cost-effective and implementable, the less reluctant they are to include such measures in projects.

- The more experience and confidence there is in evaluating mitigation measures at various decision points in the project cycle, the more likely it is that the staffs of both the national and the assistance agencies will be prepared to undertake the analysis.

1. Technical cooperation agencies

For technical cooperation agencies such as the OAS, the activities that should be included in a strategy for promoting natural hazards assessment and mitigation are:

- ***Support for national planning institutions.*** Unless they have the institutional capacity to incorporate natural hazards information into the planning process on an inter-sectoral basis, governments are not likely to show any enthusiasm about looking at individual investment projects from this perspective.

- ***Support for pilot projects.*** By initiating natural hazards assessments on a pilot basis, it is possible to demonstrate how to do them and what mitigation measures can be proposed, and thereby generate further demand when governments request project funding from donors.

- ***Support for establishing an information base.*** Once the information necessary for natural hazard assessments is available, its implications for individual investment projects become difficult to ignore.

- ***Linkage with relief and reconstruction efforts.*** In the aftermath of disasters it is easier than it would otherwise be to interest governments and development assistance agencies in natural hazards assessment and mitigation.

- ***Hazards assessment in sector planning.*** By building natural hazards assessment into the planning of the agriculture, energy, housing, tourism, transportation, and other sectors, it should be possible to focus attention on hazards in relation to various types of projects before specific investments are identified.

- ***Inclusion of financial and economic aspects of hazards in project preparation methods.*** Estimating the benefits of avoiding direct losses from natural hazards and the costs of appropriate non-structural mitigation measures will make it easier to examine their true importance in individual investment projects. An awareness of the investment losses and repair costs to governments and the private sector, and the distribution of these costs and damages, is likely to increase sensitivity to the issue among all concerned.

- ***Case studies of project design principles or components aimed at natural hazard mitigation.*** Examples of relevant experiences-liability and insurance schemes for investments, property rights designed to create incentives for hazard mitigation, subsidies for mitigation measures, institutional responsibility for coordinating disaster relief with hazard assessment and mitigation, etc.-will show how funding activities can be made more responsive to natural hazards.

The OAS has initiated programs in all these activity areas though direct technical cooperation, training, applied research, and participation in inter-national conferences and workshops. But the need for such activities is much greater than present resources allow. Financing agencies must also become more involved.

2. Convincing financing agencies

A strategy to promote natural hazards assessment and mitigation must also find means of inducing the cooperation of the agencies that actually fund the investment projects. **There are three elements that may offer this inducement: (1) a change in the context in which the donors perceive the governments and collaborating technical cooperation agencies to be addressing natural hazard assessment and mitigation issues; (2) incentives for analysis; and (3) the assignment of accountability for losses.**

A Change in Context

Changing the context in which lending and donor agencies perceive natural hazard assessment and mitigation to be taking place includes most of the activities that the OAS is already promoting: assisting governments in regional planning, pilot natural hazards assessments, assistance for information systems, increasing the quality of project identification, and building the appropriate mitigation measures into pre-investment activities. Further development of these activities raises three strategic questions: What can be done that is most cost-effective in terms of improving both the commitment and the technical and institutional capacity for hazard assessment in a country? What outputs can be generated that are most likely to appeal to lenders and therefore bridge the gap between hazard assessment and project preparation? What cooperative mechanisms can be developed between the technical assistance and donor agencies that will help reach the first two goals?

In response to the first question, implementation of the following ideas seems necessary:

- ***Focus on priority hazards.*** Efforts should be concentrated on assessing hazards that are sufficiently urgent to generate the necessary cooperation. Trade-offs must be made between the need for specific information and broad research interests.

- ***Focus on priority sectors.*** Losses in some sectors are likely to have greater immediate significance to governments and economic interests than in others, and it seems prudent to try to generate institutional support for attention to these.

- ***Choose simple and practical information collection and analysis systems.*** The burden of data collection and management often consumes all available technical and institutional capacity and resources, leaving none for decision-making and implementation. Information systems should reflect realistic priorities for hazards and the development activities that are affected.

As to the second question, the following guides should be used:

- ***Early identification and integration of mitigation issues.*** Mitigation measures built into projects from the earliest preparation stages are more likely to receive adequate review.

- ***Practical and cost-effective solutions to recurrent problems.*** For certain types of projects such solutions are less likely to be rejected if it can be shown that situations to which they are applicable are common.

- ***Commitment to implementation.*** Confidence in hazard mitigation is higher if governments appear committed to carrying it out.

As to the third question, the following ideas are suggested:

- ***Pooling of resources.*** Donor and technical assistance agencies should make their professional staff available for joint missions at varying stages of the project cycle.

- ***Exchange of experiences.*** Technical assistance agency representatives should periodically present case-study and other training material on the design and implementation of natural hazard assessment and mitigation techniques in project formulation taken from real field experiences. In turn, as their capability in this area improves, the donor agency staffs should present their policies, programs, and project evaluation criteria.

- ***Government institutional support.*** Natural hazard assessment and mitigation should be routinely included in staff development and training programs in conjunction with project formulation activities.

Incentives for Analysis

The project staff of a development financing agency will resist any requirement to incorporate natural hazards into project preparation and analysis unless it fits into the existing review mechanisms and appraisal methods. Various ways to promote this consistency exist:

- ***Provide reusable information.*** Agencies should set guidelines to alert their staffs to specific hazards, and give them examples of appropriate mitigation measures and implementation requirements. This approach depends on the institution of mechanisms to ensure that the guidelines are followed routinely.

- ***Integrate hazard concerns into existing review mechanisms such as programming missions, project identification reports, reconnaissance surveys, and project appraisal.*** Hazards will inevitably be one of many factors to be taken into account, and there is a danger that they will be overlooked if they are not made part of the standard format.

- ***Promote proven mitigation measures in relation to specific types of projects.*** Design standards, insurance schemes, diversification of crops, feasibility of hazard-resistant crops or designs are examples. Project staffs are more likely to become enthusiastic about positive project opportunities than review mechanisms.

- ***Incorporate the costs and benefits of hazards mitigation into economic appraisal.*** This makes sense to the extent that decisions are made on the basis of economic returns, that the information on which to base the economic calculations is available, and that the analysis is geared towards improving project design. It is hard to generate support for a new activity unless it can be justified on the basis of financial and economic returns. From this point of view, it is an advantage to be able to show that hazard mitigation can save financial and economic costs in the conventional cost-benefit framework.

- ***Sensitize project staff members.*** This is especially important for project staff responsible for hazard-prone regions and sectoral advisers responsible for hazard-sensitive sectors. Training, cooperation, and publicity can contribute to making project staff more aware of the issue. This, probably more than any other factor, can offset the institutional and financial resistance to hazard assessment and mitigation on the part of governments and the development financing agencies alike.

Assignment of Accountability for Losses

The concern of development financing agencies for natural hazard assessment and mitigation depends on the degree to which projects they help plan or fund suffer losses from natural disasters. There are number of ways to assign accountability:

- Evaluate losses from natural hazards not only in the context of the creditworthiness of the government or a particular sector, but also of the donor's program area and its project design and loan repayment performance.

- Study, discuss, and publish evaluations in instances where losses have been incurred for projects that failed to consider or evaluate hazard mitigation measures.

- Promote professional standards on the part of the engineers, agronomists, or others responsible for planning and executing development projects that include natural hazards assessment and mitigation.

The Organization of American States

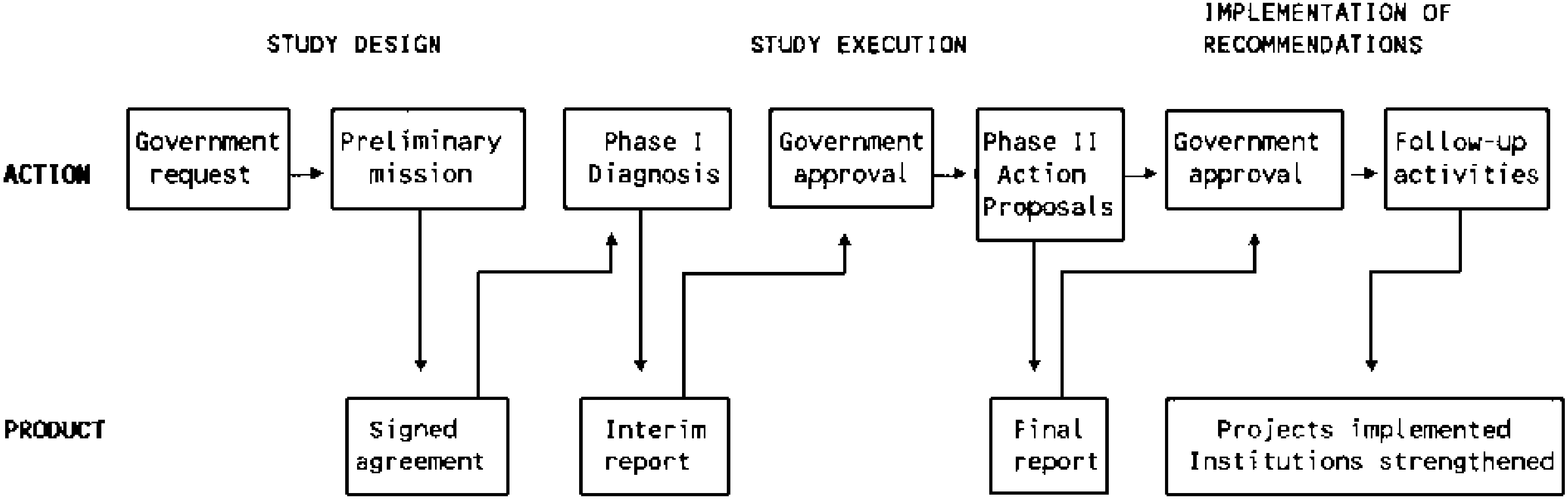
The purposes of the Organization of American States (OAS) are to strengthen the peace and security of the Hemisphere; to prevent possible causes of difficulties and to ensure the pacific settlement of disputes that may arise among the member states; to provide for common action on the part of those states in the event of aggression; to seek the solution of political, juridical, and economic problems that may arise among them; and to promote, by cooperative action, their economic, social, and cultural development.

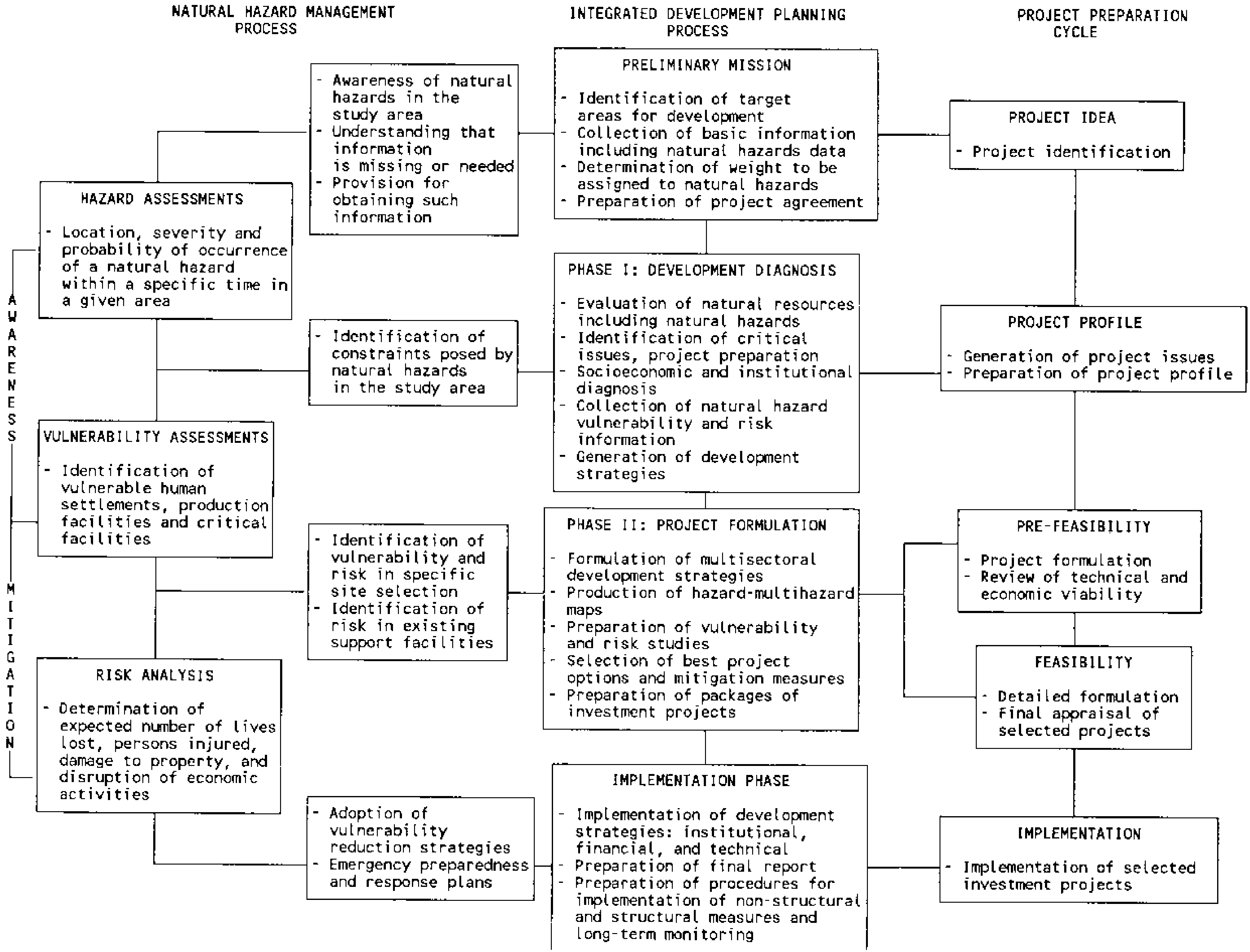
To achieve these objectives, the OAS acts through the General Assembly; the Meeting of Consultation of Ministers of Foreign Affairs; the three Councils (the Permanent Council, the Inter-American Economic and Social Council, and the Inter-American Council for Education, Science, and Culture); the Inter-American Juridical Committee; the Inter-American Commission on Human Rights; the General Secretariat; the Specialized Conferences; and the Specialized Organizations.

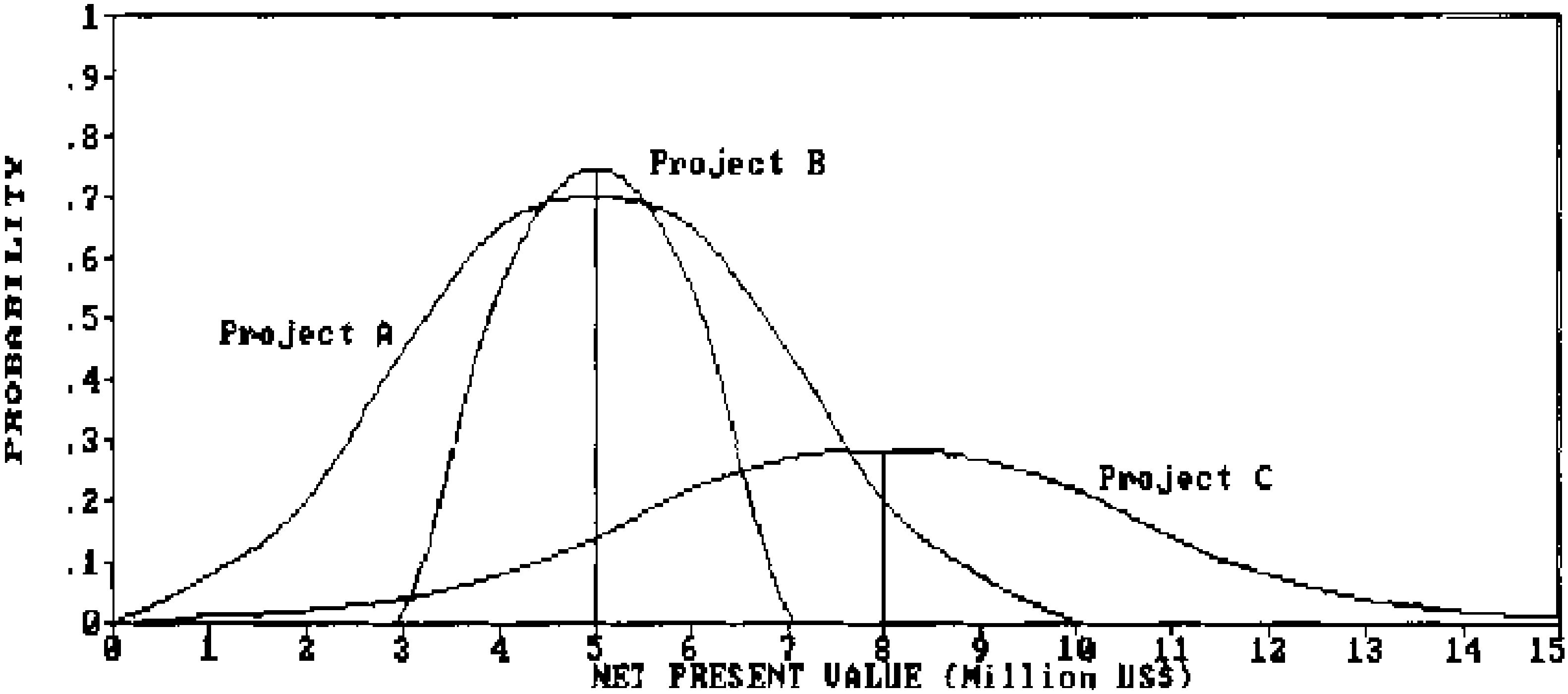
The General Assembly holds regular sessions once a year and special sessions when circumstances warrant. The Meeting of Consultation is convened to consider urgent matters of common interest and to serve as Organ of Consultation in the application of the Inter-American Treaty of Reciprocal Assistance (known as the Rio Treaty), which is the main instrument for joint action in the event of aggression. The Permanent Council takes cognizance of matters referred to it by the General Assembly or the Meeting of Consultation and carries out the decisions of both when their implementation has not been assigned to any other body; monitors the maintenance of friendly relations among the member states and the observance of the standards governing General Secretariat operations; and, in certain instances specified in the Charter of the Organization, acts provisionally as Organ of Consultation under the Rio Treaty. The other two Councils, each of which has a Permanent Executive Committee, organize inter-American action in their areas and hold regular meetings once a year. The General Secretariat is the central, permanent organ of the OAS. The headquarters of both the Permanent Council and the General Secretariat is in Washington, D.C.

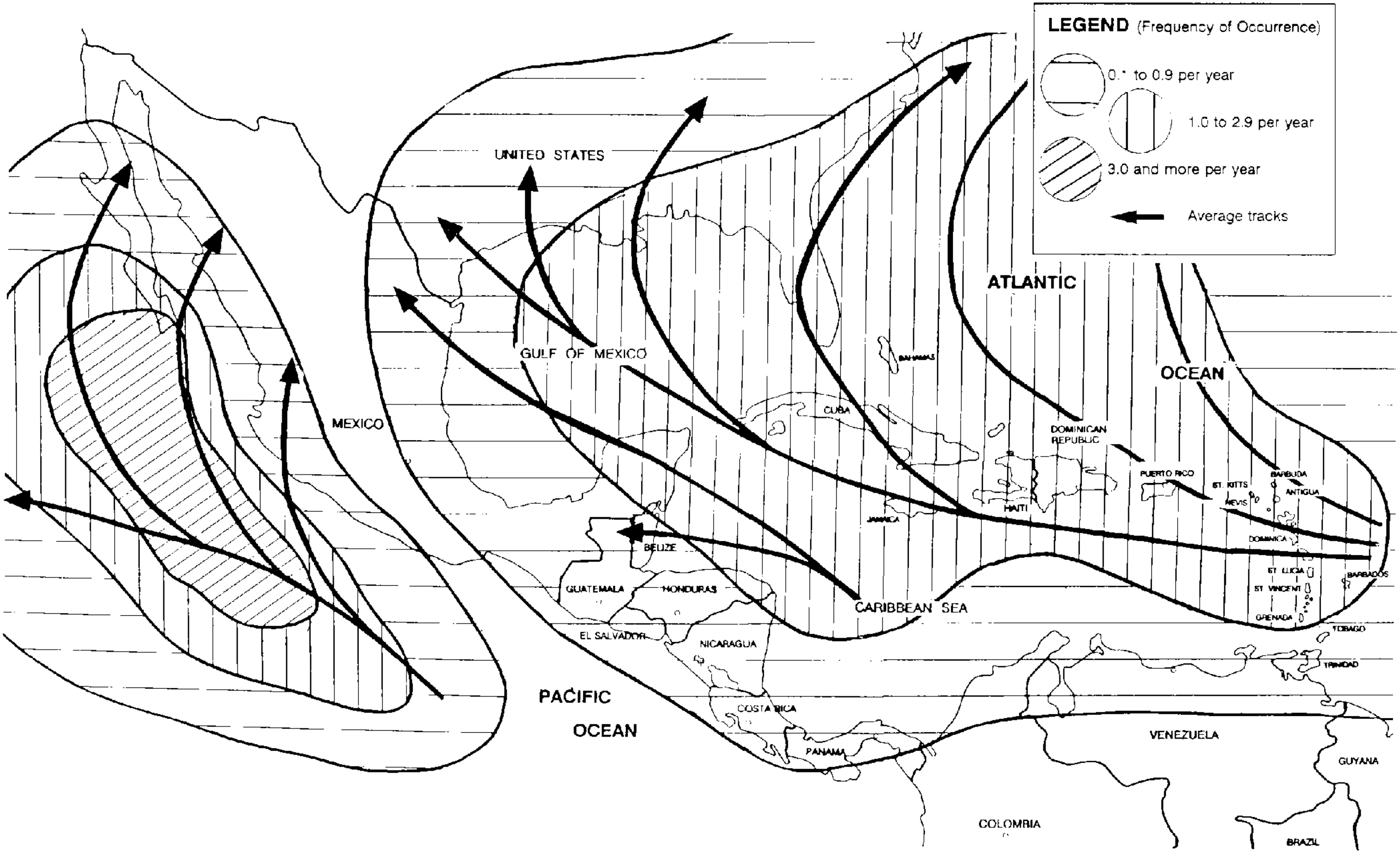
The Organization of American States is the oldest regional society of nations in the world, dating back to the First International Conference of American States, held in Washington, D.C., which on April 14, 1890, established the International Union of American Republics. When the United Nations was established, the OAS joined it as a regional organization. The Charter governing the OAS was signed in Bogota in 1948 and amended by the Protocol of Buenos Aires, which entered into force in February 1970. Today the OAS is made up of thirty-five member states.

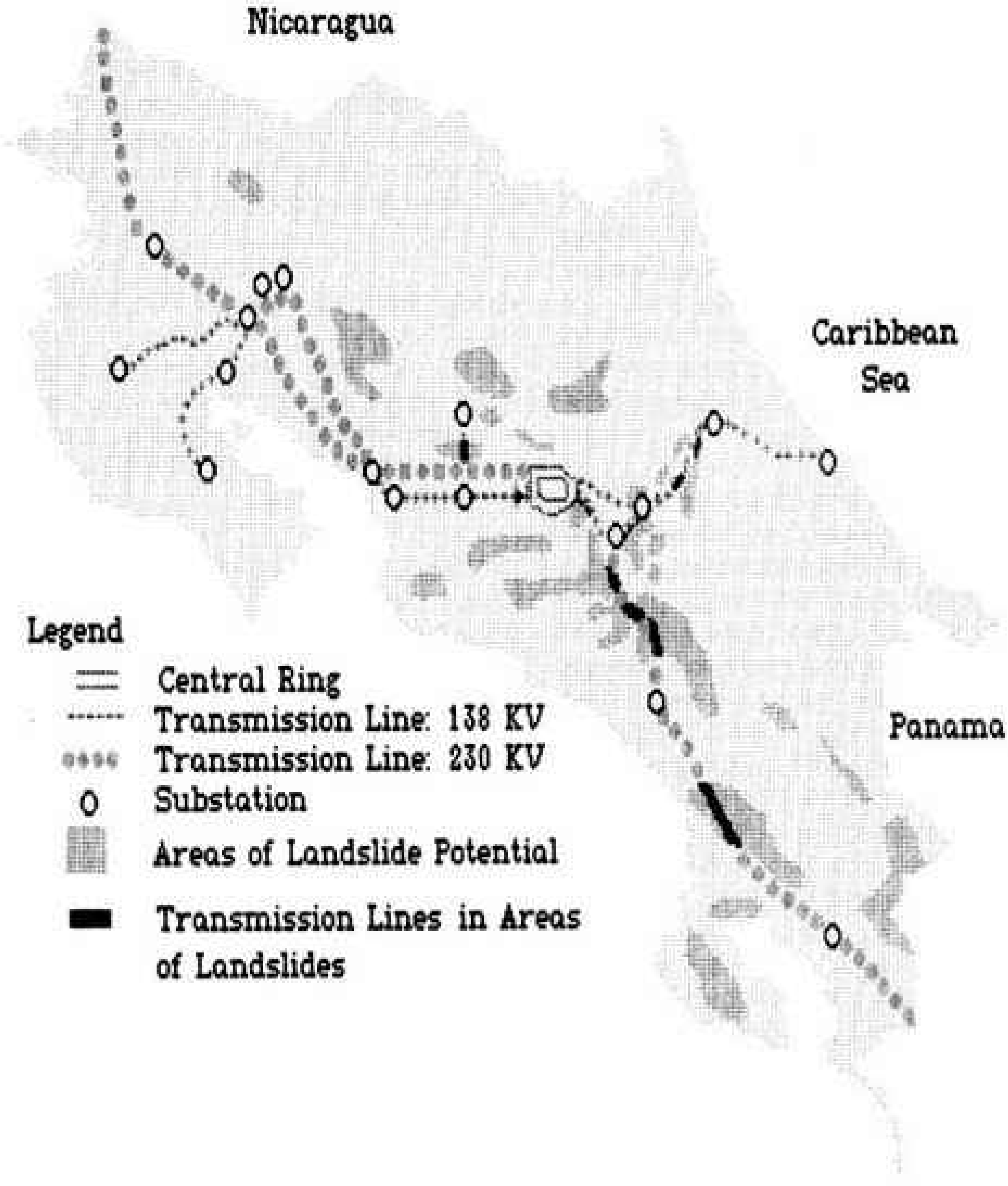
MEMBER STATES: **Antigua and Barbuda, Argentina, The Bahamas** *(Commonwealth of)*, **Barbados, Belize, Bolivia, Brazil, Canada, Chile, Colombia, Costa Rica, Cuba, Dominica** *(Commonwealth of)*, **Dominican Republic, Ecuador, El Salvador, Grenada, Guatemala, Guyana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, St. Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, Trinidad and Tobago, United States, Uruguay, Venezuela.**

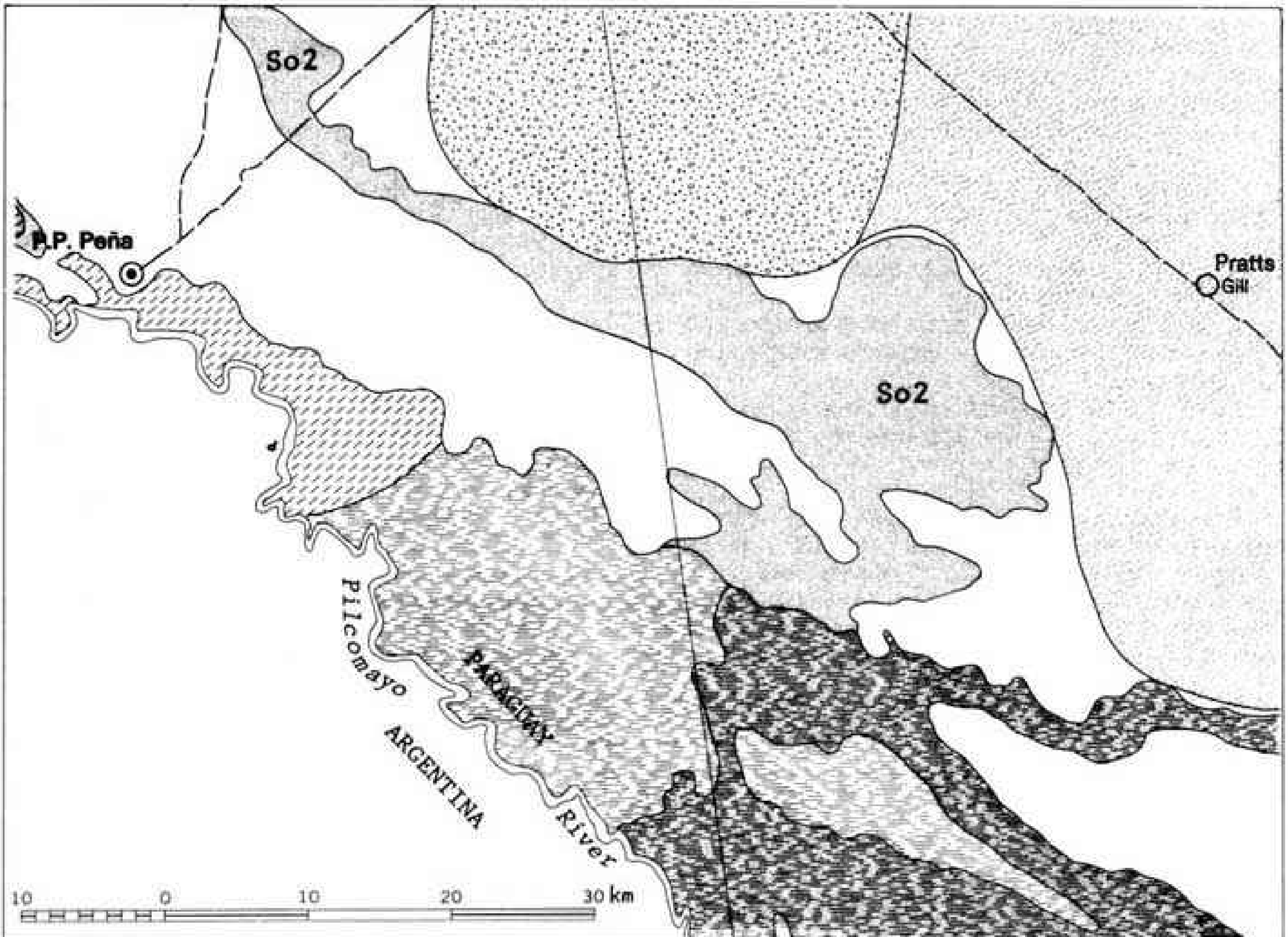

STUDY DESIGN
STUDY EXECUTION
IMPLEMENTATION OF RECOMMENDATIONS
ACTION
PRODUCT
Government request
Preliminary mission
Phase I Diagnosis
Government approval
Phase II Action Proposals
Government approval
Follow-up activities
Signed agreement
Interim report
Final report
Projects implemented Institutions strengthened


NATURAL HAZARD MANAGEMENT PROCESS
INTEGRATED DEVELOPMENT PLANNING PROCESS
PROJECT PREPARATION CYCLE
- Awareness of natural hazards in the study area
- Understanding that information is missing or needed
- Provision for obtaining such information
PRELIMINARY MISSION
- Identification of target areas for development
- Collection of basic information including natural hazards data
- Determination of weight to be assigned to natural hazards
- Preparation of project agreement
PROJECT IDEA
- Project identification
HAZARD ASSESSMENTS
- Location, severity and probability of occurrence of a natural hazard within a specific time in a given area
AWARENESS
- Identification of constraints posed by natural hazards in the study area
PHASE I: DEVELOPMENT DIAGNOSIS
- Evaluation of natural resources including natural hazards
- Identification of critical issues, project preparation
- Socioeconomic and institutional diagnosis
- Collection of natural hazard vulnerability and risk information
- Generation of development strategies
PROJECT PROFILE
- Generation of project issues
- Preparation of project profile
VULNERABILITY ASSESSMENTS
- Identification of vulnerable human settlements, production facilities and critical facilities
- Identification of vulnerability and risk in specific site selection
- Identification of risk in existing support facilities
PHASE II: PROJECT FORMULATION
- Formulation of multisectoral development strategies
- Production of hazard-multihazard maps
- Preparation of vulnerability and risk studies
- Selection of best project options and mitigation measures
- Preparation of packages of investment projects
PRE-FEASIBILITY
- Project formulation
- Review of technical and economic viability
FEASIBILITY
- Detailed formulation
- Final appraisal of selected projects
MITIGATION
RISK ANALYSIS
- Determination of expected number of lives lost, persons injured, damage to property, and disruption of economic activities
- Adoption of vulnerability reduction strategies
- Emergency preparedness and response plans
IMPLEMENTATION PHASE
- Implementation of development strategies: institutional, financial, and technical
- Preparation of final report
- Preparation of procedures for implementation of non-structural and structural measures and long-term monitoring
IMPLEMENTATION
- Implementation of selected investment projects


PROBABILITY
1
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
Project A
Project B
Project C
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
NET PRESENT VALUE (Million US$)


LEGEND (Frequency of Occurrence)
0.1 to 0.9 per year
1.0 to 2.9 per year
3.0 and more per year
Average tracks
UNITED STATES
GULF OF MEXICO
MEXICO
ATLANTIC
OCEAN
BAHAMAS
CUBA
DOMINICAN REPUBLIC
PUERTO RICO
HAITI
JAMAICA
ST. KITTS
NEVIS
BARBUDA
ANTIGUA
DOMINICA
ST. LUCIA
BARBADOS
ST. VINCENT
GRENADA
TOBAGO
TRINIDAD
BELIZE
GUATEMALA
HONDURAS
EL SALVADOR
NICARAGUA
CARIBBEAN SEA
PACIFIC
OCEAN
COSTA RICA
PANAMA
VENEZUELA
GUYANA
COLOMBIA
BRAZIL


Nicaragua
Caribbean Sea
Panama
Legend
Central Ring
Transmission Line: 138 KV
Transmission Line: 230 KV
Substation
Areas of Landslide Potential
Transmission Lines in Areas of Landslides



		AREAS SUBJECT TO DESERTIFICATION
	High Risk	High risk and moderate risk of desertification are identified by factor analysis of human pressure, climate, and land resources.
	Moderate Risk	
		AREAS SUBJECT TO FLOODING
	Very high risk	Very high risk and high risk of flooding are identified by Landsat data (MSS), aerial photography, and maps of soil, vegetation, fluviology, land use, precipitation, and desertification risk.
	High risk	
		HAZARDOUS SOILS AREAS
So2	Very high risk	Delineated areas are zones of very high risk of salinization and alkalinization. Areas with high risk of erosion were also identified.

Table A-1 - Geographic distribution of maximum earthquake intensities in South America

Location	Maximum Earthquake Intensity					
	VI	VII	VIII	IX	X	XI
ARGENTINA						
Province						
Catamarca	x	x				
Chaco	x					
Chubut	x					
Córdoba	x	x				
Corrientes	x					
Entre Ríos	x					
Jujuy	x	x	x			
La Rioja	x	x	x			
Mendoza	x	x	x	x		
Neuquén	x	x				
Río Negro	x					
Salta	x	x	x	x		
San Juan		x	x	x		
San Luis	x	x	x			
Santa Cruz	x					
Santiago del Estero	x					
Tierra del Fuego	x					
Tucumán	x					
BOLIVIA						
Department						
Cochabamba	x	x				
Chuquisaca	x	x	x			

La Paz	x	x	x			
Oruro	x	x				
Potosí	x	x	x			
Santa Cruz	x	x				
Tarija	x	x	x	x		
BRAZIL						
State						
Ceará	x					
Santa Catarina	x					
CHILE						
Province						
Aisén	x					
Aconcagua		x	x	x	x	
Antofagasta	x	x	x			
Arauco			x			
Atacama	x	x	x	x		
Bío Bío	x	x	x			
Cautín	x	x	x			
Chiloé	x	x	x			
Colchagua	x	x	x			
Concepción			x	x		
Coquimbo		x	x	x		
Curicó	x	x	x			
Linares	x	x	x	x		
Llanquihue	x	x	x			
Magallanes	x	x				
Malleco	x	x	x			
Maule			x	x		
Ñuble	x	x	x	x		
O'Higgins	x	x	x			
Osorno	x	x	x			
Santiago		x	x	x		
Talca	x	x	x	x		
Tarapacá		x	x	x		
Valdivia	x	x	x			

Valparaíso			x	x	x	
COLOMBIA						
Department						
Antioquia	x	x	x			
Arauca	x	x	x			
Atlántico	x	x				
Bolívar	x	x	x			
Boyaca	x	x	x			
Caldas			x	x		
Caquetá	x	x	x			
Cauca	x	x	x	x	x	
Choco		x	x	x		
Córdoba	x	x	x			
Cundinamarca		x	x	x		
Guajira	x	x	x			
Huila		x	x	x	x	
Magdalena	x	x	x			
Meta	x	x	x	x		
Nariño		x	x	x	x	
Norte de Santander		x	x	x	x	
Putumayo	x	x				
Santander	x	x	x	x		
Tolima		x	x	x		
Valle del Cauca		x	x	x		
Vaupés	x					
Vichada	x					
ECUADOR						
Province						
Azuay		x	x			
Bolívar			x	x		
Cañar		x				
Carchi		x	x	x		
Chimborazo			x	x	x	
Cotopaxi		x	x	x	x	
El Oro			x			

Esmeraldas		x	x	x	x	
Guayas		x	x	x		
Imbabura		x	x	x		
Los Ríos		x	x			
Loja	x	x	x			
Manabí			x	x		
Morona Santiago	x	x	x			
Napo	x	x	x			
Pastaza	x	x				
Pichincha		x	x	x		
Tungurahua		x	x	x	x	
Zamora-Chinchipe		x	x			
GUYANA		x	x			
PERU						
Department						
Amazonas	x	x	x	x		
Ancash	x	x	x	x		
Apurímac		x	x			
Arequipa		x	x	x	x	
Ayacucho	x	x	x	x		
Cajamarca	x	x				
Cuzco	x	x	x	x		
Huancavelica	x	x	x			
Huánuco	x	x	x			
Ica		x	x	x		
Junín	x	x	x	x		
La Libertad	x	x	x	x		
Lambayeque	x	x	x			
Lima	x	x	x	x		
Loreto	x	x	x	x	x	
Madre de Dios	x	x				
Moquegua		x	x	x		
Pasco	x	x	x			
Piura		x	x	x		
Puno	x	x	x			

San Martín	x	x	x	x	x	
Tacna		x	x	x		
Tumbes			x	x		
URUGUAY						
Department						
Artigas	x					
VENEZUELA						
State						
Delta Amacuro	x	x	x	x		
Amazonas	x					
Apure	x	x	x			
Aragua		x	x	x		
Anzoátegui	x	x	x	x		
Barinas		x	x	x		
Bolívar	x	x				
Carabobo		x	x			
Cojedes		x	x			
Dist. Federal				x		
Falcón		x	x			
Guarico	x	x	x			
Lara				x	x	
Mérida				x	x	
Miranda			x	x	x	
Monagas			x	x		
Portuguesa		x	x	x		
Sucre				x	x	
Táchira			x	x	x	
Trujillo			x	x		
Yaracuy			x	x		
Zulia		x	x	x		

Source: Adapted from Regional Seismological Center for South America (CERESIS). Maximum Intensity Map of South America. (Santiago, Chile: CERESIS, 1985).

Table A-6 - Tsunami hazards for population centers in South America

COUNTRY, Department or Province	Location of Calculated and/or Reported Wave Height		
	2-3 m	3-5 m	Above 5 m
COLOMBIA			
Cauca	Guapi (h)		
Nariño	San José (c)	Pizarro (h)	
	Majagual (c)	La Chorrera (h)	
	San Juan (c)	Chagui (h)	
		Trapiche (h)	
		Tumaco (h)	
		Papayal (h)	
ECUADOR			
Esmeraldas	Muisne (c)	Esmeraldas (h)	
Manabí	Pedernales (c)	Isla Salango (c)	
		Bahía de Caraquez (c)	
		Manta (c)	
Guayas	Guayaquil (h)	Isla Puna (c)	
El Oro	Machala (c)		
PERU			
Tumbes	Pto. Pizarro (c)		
Piura	Paita (c)	San Pedro (c)	
	Bayóvar (c)	Balneario Leguía (c)	
		Sechura (c)	
Lambayeque		San José (c)	Pimentel (b)
			Santa Rosa (c)
			Puerto de Etén (b)

La Libertad		Trujillo (h)	Pacasmayo (c)	
		Tambo (h)	Puerto Chicama (c)	
			Santiago de Cao (c)	
			Huanchaco (c)	
			Víctor Larco Herrera (c)	
			Salaverry (c)	
Ancash	Chimbote (h)	Santa (h)	Santa (c)	
		Samancos (h)	Chimbote (c)	
		Casma (h)	Samancos (c)	
		Caleta Tortuga (h)	Caleta Tortuga (c)	
			Casma (c)	
			Culebras (c)	
			Huarmey (c)	
Lima			Pativilca (c)	Ancón (c)
			Barranca (c)	Callao (a)
			Supe (b)	Lima (c)
			Huaura (c)	Lurín (c)
			Huacho (c)	Pucusana
			Hualmay (c)	Chilca (c)
			Salinas (b)	Mala (c)
			Chancay (c)	San Vicén
Ica		Pisco (h)	Tambo de Mora (c)	

			Pisco (c)	
			San Andrés (c)	
			Paracas (c)	
			Pto. Caballos (c)	
			San Juan (c)	
Arequipa	Lomas (h)	Mollendo (h)	Lomas (c)	Quilca (c)
			Yauca (c)	Matarani (c)
			Chala (b)	Islay (b)
			Atico (c)	Mollendo (c)
			Camaná (c)	Mejía (c)
Moquegua			Ilo (b)	
Tacna			Los Baños (c)	
			La Yarada (c)	
			Pascana del Hueso (c)	
CHILE				
Tarapacá			Arica (b)	
			Pisagua (b)	
			Iquique (b)	
			Chanabaya (h)	
			Caleta Pabellón de Pica (h)	
			Punta Lobos (b)	
			Guanillo del Norte (h)	
Antofagasta			Tocopilla (b)	
			Cobija (h)	
			Mejillones (b)	
			Antofagasta (b)	
			Taltal (c)	
Atacama		Huasco (h)	Chanaral (b)	
			Caldera (b)	

			Carrizal Bajo (c)
			Huasco (c)
Coquimbo	Tongoy (c)	La Serena (c)	Coquimbo (h)
		Coquimbo (c)	
		Los Vilos (c)	
Aconcagua		Papudo (c)	
		Zapallar (c)	
Valparaíso		Quintero (c)	Juan Fernández Is. (h)
		Valparaíso (h)	Concón (c)
			Viña del Mar (c)
			Valparaíso (c)
			Laguna Verde (c)
			Algarrobo (c)
			El Quisco (c)
Santiago			El Tabo (c)
			Las Cruces (c)
			Cartagena (c)
			San Antonio (c)
			Llolleo (c)
Colchagua			Pichilemu (c)
Curicó			Iloca (c)
Maule		Chanco (c)	Constitución (b)
			Curanipe (c)
Ñuble			Buchupureo (c)
			Coloquecura (c)
Concepción	Laraquete (c)	Dichato (c)	Coelemu (h)
		Tomé (b)	Cerro Verde (c)
		Coronel (h)	Penco (c)
			Talcahuano (b)
			Concepción (b)

			Coronel (c)
			Schwager (c)
			Lota (c)
Arauco	Arauco (c) Pto.	Lebu (b)	Tirna (h)
Cautín		Pto. Saavedra (c)	Isla Mocha (h)
		Nahuentue (c)	Mehuín (b)
			Toltén (c)
			Pto. Saavedra (h)
Valdivia	Mancera Is.(h)	Niebla (c)	Corral (h)
		Corral (c)	Valdivia (h)
Osorno			Mansa River (h)
Chiloé	Pindo Is. (h)		Ancud (h)
			Chiloé Is. (h)
			Guafo (h)
Aisén	Puerto Aisén (h)		

Legend:

c: Calculated wave height
h: Historically recorded wave height
b: Both c and h

Source:

Based on Hebenstreid, Gerald T. Assessment of Tsunami Hazards Presented by Possible Seismic Events: Near Shore Effects. (McLean, Virginia: Science Applications Inc., 1981); and Lockridge, Patricia A. Report SE-39 - Tsunamis in Peru-Chile. (Boulder, Colorado: World Data Center A for Solid Earth Geophysics, 1985).

Table A-2 - Maximum seismic intensity and conditional probability of occurrence of a large or great earthquake for coastal locations in South America

Location	Maximum Likely Seismic Intensity	Conditional Probability[a/]		
		1989-1994 (%)	1989-1999 (%)	1989-2009 (%)
COLOMBIA				
Department				
Cauca	X	≤1	≤1	≤1
Choco	IX	?	?	?
Nariño				
North	X	≤1	≤1	≤1
South	X	8	19	6
Valle	IX	≤1	≤1	≤1
CHILE				
Province				
Aconcagua	X	≤1	≤1	≤1
Aisén				
North	VI	≤1	≤1	≤1
South	VI	?	?	?
Antofagasta				
North	VIII	(10)	(20)	(39)
South	VIII	≤1	≤1	15
Arauco	VIII	1	3	12
Atacama				
North	IX	≤1	≤1	15
South	IX	2	4	10

Cautín	VIII	1	3	12
Chiloé	VIII			
Colchagua				
North	VIII	≤1	≤1	≤1
South	VIII	17	33	59
Concepción	IX	1	3	12
Coquimbo				
North	IX	2	4	10
South	IX	11	24	49
Curicó	VIII	≤17	≤33	≤59
Llanquihue	VIII	≤1	≤1	≤1
Magallanes				
North	VII	?	?	?
South	VII	4	11	29
Maule	IX	1	3	12
Ñuble	IX	1	3	12
Osorno	VIII	≤1	≤1	≤1
Santiago	IX	≤1	≤1	≤1
Talca	IX	1	3	12
Tarapacá	IX	10	20	39
Valdivia				
North	VIII	1	3	2
South	VIII	≤1	≤1	≤1
Valparaíso	X	≤1	≤1	≤1
ECUADOR				
Province				
El Oro	VIII	?	?	?
Esmeraldas	X	(41)	(66)	(90)
Guayas	IX	?	?	?
Manabí				
North	IX	(41)	(66)	(90)
South	IX	?	?	?
PERU				
Department				

Ancash				
North	IX	?	?	?
South	IX	≤1-3	≤1-8	1-24
Arequipa				
North	X	(≤1)	(≤1)	(≤1)
Central	X	6	13	29
South	X	(≤1-12)	(≤1-23)	(≤1-43)
Ica				
North	IX	(14)	(27)	(47)
South	IX	(≤1)	(≤1)	(≤1)
La Libertad	IX	?	?	?
Lambayeque	VIII	?	?	?
Lima				
North	IX	≤1-3	≤1-8	1-24
South	IX	≤1	≤1	≤1
Moquegua	IX	(≤1-12)	(≤1-23)	(≤1-43)
Piura	VIII	?	?	?
Tacna				
North	IX	(≤1-12)	(≤1-23)	(≤1-43)
South	IX	4	11	29
Tumbes	IX	?	?	?

[a/] Conditional probability refers to earthquakes caused by inter-plate movement.
? No information available
( ) Values in parenthesis represent less reliable estimates.

Source: Adapted from Regional Seismological Center for South America (CERESIS). Maximum Intensity Map of South America. (Santiago, Chile: CERESIS, 1985); and Nishenko, S.P. Summary of Circum-Pacific Probability Estimates (unpublished table). (Golden, Colorado: U.S. Geological Survey, 1989).

Table A-3 - Geographic distribution of maximum earthquake intensities in Central America

Location	Maximum Earthquake Intensity				
	VI	VII	VIII	IX	X
BELIZE					
District					
Stann Creek	x				
Toledo	x	x			
COSTA RICA					
Province					
Alajuela	x	x	x		
Cartago		x	x		
Guanacaste		x	x		
Heredia	x	x	x		
Limón	x	x	x		
Puntarenas	x	x	x		
San José	x	x	x		
EL SALVADOR					
Department					
Ahuchapán		x	x		
Cabañas	x	x			
Chalatenango	x	x			
Cuscatlán	x	x			
La Libertad		x	x		
La Paz		x	x		
La Unión	x	x	x		
Morazán		x	x		
San Miguel	x	x	x		

San Salvador	x	x	x		
San Vicente		x	x		
Santa Ana	x	x	x		
Sonsonate		x	x		
Usulatán		x	x		
GUATEMALA					
Department					
Alta Verapaz	x	x	x		
Baja Verapaz		x	x		
Chimaltenango		x	x		
Chiquimula		x	x		
El Petén	x				
El Progreso	x	x	x		
El Quiché	x	x	x		
Escuintla		x	x		
Guatemala		x	x	x	
Huehuetenango		x	x	x	
Izabal		x	x		
Jalapa	x	x			
Jutiapa		x	x		
Quezaltenango		x	x	x	
Retalhuleu		x	x		
Sacatepéquez			x		
San Marcos			x	x	
Santa Rosa		x	x	x	
Sololá		x	x		
Suchitepéquez		x	x		
Totonicapán		x	x		
Zacapa		x	x		
HONDURAS					
Department					
Atlántida	x	x	x		
Choluteca	x	x			
Colon	x	x			
Comayagua	x	x	x		

Copan	x	x	x		
Cortes	x	x	x		
Distrito Central	x				
El Paraíso	x				
Fco. Morazán	x				
Gracias a Dios	x				
Intibuca	x	x	x		
La Paz	x				
Lempira	x	x	x		
Ocotepeque	x	x	x		
Olancho	x				
Santa Barbara	x	x	x		
Valle	x	x			
Yoro	x				
NICARAGUA					
Department					
Boaco	x				
Carazo		x			
Chinandega	x	x	x		
Chontales	x				
Granada		x	x		
León	x	x	x		
Managua	x	x	x		
Masaya		x	x		
Matagalpa	x				
Río San Juan	x				
Rivas		x			

Source: Adapted from White, R.A. Maximum Earthquake Intensities in Central America (unpublished map). (Menlo Park, California: U.S. Geological Survey, 1988).

Table A-4 - Maximum seismic intensity and conditional probability of occurrence of a large or great earthquake for selected locations in Central America

Location	Maximum Likely Seismic Intensity	Conditional Probability[a/]		
		1989-1994 (%)	1989-1999 (%)	1989-2009 (%)
COSTA RICA				
Province				
Alajuela				
West	VIII	9	43	93
Central and East	VIII	≤1-3	≤1-8	4-25
Guanacaste				
West	VIII	16	31	55
East	VIII	9	43	93
Heredia (West)	VIII	≤1	≤1	≤4
Puntarenas				
North	VIII	3-9	8-43	25-93
Central	VIII	≤1	≤1	≤4
San José (West)	VIII	≤1	≤1	≤4
EL SALVADOR				
Department				
Ahuchapán	VIII	29	51	79
Cabañas	VII	≤1	≤1	≤1
Cuscatlán	VII	29	51	79
La Libertad	VIII	29	51	79
La Paz				
West	VIII	29	51	79

East	VIII	≤1	≤1	≤1
San Miguel (West)	VIII	≤1	≤1	≤1
San Salvador	VIII	29	51	79
San Vicente	VIII	≤1	≤1	≤1
Santa Ana	VIII	29	51	79
Sonsonate	VIII	29	51	79
Usulatán	VIII	≤1	≤1	≤1
GUATEMALA				
Department				
Alta Verapaz	VIII	(4)	(8)	(15)
Baja Verapaz	VIII	(4)	(8)	(15)
Chimaltenango	VIII	10	23	50
Chiquimula	VIII	29	51	79
El Progreso	VIII	29	51	79
Escuintla	VIII	10	23	50
Guatemala	X	10-29	23-51	50-79
Huehuetenango				
East	X	(4)	(8)	(15)
West	X	5	13	34
Izabal				
East	VIII	≤1	≤1	≤1
West	VIII	(4)	(8)	(15)
Jalapa	VII	29	51	79
Jutiapa	VIII	29	51	79
Quezaltenango	IX	5	13	34
Quiché	VIII	(4)	(8)	(15)
Retalhuleu	VIII	5	13	34
Sacatepéquez	VIII	10	23	50
San Marcos	IX	5	13	34
Santa Rosa	IX	10-29	23-51	50-79
Sololá	VIII	10	23	50
Suchitepéquez	VIII	10	23	50
Totonicapán	VIII	10	23	50
Zacapa	VIII	(4)	(8)	(15)

HONDURAS				
Department				
Comayagua	VIII	?	?	?
Copan				
East	VII	≤1	≤1	≤1
West	VIII	(4)	(8)	(15)
Intibuca	VIII	?	?	?
Lempira	VIII	?	?	?
Ocotepeque				
East	VII	≤1	≤1	≤1
West	VIII	<4)	(8)	(15)
Santa Barbara (West)	VIII	≤1	≤1	≤1
NICARAGUA	VIII	?	?	?

[a/] Conditional probability refers largely to earthquakes caused by inter-plate movement.
? No information available.
( ) All values in parenthesis represent less reliable estimates.

Source: Adapted from White, R.A. Maximum Earthquake Intensities in Central America (unpublished map). (Menlo Park, California: U.S. Geological Survey); and Nishenko, S.P. Summary of Circum-Pacific Probability Estimates (unpublished table). (Golden, Colorado: U.S. Geological Survey, 1989).

Table A-5 - Active volcanoes in Latin America and the Caribbean, associated volcanic hazards, and periodicity of eruptions during the last 10,000 years

Notes:

1. Sources of information for name of volcano, location, periodicity, location, date of last eruption, effects, and volcanic hazards: Simkin, T. et al. Volcanoes of the World. (Stroudsburg, Pennsylvania: Hutchinson Ross Publishing Company, 1981), and Smithsonian Institution. Global Volcanism Network. (Washington D.C.: Smithsonian Institution, 1989-90). Volcanoes with short-term periodicity are presented in capital letters. A volcano having short-term periodicity is defined for this table as one with an eruption periodicity of 100 years or less and/or one that has erupted since 1800.

2. Date of last eruption is simplified from Volcanoes of the World using three categories: (1) "Historic" - the actual eruption date is given, sometimes qualified by "?" when data is questionable. (2) "Holocene" - including the following subcategories: (a) eruptions dated by Carbon 14, hydrophone data, dendrochronology, varve count, anthropologic evidence, lichenometry, magnetism, tephrochronology, hydration rind or fission track analysis; (b) volcanoes now displaying fumarolic or solfataric activity and giving obvious evidence of

recent, although undated, eruption; (c) volcanoes virtually certain to have erupted in postglacial time even though neither dated products nor thermal features are present. (3) "Uncertain" - signifying possible Holocene activity but questionable documentation.

3. Fatalities caused by one or more eruptions.

4. Destruction of agricultural land or other property damage caused by one or more eruptions.

5. One or more eruptions were explosive.

6. Pyroclastic flows or surges and/or laterally directed blasts were associated with one or more eruptions.

7. Phreatic explosion was associated with one or more eruptions.

8. Lava flow, lava domes, or spines were associated with one or more eruptions.

9. Destructive mudflows were associated with one or more eruptions.

10. VEI = Volcanic Explosivity Index: the size or "bigness" of a historic eruption. The VEI combines total volume of products, eruptive cloud height, duration of eruption, tropospheric injection, stratospheric injection, and some descriptive terms to yield a 0-8 index of increasing explosivity as follows: 0 nonexplosive, 1 small, 2 moderate, 3 moderately large, 4 large, 5 very large, 6-8 cataclysmic.

11. Volcano number as per reference found on: Regional Seismological Center for South America (CERESIS). Preliminary Neotectonic Map of South America. (Santiago, Chile: CERESIS, 1985).

Country, Volcano, Periodicity (1)	Location		Date Last Eruption (2)	Effects		Volcanic Hazards						Volcano Ni. (11)	Comments
	Latitude	Longitude		Fatl (3)	Prop (4)	Expl (5)	Pyro (6)	PhEx (7)	Lava (8)	Mdfl (9)	VEI (10)		
Mexico													
Pinacate Peaks	31.75N	113.50W	Holocene										
San Quintin Volcanic Field	30.48N	116.03W	Holocene										
San Luis, Isla	29.97N	114.43W	Holocene										
Jaraquay Volcanic Field	29.33N	114.50W	Holocene										
Tortuga, Isla	27.39N	111.86W	Holocene										
TRES VIRGENES, VOLCAN DE LAS	27.47N	112.58W	1857?										
BARCENA (REVILLAGIGEDO IS)	19.27N	110.80W	1952			x	x		x		2		
SOCORRO (REVILLAGIGEDO IS)	18.75N	110.95W	1951					x			2		
CEBORUCO, VOLCAN	21.15N	104.50W	1870			x	x		x		3		
Brenal	24.15N	104.45W	Holocene										
SANGANGUEY	21.45N	104.98W	1859										
COLIMA, and EL VOLCANCITO	19.42N	103.72W	1977		x	x	x	x	x		1-4		
PARICUTIN VOLCANIC FIELD	19.48N	102.25	1943		x	x			x		3		
Jorullo	19.03N	101.67W	1759		x	x	x		x	x	4		
Zacapu Volcanic Field	19.80N	101.80W	Uncertain										
Valle de Santiago	20.38N	101.22W	Holocene			x			x				
Unnamed	19.10N	099.50W	Holocene			x			x		4		
Xitli	19.25N	099.22W	Holocene						x		0?		
Chichinautzin, Sierra del	19.08N	099.13W	Holocene										
Santa Catarina Range	19.20N	098.97W	Holocene										
Gordo, Cerro	19.75N	098.82W	Holocene										
Pitos, Sierra de las	19.92N	098.73W	Holocene										
POPOCATEPETL	19.02N	098.62W	1943			x					1-3		
ORIZABA, PICO DE	19.03N	097.28W	1687			x			x		3		
SAN MARTIN, VOLCAN DE	18.58N	095.17W	1838			x			x		2-4		
Catemaco, Lake	18.42N	095.07W	Uncertain										
Santa Marta, Volcán	18.30N	095.00W	Holocene										
CHICHON, EL	17.33N	093.20W	1985										
TACANA	15.13N	092.10W	1878?								1		On Guatemala border. Threatened eruption in 1985 and 1986.
Guatemala													
TAJUMULCO	15.043N	091.898W	1863?			x					2		
Siete Orejas	14.82N	091.62W	Holocene										
SANTA MARIA	14.758N	091.548W	1990	x	x	x	x		x	x	2-6		Very high VEI. Includes Santiaguito dome (SW Flank Santa Maria)
QUEMADO, CERRO	14.798N	091.52W	1823?		x	x			x		2		
Oro, Cerro de	14.88N	091.38W	Holocene										

Country, Volcano, Periodicity (1)	Location Latitude	Location Longitude	Date Last Eruption (2)	Effects Fatl (3)	Effects Prop (4)	Volcanic Hazards Expl (5)	Pyro (6)	PhEx (7)	Lava (8)	Mdfl (9)	VEI (10)	Volcano Ni. (11)	Comments
Guatemala (continued)													
ATITLAN	14.588N	091.182W	1856?		x	x			x		2-3		
Tolimán	14.614N	091.117W	Holocene										
ACATENANGO	14.503N	090.873W	1972			x		x			1-3		
FUEGO	14.482N	090.882W	1977	x	x	x	x		x	x	0-4		
Agua	14.47N	090.742W	Holocene										
PACAYA	14.38N	090.603W	1989		x	x			x		0-3		
13 Minor volcanoes east of Guatemala City	14.03-14.83N	089.35-090.45W	Holocene										
El Salvador													
Ahuachapán Geothermal Field	13.90N	089.82W	1990	x	x	x							
3 Minor volcanoes	13.90-14.27N	089.47-089.77W	Holocene										
SANTA ANA	13.853N	089.630W	1920		x	x					2-3		
IZALCO	13.815N	089.635W	1966	x	x	x	x		x		0-3		
SAN MARCELINO	13.807N	089.577W	1722		x				x		0		
Coatepeque Caldera	13.87N	089.55W	Holocene										
SAN SALVADOR	13.738N	089.288W	1917	x	x	x			x		0-4		
Guazapa	13.90N	089.12W	Holocene										
ILOPANGO	13.672N	089.053W	1879	x	x	x	x		x		3-6?		Very high VEI
6 Minor volcanoes around San Vicente	13.42-13.623N	088.32-088.852W	Holocene										
SAN MIGUEL	13.437N	088.272W	1976		x	x		x	x		1-3		
Conchagua	13.227N	087.853W	Uncertain										
CONCHAGUITA	13.22N	087.765W	1892			x					2		
Nicaragua													
COSIGUINA	12.98N	087.57W	1852		x	x	x				2-5		Very high VEI
SAN CRISTOBAL	12.70N	087.00W	1977			x		x			1-3		
Casita	12.70N	086.97W	1550										
TELICA	12.60N	086.85W	1976			x		x	x		1-3		
Rota	12.55N	086.75W	Holocene										
NEGRO, CERRO	12.50N	086.70W	1971		x	x			x	x	1-3		
PILAS, LAS	12.50N	086.68W	1954			x		x			1		
MOMOTOMBO	12.42N	086.53W	1905		x	x			x		2-3		
Apoyeque	12.242N	086.342W	Holocene										
MASAYA, NINDIRI, SANTIAGO, and SAN PEDRO	11.98N	086.15W	1974		x	x			x		0-3		
Apoyo	11.92N	086.03W	Holocene										
MOMBACHO	11.83N	085.98W	1850?			x					2-3		
Zapatera Island	11.73N	085.82W	Holocene										

CONCEPCION	11.53N	085.62W	1978	x	x	2
Madera, La	11.45N	085.52W	Uncertain			
3 Minor volcanoes	12.30- 12.53N	085.73- 086.138W	Holocene			

Country, Volcano, Periodicity (1)	Location		Date Last Eruption (2)	Effects		Volcanic Hazards						Volcano Ni. (11)	Comments
	Latitude	Longitude		Fatl (3)	Prop (4)	Expl (5)	Pyro (6)	PhEx (7)	Lava (8)	Mdfl (9)	VEI (10)		
Costa Rica													
OROSI	10.98N	085.47W	1849			x					2		
RINCON DE LA VIEJA	10.83N	085.33W	1970		x	x		x			2-3		
Miravalles	10.75N	085.15W	Holocene										
Tenorio	10.67N	085.02W	Uncertain										
ARENAL	10.47N	084.73W	1968	x	x	x	x	x	x	x	3-4		
Poco Sol, Cerro	10.320N	084.660W	Uncertain										
Platanar, Cerro	10.299N	084.366W	Holocene										
POAS	10.20N	084.22W	1980			x		x			1-3		
BARBA	10.13N	084.08W	1867			x					2		
IRAZU	09.98N	083.85W	1974	x	x	x		x	x	x	1-3		
TURRIALBA	10.03N	083.77W	1866			x					2-3		
Honduras													
Yojoa, Lake	14.98N	087.98W	Holocene										
Utila Island	16.10N	086.90W	Holocene										
Panama													
Barú	08.80N	082.558W	1550?		x	x							
Colombia													
RUIZ	04.88N	075.37W	1985	x	x	x			x	x	2-4	2	
Mesa Nevada de Herveo	05.30N	075.47W	Holocene										
TOLIMA	04.65N	075.37W	1943			x					2	1	
Machin	04.15N	075.37W	Holocene										
Huila	03.00N	075.98W	Holocene										
PURACE			1977	x	x	x			x	x	2-4	3	
Sotara	02.22N	076.62W	Holocene										
Petacas	01.57N	076.78W	Uncertain										
DOÑA JUANA	01.52N	076.93W	1897	x		x	x		x	x	4	4	
GALERAS	01.22N	077.30W	1974			x			x		2-4	5	
Azufral de Tuquerres	01.08N	077.73W	Holocene										
CUMBAL	00.98N	077.88W	1926			x					2	6	
Negro de Mayasquer, Cerro	00.80N	077.95W	Holocene			x					2	7	
Ecuador													
REVENTADOR	00.08S	077.67W	1976			x	x		x	x	2-3	8	
Cuicocha	00.30N	078.37W	Holocene										
Pululagua	00.05N	078.48W	Holocene			x	x						

Country, Volcano, Periodicity (1)	Location		Date Last Eruption (2)	Effects		Volcanic Hazards						Volcano Ni. (11)	Comments
	Latitude	Longitude		Fatl (3)	Prop (4)	Expl (5)	Pyro (6)	PhEx (7)	Lava (8)	Mdfl (9)	VEI (10)		
Ecuador (continued)													
GUAGUA PICHINCHA	00.17S	078.60W	1881			x	x				2-4	9	
ANTISANA	00.48S	078.13W	1801			x			x		0-2	10	
SUMACO	00.57S	077.65W	1933?			x					2-3?	11	
COTOPAXI	00.65S	078.43W	1942	x	x	x	x		x	x	0-4	12	
QUILOTOA	00.85S	078.90W	1759?			x					2-4?	13	
TUNGURAHUA	1.47S	078.45W	1944		x	x	x	x	x	x	2-4	14	
SANGAY	02.03S	078.33W	1976	x	x	x	x		x		2-3+	15	
FERNANDINA (GALAPAGOS)	00.37S	091.55W	1978			x		x	x		0-4		
6 VOLCANOES ON ISABELA IS.	00.02N- 00.90S	091.12- 091.55W	Holocene- 1979	x		x		x	x		0-3		
9 VOLCANOES IN GALAPAGOS IS.	00.58N- 00.88S	089.50- 090.77W	Holocene- 1958						x		0		
Peru													
4 Minor volcanoes	14.37- 15.80S	071.17- 072.70W	1990		x	x	x		x				Sabancaya Volcano
MISTI, EL	16.302S	071.414W	1870?		x	x					2-3	16	
UBINAS	16.355S	070.903W	1969		x	x					2-3?	17	
HUAYNAPUTINA	16.584S	070.87W	1667	x	x	x	x			x	2-4	18	
Ticsani	16.77S	070.60W	Holocene										
TUTUPACA	17.025S	070.358W	1902			x					2-3	19	
Yucamani	17.18S	070.20W	1787									20	
Northern Chile and Bolivia													
Chupiquina, Nevado	17.67S	069.80W	Holocene										
Tacora	17.72S	069.78W	Holocene										
6 Minor volcanoes	17.92- 18.42S	068.53- 069.80W	Holocene										On Chile-Bolivia border
GUALLATIRI	18.42S	069.10W	1960			x					2	21	
6 Minor volcanoes	18.38- 19.15S	068.08- 069.47W	Holocene										On Chile-Bolivia border
ISLUGA	19.15S	068.83W	1960		x	x			x		2	22	
11 MINOR VOLCANOES	20.73- 21.78S	066.50- 068.47W	Holocene- 1865										On Chile-Bolivia border; one erupted in 1865. Volcano No. 23 is one of these 11 volcanoes
SAN PEDRO	21.88S	068.40W	1960?		x	x			x		2	24	
11 MINOR VOLCANOES	21.92- 23.13S	067.18- 068.23W	Holocene- 1972										On Chile-Bolivia border; one erupted in 1972. Volcano No. 25 is one of these 11 volcanoes.
LASCAR	[illegible]	[illegible]	[illegible]			x					[illegible]	[illegible]	

[illegible]	[illegible]	[illegible]	[illegible]	x	[illegible]	[illegible]	
5 Minor volcanoes	23.58–24.45S	067.53–068.57W	Holocene				On Chile-Argentina border

Country, Volcano, Periodicity (1)	Location Latitude	Location Longitude	Date Last Eruption (2)	Effects Fatl (3)	Effects Prop (4)	Volcanic Hazards Expl (5)	Pyro (6)	PhEx (7)	Lava (8)	Mdfl (9)	VEI (10)	Volcano Ni. (11)	Comments
Northern Chile and Bolivia (continued)													
LLULAILLACO	24.72S	068.55W	1877			x			x		0-2	27	
4 Minor volcanoes	25.17–27.32S	067.88–069.13W	Holocene										On Chile-Argentina border. Volcano No. 28 is one of these four volcanoes.
Central and Southern Chile, Argentina													
TUPUNGATITO	33.40S	069.80W	1980			x			x		2	29	
SAN JOSE	33.80S	069.92W	1895			x					2	30	On Chile-Argentina border. Fumarolic activity afterwards.
MAIPO	34.17S	069.87W	1912?			x						31	On Chile-Argentina border
TINGUIRIRICA	34.82S	070.35W	1917									32	
PETEROA	35.25S	070.57W	1967			x			x	x	1-4	33	On Chile-Argentina border
DESCABEZADO GRANDE	35.58S	070.75W	1932			x					2	34	
AZUL, CERRO	35.67S	070.77W	1967			x			x		2-5	35	Very high VEI
Maule, Laguna del	36.02S	070.58W	Holocene										
CHILLAN, NEVADOS DE	36.87S	071.38W	1973			x			x	x	1-3	36	
ANTUCO	37.40S	071.37W	1972			x			x		0-2	37	
CALLAQUI	37.92S	071.42W	1850?									38	On Chile-Argentina border
Copahues	37.85S	071.17W	1750?			x						39	
LONQUIMAY	38.37S	071.58W	1889			x			x		0-2	40	
LLAIMA	38.70S	071.70W	1979		x	x			x	x	2-4?	41	
VILLARRICA	39.42S	071.95W	1980	x	x	x	x		x	x	2-3	42	
Quetrupillán	39.48S	071.70W	Holocene										
RINIHUE (or CHOSHUENCO MOCHO)	39.93S	072.03W	1864			x					2	43, 44	
NILAHUE	40.35S	072.07W	1979	x	x	x			x	x	2-4	45	
Casablanca, Volcan	40.75S	072.20W	Holocene									46	
PUYEHUE	40.57S	072.10W	1960			x			x		3-4	47	
PUNTIAGUDO, CERRO	40.95S	072.27W	1930?										
OSORNO	41.10S	072.50W	1869			x			x		0-2	48	
CALBUCO	41.32S	072.60W	1961		x	x		x	x	x	1-2	49	
Cayute-La Vigueria	41.98S	072.27W	Holocene										
HUEQUI	42.37S	072.58W	1920?			x			x		0-2	50	
MINCHINMAVIDA	42.78S	072.43W	1835						x		2	51	
CORCOVADO	43.18S	072.80W	1835			x					2		
Maca	45.10S	073.20W	Holocene									52	
HUDSON, MT.	46.17S	072.92W	1971	x	x	x				x	3	53	
LAUTARO	49.02S	073.55W	1961			x					1-2	54	
BURNEY, MONTE	52.33S	073.40W	1910			x					2	55	

Palei-Aike Volcanic Field	52.15S	069.95W	Holocene	x	x	-	--

Country, Volcano, Periodicity (1)	Location		Date Last Eruption (2)	Effects		Volcanic Hazards						Volcano Ni. (11)	Comments
	Latitude	Longitude		Fatl (3)	Prop (4)	Expl (5)	Pyro (6)	PhEx (7)	Lava (8)	Mdfl (9)	VEI (10)		
West Indies													
Saba (Caribbean)													
Mountain, The	17.63N	063.23W	Holocene										
St. Eustatius													
Quill, The	17.48N	062.95W	Holocene										
St.Kitts and Nevis													
MISERY, MOUNT (ST. KITTS)	17.37N	062.80W	1843?			x		x					
Nevis Peak (Nevis)	17.15N	062.58W	Holocene										
Montserrat													
Soufriere Hills	16.72N	062.18W	Holocene			x							
Guadeloupe													
SOUFRIERE DE LA GUADELOUPE	16.05N	061.67W	1976			x	x	x		x	1-3		
Dominica													
Diable, Morne au	15.62N	061.45W	Holocene										
Diablotins, Morne	15.50N	061.42W	Holocene										
MICOTRIN	15.33N	061.33W	1880					x			3		
Patates, Morne	15.22N	061.37W	Holocene										
Martinique													
MONTAGNE PELEE	14.82N	061.17W	1929	x	x	x	x	x	x	x	3-4		
St. Lucia													
Qualibou (Soufriere)	13.83N	061.05W	1776					x			1		
St. Vincent													
SOUFRIERE	13.33N	061.18W	1979	x	x	x	x	x	x	x	0-4		
Grenada													
KICK-EM-JENNY (submarine)	12.30N	061.63W	1977								0		