Annex 1. Deaths and Number Affected by Major Disasters

Major Earthquakes in Latin America, 1985 - 1989

YEAR	COUNTRY	DEATHS	AFFECTED
1985	Argentina	6	38,000
1985	Chile	177	170,000
1985	Mexico	10,000	60,000
1985	Guatemala	-	12,000
1986	Peru	15	8,000
1986	El Salvador	1,100	500,000
1986	Brazil	1	15,000
1987	Ecuador	300	150,000

Major Volcanic Eruptions in Latin America, 1976 - 1989

YEAR	COUNTRY	DEATHS	AFFECTED
1976	Costa Rica	-	70,000
1976	Guadeloupe	-	75,000
1979	St. Vincent	2	20,000
1982	Mexico	100	60,000
1985	Colombia	23,080	200,000

Major Floods in Latin America and the Caribbean, 1986 - 1989

YEAR	COUNTRY	DEATHS	AFFECTED
1986	Bolivia	29	260,000
1986	Peru	12	150,000
1986	Argentina	3	144,000
1986	Jamaica	54	40,000
1986	Chile	15	54,118
1986	Haiti	79	85,000
1986	Haiti	69	45,000
1986	Colombia	13	250,000
1987	Bolivia	20	20,000
1987	Peru	100	25,000
1987	Chile	55	116,364
1987	Haiti	13	5,000
1987	Guatemala	84	6,500
1988	Costa Rica	9	4,200
1988	Brazil	300	70,000
1988	Argentina	25	57,000

Major Hurricanes in the Caribbean and Central America, 1980 - 1989

YEAR	COUNTRY	DEATHS	AFFECTED
1980	St. Vincent (Allen)	N/A	20,000
1980	St. Lucia (Allen)	17	70,000
1980	Jamaica (Allen)	9	10,000
1980	Haiti (Allen)	220	835,000
1982	Cuba (Albert)	40	105,000
1983	Mexico (Taco)	135	10,000
1985	Cuba (Kate)	2	475,000
1988	Jamaica (Gilbert)	45	500,000
1988	Mexico (Gilbert)	250	200,000
1988	Nicaragua and others (Joan)	116	185,000

Major Volcanic Eruptions in Latin America, 1976 - 1989

YEAR	COUNTRY	DEATHS	AFFECTED
1976	Costa Rica	-	70,000
1976	Guadeloupe	-	75,000
1979	St. Vincent	2	20,000
1982	Mexico	100	60,000
1985	Colombia	23,080	200,000

Annex 2. Damaged or Destroyed Hospitals (*)

Type of Disaster	No. Hospitals	No. Beds
Earthquake, Mexico (D.F. Sept. 1985)	13	4,387
Earthquake, El Salvador (San Salvador, Oct. 1986)	4	1,860
Hurricane, "Gilbert" (Jamaica, Sept. 1988)	22	5,085
Total	39	11,332

(*) PAHO and other sources.

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Disaster Prevention and Mitigation in Latin America and the Caribbean

Stephen O. Bender
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This is not the first time that the Bank, the Organization of American States (OAS), and other institutions present this afternoon have joined together to discuss the relationship between disasters and development. Three years ago, we gathered for a much smaller discussion, the result of which led to the presentation and publication of the document, *Incorporating Natural Hazard Assessment and Mitigation into Project Preparation*, published by the Committee of International Development Institutions on the Environment (CIDIE) and the OAS earlier this year.

"The best opportunity to lessen disaster vulnerability in the region is to affect the way development takes place by assuring that hazard assessment and mitigation are part of development policy and its programs, and, most importantly, the project preparation process from the earliest stages."

Now, as then, the issue is how to better integrate natural hazard management concerns into the development planning process.

A comment should be made on the title of the Colloquium, "Disasters, Sustainability, and Development." How well we will be able to manage the complex interactions between these three elements will determine the future success of the common mission of our institutions. This title also encompasses the prime objective of the Natural Hazards Project of the OAS. That objective is to reduce disaster vulnerability through the context of integrated development planning. The project is a specific technical cooperation activity carried out since 1983 by the OAS' Department of Regional Development, which has been involved in natural

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resource management for more than 27 years.

Through the project's three principal and interrelated activities -- technical cooperation, training, and technology transfer -- we have worked at the countries' request, often in coordination with several of the institutions present here, to identify hazards, propose mitigation measures, train mid-level professionals from various disciplines, and introduce effective, cost-efficient methods for hazards assessment and mitigation in more than 20 OAS member states.

The primary support for the project has come from USAID's Office of Foreign Disaster Assistance (OFDA). This office is primarily responsible for emergency preparedness and response, but it has seen fit to provide funds for longer-term prevention activities. Such support is presently far too scarce, and it often comes from humanitarian assistance offices while mainstream development assistance agencies usually provide funding only after the occurrence of a disaster.

Prevention activities carried out by the project have covered geographical areas as large as the Paraguayan Chaco and as small as individual villages in Caribbean island countries. They have included subject matter as diverse as flood, landslide, and desertification evaluation; the use of geographic and geo-referenced information systems for planning and emergency management; satellite remote sensing technology; videos and printed manuals for use by local officials; lifeline mapping of critical facilities; and mapping for development planning studies of natural hazards, natural resources, population, and infrastructure information in the form of data sets, technical reports, and computer-generated maps.

From this perspective, let us quickly review what a look towards the 1990s includes for disaster prevention and mitigation in the region.

First of all, let it be said that of the three major organizational groups related to disaster management that function nationally and internationally -- natural phenomena and engineering research entities, emergency preparedness and response agencies, and development planning and financing institutions -- the latter has been the last to deal on a non-crisis basis with hazard management issues. At the same time, it is the planning community which is in the best position to act as a catalyst to bring these three groups together. Planners are both users and producers of natural hazard information. While not often formally charged with the task, planners produce hazard evaluations, particularly in the areas of atmospheric and hydrologic hazards. They should take the lead in setting research priorities. They are best placed to identify those elements of the existing and proposed production and service infrastructure which are at risk, and for which political, economic, and social decisions dictate that a substantial reduction in vulnerability is either impossible or improbable. Responding to repeated calls from the emergency management group for hazard maps, planners should increase their activities in hazard assessment as part of development planning studies. Representatives of all three groups are here this afternoon; such encounters must continue.

Second, there is a direct, if not much discussed, relationship between disasters, the environment, and development. In Latin American and the Caribbean, growing population pressure and increasing demand on the region's ecosystems have long outstripped the environment's capacity to provide sufficient goods and services in a non-value added condition, particularly in urban areas. Safe building sites, together with food, fuel, and building materials, are all naturally occurring goods and services in great demand, particularly by the urban poor. As their immediate availability has become scarce, these goods and services must be brought from distant sources. Value must be added in the form of energy, transportation, transformation, commercialization, and profit, to name the most common components. These components are often the substance of development plans and investments.

"We must avoid a situation where disaster relief becomes synonymous with development assistance, and where post-disaster reconstruction depletes scarce resources otherwise destined for new investments."

Building sites safe from natural hazards, pollution, and accidents must often be engineered for homes, businesses, and public infrastructure. But far too often, disaster mitigation is limited to on-site design, which at best allows for the passing on of the hazard. In the worst case, the inhabitants have neither the technical nor the financial means to reduce the vulnerability even of their own endeavors.

If sustainability includes the continuing provision of safe building sites, then the environment, whether in rural or urban areas, must be managed in an integrated way with the understanding of how natural events impact their surroundings, both in terms of their attributes and hazards.

Third, during the remaining years of this century and beyond, development theory and practice will be shaped to an ever-increasing degree by the timely response to natural and human events, many of which will cause strife, conflict, and disasters. This is in contrast to previous shaping forces such as the availability of broad expanses of uninhabited or little developed forests, valleys, and plains; the creation of entire new cities built around the extraction or transformation of a single resource; and the single purpose extension of infrastructure networks to colonize remaining large tracts of land. Natural and human events in the future will dictate the location, beneficiaries, affected sectors, and providers of financial support, often without the availability of alternatives in the traditional context of development.

For the region, we must avoid a situation where disaster relief becomes synonymous with development assistance, and where post-disaster reconstruction depletes scarce resources otherwise destined for new investments. We must be vigilant over institutional divisions between disaster management and development assistance so as not to create a void in policies, programs, and projects which address the utilization of resources in the face of ever-increasing demands and vulnerability, particularly of the poor.

Fourth, the upcoming Decade for Disaster Reduction gives all of us a mandate to affect the way development will take place, particularly with regard to lessening disaster vulnerability through development planning.

To some extent, time is on our side. Mid-level professionals in public and private service will mature during the Decade and by its end, they will have assumed leadership positions in their respective sectors. Sectoral programs and projects, recently identified and those yet to come, can be shaped by a planning process that includes hazard analysis and a selection of appropriate mitigation measures. Single-focus development mandates, so prevalent during the past two decades, are giving way to multisectoral and interdisciplinary approaches which concentrate on the competition inherent in assuring the continuous use of resources and the need for conflict resolution. This is of particular relevance to disaster reduction. The attractiveness of creating a specialty area out of each new development focus can and should give way to a better understanding on the part of all involved disciplines of the importance of considering the consequences of natural events.

What, then, is of relevance and importance to the region?

First of all, we must recognize that the next decade presents an opportunity to continue important work already begun. Increased support is needed to further expand and share the knowledge and experience already gained in disaster preparedness and response. Policies, programs, and projects are in place which will help to prepare public and private sectors alike in their response to disasters. The countries of the region are voicing their concerns, priorities, and needs for new and better information, technology, training, and equipment. There exists skilled professionals and technicians who can and should benefit from further participation in international activities, but who also are willing and able to carry out requested activities in the region as well as in their own countries.

Likewise, research and engineering institutions exist which have long dealt with hazard assessment, particularly in the area of geologic hazards. It is time to initiate new activities as well as support existing endeavors as these institutions set out priorities in terms of training, technology transfer, and information sharing.

"Single-focus development mandates, so prevalent during the past two decades, are giving way to multisectoral and interdisciplinary approaches which concentrate on the competition inherent in assuring the continuous use of resources and the need for conflict resolution."

For the planning community, the challenge of the Decade is particularly important because planning mechanisms at the national, sub-national, and local levels in most countries are already in place. The best opportunity to lessen disaster vulnerability in the region is to affect the way development takes place by assuring that hazard assessment and mitigation are part of development policy and its programs, and, most importantly, the project preparation process from the earliest stages.

A three-part approach is called for:

First, mechanisms exist for the creation and distribution of basic hazard information briefs to be incorporated into country development strategies, environmental profiles, natural resource atlases, preliminary mission reports, project programming documents, and other similar items.

Second, training focus areas, course content, and institutional support mechanisms have been identified to offer programs in hazard analysis, mitigation measure selection, and hazard assessment and mapping as part of multisectoral, interdisciplinary development planning studies.

Third, professionals from the region with academic preparation and disaster-related experience are available to continue their work in development planning and training.

The constraints to take full advantage of these resources will come as no surprise, but they can be addressed.

Through government mandates, funding agency requirements, and development assistance offerings, hazard assessment and mitigation measure selection must be part of the planning process. Without separating out hazards as a sector or an impact analysis operation, all involved disciplines must be prepared to present and discuss disaster vulnerability and to participate in the decision-making process which weighs vulnerability with competing social, economic, political, and financial claims for resource use.

For the Latin American and Caribbean region, we should strive to create and implement during the first 36 months of the Decade's activities additional training to mid-level professionals from the various disciplines involved in project preparation and hazard assessment. A target goal for training and follow-up technical assistance should be set at 1,200 professionals, using existing institutional settings in each of the three sub-regions -- Central America, South America, and the Caribbean. We should also set as a goal to have at least one operational unit in each country's planning mechanism to provide hazard information for use in the documents and missions described earlier. We should continue to work through other initiatives, including those begun by the environmentalists, to include natural phenomena information in the data bases of natural resources and environmental management problem areas. And finally, we should use ongoing planning and development projects, beginning at the sub-national and national level, to reinforce the use of personnel and information that is available and that will become available through the actions described above. And of course, the planning community, which must take an increasing role in long-term disaster prevention, should seek out opportunities to produce and share information and experience with the emergency management and research and engineering communities.

Satellite Remote Sensing Applications for Natural Hazard Preparedness and Emergency Response Planning

Glenn Morgan
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Introduction

A growing area of concern in natural hazard assessment and emergency response planning is improving the availability and use of information about the nature and spatial extent of disasters. Ultimately, the effectiveness of any program addressing natural disaster preparedness and emergency response will depend on the timeliness and accuracy of scientific and social information gathered from the field. Unfortunately, timely and accurate data are not always available from field stations, and other data sources must be considered. This paper addresses the contribution of satellite remote sensing technology as a complementary and supplemental tool for the collection and management of such information.

"Remote sensing technologies are of relevance to the disaster field for several reasons. Most importantly, the technology holds the promise of rapid, low-cost reconnaissance over large often remote areas. In many situations, remote sensing techniques may be the only viable data collection alternative. Satellite imagery of various types can be useful in three distinct ways: as a pre-disaster planning tool; as a tracking and monitoring tool during disaster events; and as a post-disaster assessment tool."

The paper reviews the major operational satellite remote sensing technologies currently available and evaluates their relevance to disaster planning and emergency response programs. It also describes some of the operational experiences and constraints of the technologies as applied to various types of disasters and natural hazards, and summarizes the potential contribution of future developments in the field. The report provides a representative sample of recent remote sensing literature related to hazards assessment and management.

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Satellite Remote Sensing Systems with Operational Relevance to Disaster Preparedness

Viewing the earth from space platforms is thought to open many new perspectives for the analysis and management of natural disasters. The variety of operational and planned earth-observation satellite systems offer unique capabilities to study the earth and its physical systems at various levels of resolution and at different time intervals. Hutchinson (1989) describes three types of satellite-derived information that would be of use to disaster preparedness and emergency relief efforts: baseline information describing an area's vulnerability to disaster; information related to the monitoring of events which could precipitate a disaster; and lastly, information on the extent, magnitude, and duration of a disaster event. The contribution of remote sensing data will vary according to the requirements for these informational needs.

During the last three decades, numerous remote sensing sensors have been developed for a wide variety of applications. Presently, there are a multitude of sensors available which have operational relevance to hazard preparedness and emergency response planning. In 1985, Slater described 56 such satellite systems in operation at that time. These included the National Oceanic and Atmospheric Administration's (NOAA) Advanced Very High Resolution Radiometer (AVHRR), the Nimbus 7 Coastal Zone Color Scanner (CZCS), the European SPOT system, the American LANDSAT system, the Indian Resources Satellite (IRS), and the Japanese Marine Observation Satellite (MOS), to name a few (see tables 1 and 2). In addition, there are numerous systems which will soon become operational, such as Canada's RADARSAT and the European Space Agency's ERS-1 system. These are by no means the only remote sensing instruments available today. Several interesting developments have also taken place with respect to aircraft mounted multispectral scanners, video imaging technologies, and of course, aerial photography. Airborne technologies, however, will not be dealt with in this paper.

"As one might expect, each spectral imaging system has inherent strengths and weaknesses, and the utility of any one system will depend on the nature of the problem being studied. Though many satellite remote sensing systems work on the same principle of measuring the energy reflected from features on the earth's surface, they vary widely with respect to the area that can be covered, the regularity with which imagery can be provided, the resolution of the images, and of course, the ultimate cost of the information."

As one might expect, each spectral imaging system has inherent strengths and weaknesses, and the utility of any one system will depend on the nature of the problem being studied. Though many satellite remote sensing systems work on the same principle of measuring the energy reflected from features on the earth's surface, they vary widely with respect to the area that can be covered, the regularity with which imagery can be provided, the resolution of the images, and of course, the ultimate cost of the information.

LANDSAT Thematic Mapper imagery, for example, has a ground resolution of 30 m but records information in seven spectral bands. SPOT, on the other hand, has two sensors capable of

Table 1.

Present and Future Earth Observation Capabilities from Space

Type of Space Platform	Instrument/Channels/Spectral Range	Horizontal Resolution (km)	Repetition Rate of Observation	Status
Geosynchronous Satellites (GOES, GMS, METEOSAT, INSAT)	VISSR, MSR/2-3/0.5-1.1, (5-7), 10-12 microns VAS/12/0.63, 3.9-14.7 microns	0.75-9 7-14	15-30 min	operational
Next Generation	more spectral channels, eventually microwave sensors	1-2	15-30 min	from mid 1990s and beyond
NOAA Polar Orbiters	AVHRR/5/0.58-12.5 microns HIRS/20/mostly thermal IR MSU/4/50.3-57.9 GHz AMSU/20/10-90 (180) GHz ACZCS/9/0.4-0.9, 10.5-12.5 microns	1 17.4 109 50 1	12 hours	operational
LANDSAT	MSS/5/0.5-1.1 microns TM/7/0.45-12.5 microns	0.08 0.03/0.1	16 days	operational
DMSP (Defence Meter. (Satellite Program)	OLS/2/0.4-1.1, 10.4-12.4 microns	0.6	12 hours	operational
SPOT	SPOT/4/0.5-0.9 microns	0.02/0.01	2.5 days	operational
MOS - 1 (Japan)	MESSR/4/0.51-1.1 microns VTIR/4/0.5-12.5 microns MSR/2/23.8, 31.4 GHz	0.05 0.9-2.7 32/23	17 days	operational
IRS - 1 (India)	LISS-1/4/0.45 - 0.86 microns	.036/.072	18 days	operational
ERS - 1	AMI:SAR/1/5.3 GHz ASTR/3/3.7, 11, 12 microns	0.03 1	undefined	1989
Polar Platforms	MODIS/25/0.58-2.13 microns HIRIS/7/3.75-12.0 microns HMMR/27/1.4 - 183 GHz Possibly additional instruments	0.5	2 days	from late 1990s and beyond

Source: Becker 1987, Table 2.1, p. 25.

Table 2.
Sample of Satellite-Borne Sensors of Relevance to Disaster Preparedness

HRV: High Resolution Sensor on the SPOT Satellite - This device images in two modes: multispectral and panchromatic. In the multispectral mode, it images with a ground resolution of 20 m in three spectral bands. In panchromatic mode, HRV acquires images with a ground resolution of 10 m in one spectral band. The SPOT HRV sensor orbits in a sun-synchronous course at an altitude of 822 km. Repetitive global coverage is provided every 28 days, but off-nadir imagery permits programming of the satellite in a manner permitting a revisit capability every three days.

TM: Thematic Mapper (LANDSAT) - This sensor, mounted on the LANDSAT 4 and 5 satellite, has a ground resolution of 30 m for the six visible and infrared spectral bands and a 120 m resolution in the thermal band. The satellite has revisit capabilities of about 16 days.

LISS: Linear Imaging Self-Scanning Cameras - The LISS scanner is currently mounted on the Indian Resources Satellite IRS-1A. The scanner has a ground resolution of 36 m and 72 m with a ground swath of 148 km. Each camera operates in four spectral bands similar to the first four bands of LANDSAT TM. The satellite orbit permits revisit after 22 days. The imagery is currently only available over the Indian subcontinent; however, the Indian Remote Sensing Agency is currently negotiating for privileges at ground stations worldwide.

MSS: Multispectral Scanner (LANDSAT) - MSS imagery has a ground resolution of 80 m and records information in four visible and near infrared spectral bands. MSS is carried on the LANDSAT 4 and 5 satellite and has a revisit capability of 16 days.

AVHRR: Advanced Very High Resolution Radiometer - This is a four or five band scanner with a ground resolution of 1 km. This device has produced significant information on atmospheric processes through its ability to map clouds, and is now being increasingly used for mapping regional vegetation and crop patterns.

METEOSAT - This is a series of European-launched, geosynchronous, meteorological satellites designed to fulfill the need for meteorological data for short-term weather forecasting and atmospheric profiles of temperature and water vapor content. Meteosat's ground resolution is 2.5 km in the visible band and 5 km in the thermal-infrared and water vapor bands. Current products include cloud motion vectors, sea-surface temperatures, upper tropospheric humidity, precipitation index, cloud top height, and cloud analysis.

CZCS: Coastal Zone Color Scanner - This multiband scanner flew on the NIMBUS-7 satellite primarily to quantify chlorophyll concentrations in near-coastal waters. There are five visible spectral bands and one thermal-infrared band.

VISSR: Visible Infrared Spin-Scan Radiometer - This scanning radiometer records radiation in two spectral bands with a ground resolution of .78 km in the visible band and 7 x 3 km in the thermal band. The whole earth disk is scanned and transmitted every 30 minutes. This device is mounted on the GOES satellite in a geosynchronous orbit. An improved version of the device is the visible infrared spin-scan radiometer atmospheric sounder (VAS).

GMS: Geosynchronous Meteorological Satellite - These are Japanese meteorological satellites in geosynchronous orbits which measure radiant energy in both the visible and thermal-infrared bands.

Source: Duggin, M.J. (1987) in Vaughn (1987), pp. 56-63.

measuring 10 m and 20 m pixel resolution, respectively, but it only measures in three spectral bands. In addition, SPOT can require as many as nine times the number of images to cover an area equivalent to one LANDSAT TM scene. Other sensors like the NOAA/AVHRR can provide imagery on a daily basis, though the pixel resolution is relatively coarse (1 km pixel size). The point is not to suggest that one type of sensor is inherently better or worse. Rather, that tradeoffs must be made when selecting remote sensing imagery. These tradeoffs include spatial resolution, spectral resolution, revisit capability, area of coverage, and last but not least, cost.

"Operational experience has shown that the technology's relevance will vary depending on the nature of the hazard being studied as well as on the type of sensor being utilized. What is effective in one setting may not be effective in another. The technology's contribution will vary temporally -- often more useful long before or long after disasters strike rather than during the events themselves -- and will vary depending on the specific application (risk assessment, early warning system, emergency response, or relief planning). Easy generalizations regarding the value of such images are elusive."

__Operational Potential of Remote Sensing__

Since the earliest days of meteorological and earth-observation satellite programs, researchers have attempted to utilize satellite-gathered images as tools to study the nature and extent of natural disasters. Remote sensing technologies are of relevance to the disaster field for several reasons. Most importantly, the technology holds the promise of rapid, low-cost reconnaissance over large often remote areas. In manysituations, remote sensing techniques may be the only viable data collection alternative. Satellite imagery of various types can be useful in three distinct ways: as a pre-disaster planning tool; as a tracking and monitoring tool during disaster events; and as a post-disaster assessment tool. The technology can help to establish baseline inventories against which dynamic changes associated with hazards and disasters can be measured, and it can provide sufficient economies of scale in studying large areas.

But operational experience has shown that the technology's relevance will vary depending on the nature of the hazard being studied as well as on the type of sensor being utilized. What is effective in one setting may not be effective in another. The technology's contribution will vary temporally -- often more useful long before or long after disasters strike rather than during the events themselves -- and will vary depending on the specific application (risk assessment, early warning system, emergency response, or relief planning). Easy generalizations regarding the value of such images are elusive.

Howarth (1983) points out that the overall utility of different types of remote sensing data is determined by the following characteristics:

(i) __The size of the disaster-affected area.__ Satellite imagery is generally more useful as the size of the study area increases. Hazards, such as fires and flooding, typically occur over large areas. The contribution of the imagery clearly increases in these cases. The __extent of spatial change associated with disasters__ is one of the most important determining factors regarding the contribution of various sensors. Typically, positive identification of ground features in an image will require clusters of image pixels (often ten or more pixels are required for a positive identification). Therefore, changes on the ground associated with a disaster must be over a rather large area to show up in an image. In the case of SPOT multispectral imagery, the disaster-affected area would need to be on the order of 200 m^2 before positive identification would be possible (assuming ten pixels). SPOT panchromatic imagery, on the other hand, would only require an affected area of 100 m^2. (Likewise LANDSAT TM would require 300 m^2; LANDSAT MSS would require 800 m^2, etc.)

Another constraint imposed by the size of the disaster area relates to the minimum unit which can be physically shown on a map. Assuming that an area no smaller than 2 to 3 mm^2 would be shown on a map, to be physically depicted, areas of change on the ground would need to be greater than 100 m^2 on maps at a scale of 1:50,000, or 200 m^2 at a scale of 1:100,000. The implication is that imagery data is better suited for disasters affecting large, contiguous areas.

(ii) <u>The degree of spectral change associated with disasters.</u> Most natural disasters involve spectral changes which, if significant enough, can be detected with imaging systems. For example, forest fires and flooding lead to significant spectral changes which are easily detectable. Surface water is particularly easy to study because of its high degree of spectral contrast with surrounding ground features. However, damage associated with earthquakes, though devastating, is typically localized in its impact and results in very little spectral contrast with surrounding areas.

(iii) <u>Time frame and temporal dynamics of the disaster.</u> The temporal dynamics of a natural hazard will also determine the utility of different imaging technologies. For example, while satellite imagery such as LANDSAT can distinguish water quite readily, repeat coverage of a flood area can only be achieved every 16 days. A flood could easily occur and recede within that time period. On the other hand, land-use changes in coastal areas occur gradually over several years. Imagery could be particularly effective in monitoring those changes. Events which are seasonal, predictable, or highly correlated with other events, such as flooding or wildfires, are more likely to benefit from imagery than events which occur randomly or unpredictably, such as earthquakes or tsunamis.

A review of the remote sensing literature reveals numerous attempts to use remotely sensed imagery both for operational and experimental applications. The following sections describe some of the operational possibilities for the application of satellite-based remote sensing technology. One must bear in mind that the following descriptions are only meant to be indicative of the materials to be found in the research literature.

<u>Earthquakes</u>

Direct operational experience with the use of satellite remote sensing for earthquake damage assessment has been very limited. Sabins (1986) indicates that remote sensing has limited application for the prediction of individual earthquakes. Nevertheless, geologic structural mapping has been a common application in geology for some years (Siegal and Gillespie 1980). The value of satellite remote sensing for geological applications is its ability to provide a synoptic view over large areas and its role in seismic risk analysis. The major contribution for seismic research has been in the imagery's ability to provide information about previously undetected lineaments, such as active faults and fracture systems, indicating subsurface phenomenon of relevance to risk analysis (Bagheri 1985). High-resolution imagery can be used effectively to identify many surface features commonly associated with active faults, such as linear valleys, offset drainage channels, and sag ponds (Sabins 1986). Identifying concentrations of lineaments can indicate structural weaknesses and therefore help to pinpoint where seismic activity is more likely to occur. The utility of the imagery derived from space platforms will be most useful in identifying areas which are at relatively high risk to earthquake damage.

LANDSAT imagery has been used to monitor tectonic activities in the Jiangsu-Shandong-Anhui area of China (Wang 1986) and in central Mexico (Johnson 1987). Higher resolution imagery, like SPOT, could possibly be used to study damage to infrastructure (roads, railways, etc.), but the resolution is probably still too coarse to be of value in planning emergency response. For these types of studies, aerial photography is still the preferred remote sensing approach. Another area where the imagery could be of value is in the study of the spatial extent of landslides which may be associated with earthquakes (see Landslides and Slope Failures).

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Flood Prediction and Assessment

Satellite imagery of various types have been used effectively in flood monitoring programs. Indeed, flood detection and mapping applications provide some of the most striking examples of operational remote sensing for disaster assessment. Wiesnet and Deutsch (1985) report, "flood mapping with satellite data can be done much more rapidly, at less cost and with greater accuracy than ever before...satellite remote sensing can be used effectively for mapping floods in progress, post-flood delineation of inundated areas, identification of flood prone areas, and prediction of flooding." The information derived from satellite imagery has been used effectively to determine the baseline norms, such as maximum flooding levels, and assessment of other periodic river and coastal fluctuations. In addition, many researchers have conducted studies determining river channel morphology and siltation problems, both of which have direct impact on flood risk (Wiesnet and Deutsch 1986).

But the technology for flood mapping and forecasting is not without problems. Huthnance (1987) correctly

"Satellite remote sensing for flood assessment has numerous positive and negative aspects. First, flood monitoring is likely to be more operational than other natural disaster applications because floods usually occur seasonally or on some predictable cycle. This is clearly an advantage because the satellites can then be programmed to acquire imagery over a flood-prone area before the floods begin. Unfortunately, flooding is frequently associated with heavy rainfall, and hence, extensive cloud cover. This, in turn, reduces the chances of acquiring good imagery over the area of interest."

reports that the operational use of satellite technology is limited by widely spaced orbits and by cloud cover problems. Geostationary satellites using AVHRR technology, for example, while providing repeat coverage every few hours, have a limited spatial resolution. Still, he reports successful applications with these lower resolution systems for monitoring mean sea level change and for providing overviews of coastal development, sediment movement, and wave behavior.

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The use of imaging technologies for the assessment of tsunamis and associated coastal damage has not been widely reported in the remote sensing literature. While satellite images may not be useful for studying tsunamis themselves, they could be used effectively to assess coastal tsunami risk, to develop coastal area management plans, and to monitor land-use change in coastal areas (see Howarth 1983; and La Loggia et al. 1988) that are prone to tidal waves or recurrent flooding. Zhaumu and Xia (1986) describe the use of satellite imagery as a means of modeling coastal dynamics, for mapping recent changes in the course of a river, and for correcting assumptions regarding tidal influences in the Huanghe river delta and coastal zones in order to support development of coastal zone management plans.

Landslides and Slope Failures

Applications of remote sensing technology for assessing landslides and slope failures after they have occurred are relatively commonplace. However, as Sabins (1986) points out, individual landslide events are difficult, if not impossible, to predict by remote sensing techniques. The imagery has been found to be quite useful for mapping regional occurrences of slide activity and has been utilized with considerable success to assess relationships between landslides and other types of hazards, such as violent storms, earthquakes, and volcanic events. Although it is difficult, if not impossible, to predict the occurrence of individual landslides by satellite remote sensing techniques, other types of remote sensing, such as stereoscopic air photographs, airborne radar, and side-scanning sonar, are useful tools for identifying actual landslides and/or unstable areas (Sabins 1986).

A promising area of research is the use of imagery for developing watershed management plans. Remote sensing data has been effectively utilized for geomorphological mapping and assessment of watershed land-use conditions at scales up to 1:50,000 and 1:25,000. Several studies have addressed the use of imagery for studying the mechanics of deposition and siltation patterns associated with erosion and landslides (Rosenfeld 1985; and Gimbarzevsky 1983). But, as with most remote sensing applications, the results have been mixed. Connors (1987) analyzed SPOT data to derive landscape stability maps for semiarid areas based on geomorphic conditions readily apparent in the higher resolution imagery, such as eolian-mantled uplands, coppice dunes, and poorly vegetated silty and fine sandy areas. Used in these ways, imagery can provide valuable pre-disaster information and can help to identify those areas which are at significant risk to slope failures and erosion hazards.

Volcanic Eruption

Many areas of known active volcanos are densely settled, placing many thousands of individuals at risk to lava flows, hot avalanches, mudflows, floods, and volcanic ash and gases (Sabins 1986). Satellite remote sensing technology is one of many data sources geologists and volcanologists use to evaluate the warning signs of increased volcanic activity. Volcanic hazards, such as venting, tephra falls, and lava flows, can be directly monitored by satellites such as LANDSAT and SPOT. Records of LANDSAT images on volcanic activities include lava flows from Mount Nyiragongo in Zaire, 1973, and flows from Fernandia on the Galapagos Islands of Ecuador, 1973 (Colwel 1983).

Ozaner's study (1986) reported the combined use of LANDSAT and air photos to study volcanic change in Katakekaumeae, Turkey. The author claimed that the use of remote sensing technology contributed to the enhancement and correction of the ground survey. Rothery et al. (1988) studied the eruption of Lascar in Chile in September 1986 and found that a magmatic precursor registered on LANDSAT images from March and July 1985. The authors also found unreported major changes in the dissemination of lava lakes on Erta'Ale, Ethiopia, and a minor eruption on Mount Erebes, Antarctica.

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One of the most closely studied volcanic eruptions of all time was the 1980 eruption of Mount St. Helens. Carson (1983) utilized aerial photographs to study the morphology and other volcanic phenomena of Mount St. Helens. He indicated that many of the structural features of volcanos, such as eruption clouds, steam blasts, fumarolic activity, and dome growth, were clearly observable and measurable. Carson also reported on the use of thermal imagery on Mount Rainier, Lassen Peak, and Mount St. Helens which, though less common than air photos, was found to be quite helpful.

Rosenfeld et al. (1985) reported excellent results from the use of airborne SLAR (Side Looking Airborne Radar) and air photos for evaluating surface water detention, landslides, and mass wasting associated with the Mount St. Helens eruption. The imagery data has correlated very well with sampling results of field sediment and provided significant insights into the processes which yielded enormous erosion rates in the region. The imagery provided details of sediment sources, potential sediment sinks, and temporary storage areas such as fans, lakes, sand bars, and stream bed channels. High-resolution satellite imagery, such as SPOT and LANDSAT, also provided meaningful information on the post-depositional landscape, though with less accuracy than air photos.

Studying volcanic activity with imagery is a sound approach to post-eruption evaluation of lava flows, landslides, and mudflows. Thermal-Infrared Scanner Data was also found to be helpful in evaluating the revegetation of denuded slopes following the Mount St. Helens eruption (Langran 1985), provided adequate terrain information was also available. On a regional scale, satellite remote sensing would be very helpful for global mapping of active volcanoes, for preliminary assessment of risk in active regions, and for determining the environmental impacts of potential eruptions.

Wildfires

The study of wildfires and burn areas is another application of remote sensing with significant potential, both because of the large areal extent and spectral changes associated with fires. Several possible applications are apparent. First, imagery is useful as a pre-fire planning and modeling tool. Second, it can be used to track fires as they spread across a region. Third, images are an efficient way of assessing the total affected area after the fire has been suppressed and for monitoring ecological recovery following the fire.

Miller et al. (1986) review the U.S. Bureau of Land Management's (BLM) use of small-scale AVHRR data to derive forest fuel maps for western United States. They report that the imagery is particularly useful in three ways: as a means of detecting, locating, and ranking areas according to their accumulation of green biomass; as a way of estimating the senescence of herbaceous vegetation to indicate when fire problems will occur; and as a way to identify areas of wildfire risk in order to more effectively locate fire suppression and emergency response field teams. The utilization of such imagery has become an integral part of BLM's Wildfire Initial Attack Management System (IAMS) and the National Fire Danger Rating System (NFDRS). The AVHRR data is currently used to monitor and map fire fuel on all 180 million acres of land under the jurisdiction of the BLM.

Isaacson et al. (1982) report on the use of remote sensing (air photos and LANDSAT) for monitoring post-fire erosion rates of burn areas associated with the 1978 Bridge Creek fire in Oregon's Deschute National Park. Satellite data were utilized in a pre-fire analysis mode to determine the extent of various land cover classes. Following the fire, imagery-derived data was demonstrated to be useful for assisting in the design of programs which addressed watershed revegetation, construction of drainage control structures, and residue treatment programs.

Satellite-derived data have also been utilized in predictive modeling of fire risk. Brass and Peterson (1983) demonstrated how the analytical capabilities of image data and geographic