

CHAPTER 10
LANDSLIDE HAZARD
ASSESSMENT

CHAPTER 10

LANDSLIDE HAZARD ASSESSMENT

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LANDSLIDE HAZARD ASSESSMENT

SUMMARY

This chapter presents (1) key terms, concepts, and important considerations related to landslide susceptibility; (2) a technique--hazard zonation mapping--for examining landslide risks; and (3) the critical issues that need to be addressed in integrating landslide hazards into the development planning process.

In 1974, one of the largest landslides in recorded history occurred in the Mantaro River valley in the Andes Mountains of Peru (Hutchinson and Kogan, 1975). A temporary lake was formed when the slide dammed the Mantaro River, resulting in the flooding of farms, three bridges, and twelve miles of roadway. Almost five hundred people in and around the village of Mayunmarca lost their lives. This disaster is one example of the destructive potential of landslides and why they are considered hazards. While not every landslide results in catastrophe, the damage from many small ones may equal or exceed the impact of a single major failure. Thus, both large and small landslides are capable of causing significant damage and loss of life.

Assessing relative landslide hazard is the objective of the method described in this chapter. Its primary product, a landslide hazard map, provides planners with a practical and cost-effective way to zone areas susceptible to landsliding.

This method can be used both by planners and by landslide technical specialists. The planner will gain a working knowledge of concepts and considerations for incorporating landslide hazard evaluation into the planning process, using a level of evaluation suitable for each stage of the process, and thus should be able to ask the appropriate questions of the technical specialist and prepare terms of reference to ensure that the needed information is obtained. The technical specialist will find a review of landslide hazard issues and guidelines for conducting a landslide zonation. As is often the case in natural hazards management, planning studies are often the link between scientific information and the general development planning process.

The method presented, one of several that are available, has the following characteristics:

- Various thematic maps and remote sensing information usually available to a development study are used.

- It is designed to provide landslide hazard information appropriate for each of the stages of the planning process
- Relative susceptibility to landsliding is used as a measure of the potential hazard within an area.
- It is applicable to regions with different geomorphologic and vegetation characteristics
- It can usually be used within the time and budget constraints of a planning study.

A. Overview of Landslide Hazard Mapping and the Development Planning Process

The susceptibility of a given area to landslides can be determined and depicted using hazard zonation. A landslide hazard map can be prepared early in the planning study and developed in more detail as the study progresses. It can be used as a tool to help identify land areas best suited for development by examining the potential risk of landsliding. Furthermore, once landslide susceptibility is identified, investment projects can be developed which avoid, prevent, or substantially mitigate the hazard.

Determining the extent of landslide hazard requires identifying those areas which could be affected by a damaging landslide and assessing the probability of the landslide occurring within some time period. In general, however, specifying a time frame for the occurrence of a landslide is difficult to determine even under ideal conditions. As a result, landslide hazard is often represented by landslide susceptibility (Brabb, 1985). Similar to the concept of flood-prone areas (see Chapter 8), landslide susceptibility only identifies areas potentially affected and does not imply a time frame when a landslide might occur. To simplify these concepts, landslide susceptibility will be referred to as landslide hazard in this chapter. Comparing the location of an area of proposed development to the degree of landslide hazard present enables the planner

DEFINITIONS

- **Landslide Hazard:** as represented by susceptibility, which is the likelihood of a potentially damaging landslide occurring within a given area.
- **Vulnerability:** the level of population, property, economic activity, including public services, etc., at risk in a given area resulting from the occurrence of a landslide of a given type.
- **Risk (specific):** the expected degree of loss due to a particular landslide phenomenon.

to estimate the landslide risk. This can be used to define land use capability and identify appropriate mitigation measures.

A landslide hazard map which identifies areas of differing landslide potential may be generated. The need for such landslide hazard information may vary according to the future land use. The degree of landslide hazard present is considered relative since it represents the expectation of future landslide occurrence based on the conditions of that particular area. Another area may appear similar but, in fact, may have a differing landslide hazard due to a slightly different combination of landslide conditions. Thus, landslide susceptibility is relative to the conditions of each specific area, and it cannot be assumed to be identical for a similar appearing area.

Even with detailed investigation and monitoring, it is extremely difficult to predict landslide hazards in absolute terms. Sufficient understanding of landslide processes does exist, however, to be able to make an estimation of landslide hazard potential. The planner can use this estimation to make certain decisions regarding site suitability, type of development, and appropriate mitigation measures. Thus, the planner is determining acceptable risk.

1. DETERMINING ACCEPTABLE RISK

Determining whether there is a need for landslide hazard information is the first step in ensuring that landslide risk does not exceed an acceptable level in planning future land use. The objective of landslide information is to identify which relatively landslide-susceptible areas are best suited for what types of development activities. For example, assessing landslide hazard would have a low priority in planning areas to be set aside for national parks or game preserves. Conversely, landslides can be an important

factor in the development of newly cleared forest areas or in building infrastructure in mountainous or hilly terrain. Clearly, the amount of landslide hazard information needed is based on the level and type of anticipated development for an area. Failure to understand the potential effects landsliding can have on a project or how the project might affect landslide potential can bring increased risk.

Natural changes as well as human-induced changes can affect the susceptibility to landslides and must be understood when assessing the landslide potential of an area. It is critical for a planner to appreciate these issues early in the planning process. A decision is ultimately made regarding the degree of risk that is acceptable or unacceptable to a project. Mitigation strategies are then designed to reduce risk. These concepts are discussed at more length later in this chapter.

Early consultation with landslide technical specialists is recommended so that they can assess the risk of proposed activities in a landslide hazard area. The planner, while not expected to be a technical expert, must know the questions to ask of a landslide specialist. By asking the appropriate questions, the planner will be able to identify and evaluate measures to minimize or avoid landslide vulnerability.

2. LANDSLIDE HAZARD MAPPING

Interpretation of future landslide occurrence requires an understanding of conditions and processes controlling landslides in the study area. Three physical factors--past history, slope steepness, and bedrock--are the minimum components necessary to assess landslide hazards. It is also desirable to add a hydrologic factor to reflect the important role which ground water often plays in the occurrence of

landslides. An indication of this factor is usually obtained indirectly by looking at vegetation, slope orientation, or precipitation zones. All of these factors are capable of being mapped. Specific combinations of these factors are associated with differing degrees of landslide hazards. The identification of the extension of these combinations over the area being assessed results in a landslide hazard map. The technique used to prepare hazard maps is called a combined factor analysis and is described in detail in Section C of this chapter.

3. INTEGRATING LANDSLIDE HAZARD ZONATION MAPS INTO THE DEVELOPMENT PLANNING PROCESS

Landslide hazard information serves as one of the many components in an integrated development planning study. Since landslide activity can adversely affect or interfere with human activity, landslide hazards constrain or limit land-use capability. For this reason, it is important to identify relative landslide hazard levels early in the planning process. This permits planners to determine the degree of landslide risk that is acceptable or unacceptable to a development program. Decisions can then be made regarding which of these measures will be taken: avoidance, prevention, or mitigation of existing and future landslide hazards in the development program. The method described in this chapter places emphasis on landslide hazard identification and its use in an integrated planning study as natural resources are evaluated, a development strategy is formulated, and investment projects are identified at the profile level.

a. Preliminary Mission

During the Preliminary Mission of an integrated development planning study, an initial review is made of the type and content of available information, including natural hazard information (see Appendix A). The availability of geologic, topographic, hydrologic, and vegetation maps and aerial photographs is usually ascertained. This information is essential for executing a landslide hazard zonation (see Figure 10-1). Also during this stage of the study, available information should be collected and reviewed concerning assessments of natural hazards, including landslides and disasters, which are known to have affected the study area. See Chapter 1 for a more detailed discussion of the integrated development planning process.

b. Phase I—Development Diagnosis

In the context of planning the development of a river basin, province, or other planning unit, a development diagnosis assists in identifying areas with highest development potential. These are designated "target areas," in which subsequent, more detailed studies are concentrated. Part of the development diagnosis process involves identifying and delineating natural resource factors that favor or constrain development in a particular area. Landslide hazard is an undesirable factor, and the greater the hazard, the more it may shape the development potential.

When a potential hazard is present in the study area, the first step is to undertake a brief survey to establish whether landslides have occurred in recent

PRELIMINARY MISSION (STUDY DESIGN)

QUESTIONS PLANNERS NEED TO ASK:

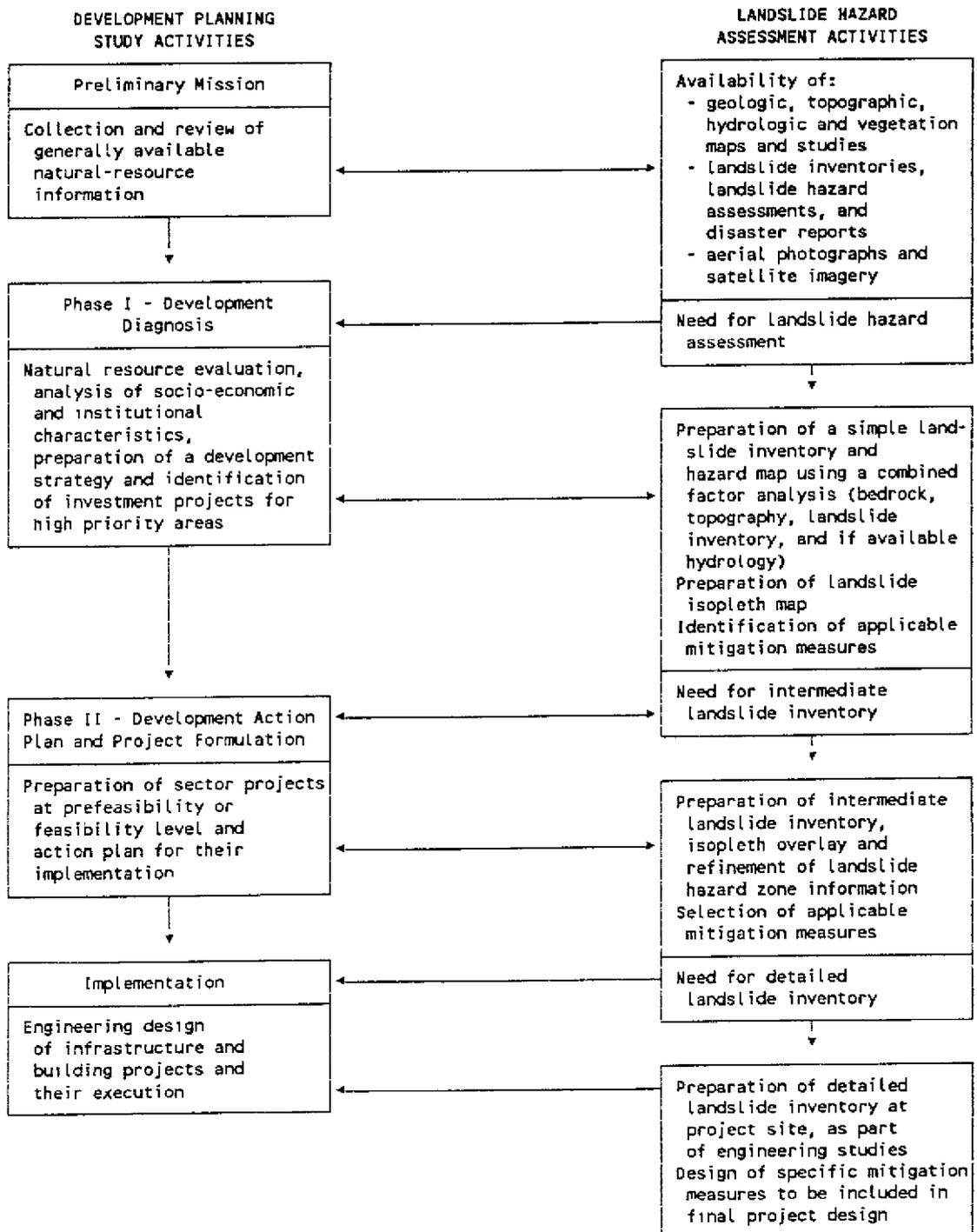
- Are geologic, topographic, hydrologic, and vegetation maps available? At what scale?
- Are aerial photographs available? At what scale?
- Does the study area have a history of landslides and/or disasters caused by landslide events?
- Is landslide hazard assessment information available?

KEY DECISIONS TO BE MADE AT THIS STAGE:

- Is it likely that landslides will affect major and/or significant portions of the study area?
- Will the study have access to landslide hazard assessment information other than what it may produce?

Figure 10-1

DEVELOPMENT PLANNING STUDY AND LANDSLIDE HAZARD ASSESSMENT ACTIVITIES



**PHASE I: DEVELOPMENT DIAGNOSIS
(STRATEGY AND PROJECT IDENTIFICATION)**

QUESTIONS PLANNERS NEED TO ASK:

- Is sufficient information to prepare a landslide inventory map, an isopleth map of existing landslides, and/or a landslide hazard map using factor analysis available?
- How will the assessment be carried out? During what time period?
- How will the assessment information be integrated into the overall study development strategy and project identification activities?

KEY DECISIONS TO BE MADE AT THIS STAGE:

- Is a landslide hazard map necessary?
- At what scale should the map be prepared?
- Who will execute the assessment?
- Who will be responsible for incorporating the assessment information into the overall study activities?

times. Roads, railroads, and river banks are good sites for seeking signs of past landslide occurrence. Discussions with local authorities responsible for public works, forestry, and agricultural activities can prove to be a valuable source of information since they may be familiar with past landslides in an area. However, it is important to bear in mind that new development activities may increase landslide hazards, and the absence of evidence from past landslides does not guarantee that landslides will not pose any problems in the future.

The areal extent and variety of development activities being considered make determining the landslide susceptibility based on all existing landslides, regardless of type, an appropriate approach (DeGraff, 1982). A simple inventory of past landslides, along with data regarding bedrock, slope steepness, and—when available—the hydrologic factor, produces a landslide hazard map that will satisfy the needs of the development diagnosis (see Figure 10-1). Suitable scales for the landslide hazard map range from 1:250,000 to 1:50,000. (See Figure 10-2 for a description of hazard identification needs and appropriate map scales for the different planning stages).

Having limited or insufficient data for preparing the combined factor analysis is most likely to be a problem encountered at the development diagnosis level. When this situation arises, there are two options: (1) invest the money and human resources to obtain the data needed to produce a landslide hazard map, or (2) prepare an isopleth map of existing landslides

(described in Section C of this chapter). The isopleth map shows areas of frequent or infrequent landslide occurrence. While this type of map provides some idea of where landslides can be a major influence on development, it is only a rough approximation of where a problem can be encountered during development. Isopleth maps are an acceptable option at this stage of development but are wholly unsuitable for use in the more detailed planning stages.

The degree of landslide hazard in an area is a limiting factor only for those activities that may alter the existing balance between forces driving and resisting movement on an unfailed slope. Planners need to understand what effects development activities may have on this balance of forces. For example, placing a fence around a field is not going to produce a landslide, nor will it prevent one. Removing forest cover to create a field for cultivating crops is much more likely to lead to landslide occurrence, since it alters the balance of forces and may increase the susceptibility to slope failure by some triggering event, such as prolonged rainfall, which would not have produced the landslide under the original conditions. This increased susceptibility may not be immediately apparent since there may be a lag time before this is evident.

Landslide hazard zonation can be represented as an individual factor limiting land capability or it can be combined with hazard zonation for other natural hazards as an aggregate hazard. There are at least 10 different approaches that have been used to generate land capability maps (Hopkins, 1977).

Figure 10-2

**LANDSLIDE HAZARD CONSIDERATIONS
AT DIFFERENT PLANNING STAGES**

Planning Stage	Hazard Identification Need	Landslide Inventory Level	Suitable Scales For Hazard Maps
Preliminary Mission	Identify hazard issue	As available	As available
Phase I-- Development Diagnosis	Degree of hazard from all types of landslides	Simple	1:250,000 to 1:62,500
Phase II-- Action Plan and Project Formulation	Degree of hazard from all types of landslides supplemented by hazard from some specific types	Intermediate	1:62,500 to 1:10,000
Project Implementation	Site-specific hazard based on geotechnical models	Detailed	1:12,500 to 1:500

Chapter 3 discusses land capability in more detail. The method for landslide hazard assessment presented in this chapter results in the production of a map. Thus, it can be considered in the application of land-use capability approaches

There are two main applications of a landslide hazard assessment in land-use capability that includes relative surveys. First, it is used in overall development planning to emphasize the subjective nature of assigning land-use capability. For example, at the development diagnosis stage, the relative classification of "highest" capability can be assessed in relation to the constraints that possible increased landslide hazards may pose to proposed development activities. Second, it can show where existing development may face some risk previously unidentified. This enables prioritizing mitigation activities to be assigned to different development activities.

c. Phase II--Development Strategy and Project Formulation

An action plan is defined with the objective of facilitating development of target areas identified in Phase I. Development projects considered for the

target area are formulated at this stage. Also at this time, landslide hazard evaluation within the study area is refined. The general landslide hazard assessment must be supplemented with an intermediate inventory to show the degree of hazard for specific types of landslides that may impact on proposed development activities. For example, introducing widespread agricultural activities into a forested environment requires a greater understanding of the hazard from shallow landsliding rather than from deep-seated rockslides.

In developing areas with landslide hazards, mitigation measures should be selected if they are not already part of the project identification information. It is possible to reduce the possible impact of natural landslide activity and limit landslides which occur as a result of human activity (Kockelman, 1985). There are two basic approaches: first, to avoid landslide-susceptible areas, and second, to design measures to compensate for the inducement of landslides (see the box below). For example, make location decisions so as to avoid building in certain areas, such as placing dwellings and critical infrastructure outside areas with a high likelihood of natural landslide activity. In some instances, the potential effects of a landslide can be

LANDSLIDE TRIGGERING ACTIONS, MITIGATION APPROACHES, AND DEVELOPMENT VARIABLES

- **Triggering Actions:**
 - From other hazards:
 - Earthquakes
 - Floods
 - Fire (and resulting loss of vegetation)
 - Volcanoes
 - Development related:
 - Changes in vegetation cover
 - Earthen dams
 - Excavation and mining
 - Irrigation
 - Infrastructure and structure construction
 - Liquid disposal (sanitary, sewers, latrines, etc.)
 - Pillings
 - Soils deposits
- **Mitigation Approaches:**
 - Avoidance
 - Insurance and taxation
 - Land-use zoning
 - Stabilization
 - Structural design
- **Development Variables:**
 - Available information
 - Economic, social, and political concerns
 - Existing development
 - Proposed development

mitigated. Landslide hazards resulting from development can be reduced by designing changes to counteract the impact that development may have on slope integrity. This might take the form of permitting only warehouses and storage facilities in higher hazard areas, to reduce the vulnerability to the population should a landslide occur

In formulating investment projects, a more detailed hazard zonation map is needed. An intermediate landslide inventory is needed which provides greater detail to distinguish different landslide types. This data can be used for a reanalysis of the combined factor analysis. This reanalysis yields an improved landslide hazard map. If the hydrologic factor was not part of the earlier landslide hazard analysis, its inclusion at this stage would greatly improve the resulting hazard map.

At this stage, the value of a landslide hazard map to planners can be enhanced by representing areas

where specific landslide types are prevalent. This is accomplished by preparing an isopleth map, as mentioned in Phase I. Preparation, however, should be altered to meet the specific needs of this planning stage. Alteration of the isopleth map is described in detail in Section C's discussion of "Compensating for Insufficient Data--The Isopleth Map". This produces a map representing the intensity of past landslide occurrence in a form resembling a topographic map. The isopleth lines appear similar to the contour lines showing elevation. The final isopleth map is used as an overlay on the landslide hazard map.

It should be noted that the isopleth map does not alter the basic hazard zones determined previously. It is still an analytic map, which in this instance shows the varying prevalence of a specific landslide type in an area. It provides an additional criterion for the planner to make use of in deciding which area may be best suited for certain development activities. This is especially helpful in evaluating moderate hazard zones.

PHASE II: PROJECT FORMULATION AND ACTION PLAN DEFINITION

QUESTIONS PLANNERS NEED TO ASK:

- Does the initial combined factor analysis landslide hazard map provide sufficient information to proceed with investment project formulation?
- If not already included, is there a hydrologic factor which could be added for further detail on hazard zones?
- Should an isopleth overlay be added to the hazard zonation map?
- Are there certain proposed land uses for which recommendations for mitigation should be included in the formulation of investment projects?

KEY DECISIONS TO BE MADE AT THIS STAGE:

- Who will execute the intermediate landslide hazard assessment?
- Which areas should be included in the additional assessment?
- Who will be responsible for incorporating additional information in investment project formulation activities?

Where proposed land use is recognized as susceptible to a specific landslide type, the proposed activity is best located in a low hazard zone or moderate hazard zone with the lowest occurrence, i.e., smallest isopleth value, of that landslide type. The improved landslide hazard map and isopleth overlay require that an intermediate landslide inventory be prepared at this planning level. The landslide hazard map suitable for formulating development projects should be at a scale of 1:62,500 to 1:12,500 (see Figure 10-2).

d. Project Implementation

The landslide hazard map can contribute to planning for a project's implementation. There are two situations when this map may prove beneficial, both of which are related to mitigating the potential effects of landslides. In one case, it is conceivable that if areas identified with a moderate landslide hazard are targeted for development, greater detail of those areas is needed to ensure the project design compensates for this greater hazard potential. For example, moderate or higher hazard areas may not be entirely avoidable along a proposed road. Detailed investigation can provide information on groundwater conditions and on the stability characteristics of soil and rock to ensure a stable design (Morgenstern and Sangrey, 1978).

In another case, existing infrastructure or communities may be located in previously unidentified high hazard zones. These areas should be given priority for introducing some measure of mitigation

For example, the effect of landslides issuing into an inhabited area from nearby mountain canyons might be mitigated by constructing debris basins to trap most of the material. Where such mitigation is impossible and the risk is identified as being extremely high, relocation to a safer area may be considered.

A detailed hazard map for the specific site in question is necessary at this stage of project design. Preparation of a detailed landslide inventory is now necessary. The large-scale features represented on landslides mapped in this detailed inventory are valuable for test drilling of a site and other sampling activities of engineering design work. Detailed landslide inventories and related interpretation of test results require map scales from 1:12,500 to 1:500 (see Figure 10-2).

The next section provides a detailed discussion of the types and nature of landslides, the basis for assessing landslide hazards, and the factors associated with landslide activity.

B. Landslides, Landslide Hazard Assessment, and Areas of Concern

1. LANDSLIDES AND LANDSLIDE SUSCEPTIBILITY

Landslides are caused when the force of gravity pulls rock, debris or soil down a slope. They are one

PROJECT IMPLEMENTATION

QUESTIONS PLANNERS NEED TO ASK:

- What type of landslide problems exist?
- What site-specific conditions need to be known for final design of an investment project with low landslide vulnerability?

KEY DECISIONS TO BE MADE AT THIS STAGE:

- Who will execute the detailed landslide hazard assessment?
- Which mitigation measures should be considered to reduce the risk to an acceptable level?
- Who will be responsible for incorporating the additional information in project implementation activities?

of the forms of erosion called mass wasting, which is broadly defined as erosion involving gravity as the agent causing movement. Because gravity constantly acts on a slope, landslides only occur when the stress produced by the force of the gravity exceeds the resistance of the material. This is distinct from some other forms of erosion caused by running water, for instance, which occurs when precipitation falls on a slope or within a channel carrying a stream or river. Figure 10-3 depicts a list and diagram with terminology commonly used for describing landslides.

Landslide movement is perceptible and may take the form of falls, topples, slides, or flows. It can consist of free-falling material from cliffs, broken or unbroken masses sliding down mountains or hillsides, or fluid flows. Materials can move up to 120mph or more, and slides can last a few seconds or a few minutes, or can be gradual, slower movements over several hours or days. Accordingly, landslides are recognized on the basis of type of movement

The most widely used classification scheme divides landslides into different types according to the material being moved and type of movement (Varnes, 1978). Speed of movement and amount of water mixed with the material are secondary parameters defining some landslide types. Recognizing the types of landslides presents in an area helps explain how and where factors have contributed to natural slope instability in the past.

Factors influencing where landslides occur can be divided into two sets, permanent and variable (Sharpe, 1938). Permanent factors are characteristics of the landscape which remain unchanged or vary little from a human perspective. The steepness of a slope or the type of rock, for example, presents changes only with

the passage of long periods of time. Permanent factors such as rock type and slope steepness can be recognized and identified for specific landslides long after their occurrence (DeGraff, 1978). By examining existing landslides in an area, it is possible to recognize how permanent factors contributed to these slope failures. Identifying conditions and processes promoting past instability makes it possible to use these factors to estimate future landslides (Varnes, 1985).

Variable factors are landscape characteristics that change quickly as a result of some triggering event. Ground vibration due to earthquakes, a rapid rise in groundwater levels, and increased soil moisture due to intense precipitation are examples of variable factors. It is often necessary to be present at the time a landslide occurs or shortly thereafter to assess these factors. Due to the lack of long-term records relating landslide activity to historic earthquakes, storms, or other initiating factors, permanent factors are usually used to estimate landslide hazard. As such, identifying landslide areas is not an accurate science and leads, in general, to depicting hazard-prone areas based on an estimation. At best, landslide and landslide susceptible areas can be identified along with expected triggering events. At worst, some areas may not be detected at all

2. HAZARD ASSESSMENT OF LANDSLIDES

Landslides are not currently amenable to risk assessment since there is no basis to determine the probability of landslides occurring within a given time period. Hazard assessments are possible and can be used in place of risk assessments. Hazard assessments are estimations of an area's susceptibility

TYPES OF LANDSLIDES

- **Falls:** a mass detaches from a steep slope or cliff and descends by free-fall, bounding, or rolling.
- **Topples:** a mass tilts or rotates forward as a unit.
- **Slides:** a mass displaces on one or more recognizable surfaces, which may be curved or planar.
- **Flows:** a mass moves downslope with a fluid motion. A significant amount of water may or may not be part of the mass.

to landslides based on a few key factors. These are each capable of being mapped and allow land areas to be evaluated on their relative susceptibility to landslides.

Three principles guide landslide hazard assessment. First, landslides in the future will most likely occur under geomorphic, geologic, and topographic conditions that have produced past and present landslides. Second, the underlying conditions and processes which cause landslides are understood. Third, the relative importance of conditions and processes contributing to landslide occurrence can be determined and each assigned some measure reflecting its contribution (Varnes, 1985). The number of conditions present in an area can then be factored together to represent the degree of potential hazard present.

Landslide hazard has been determined with a high degree of reliability for only a few locations. These have required careful, detailed study of the interaction of pertinent permanent and variable conditions in the target area. This can be a very expensive and time-consuming process that is unjustified for the purpose of broad-scale development planning. Landslide hazard zonation is one technique that can be used in the early stage of a planning study.

Most assessment procedures for landslide hazard zonation employ a few key or significant physical factors to estimate relative landslide hazard. The method described here requires a minimum of three factors mentioned earlier: distribution of past landslides, type of bedrock, and slope steepness, and a fourth, hydrologic factor may be added to reflect the important role which groundwater often plays in landslide occurrences (Varnes, 1985, and USGS, 1982).

Each factor is represented in a quantitative or semi-quantitative manner to facilitate the identification of different degrees of landslide hazard in an area.

Since all of these are permanent features, it is usually possible to map each factor. Specific combinations of these factors can be associated with differing degrees of landslide hazard. By extending these combinations over an entire area, a landslide hazard map is produced.

3. FACTORS ASSOCIATED WITH LANDSLIDE ACTIVITY

The distribution of past landslides within the area, type of bedrock, and slope steepness represent, respectively, geomorphic, geologic, and topographic factors (Varnes, 1985, and USGS, 1982). Each of these factors is described in more detail below to give the planner a better understanding of their contribution to landsliding. The final section, "C. Mapping Physical Factors and Preparation of a Landslide Hazard Map," provides information on mapping them.

a. Past Landslides and Their Distribution

Interpreting the likelihood of future landslide occurrences requires an understanding of conditions and processes controlling past landslides in the area of interest. This can be achieved by examining and mapping past landslide activity in the area. Geologic, topographic, and hydrologic circumstances associated with past landslides indicate which natural or artificially created circumstances are likely to produce landslides in the future.

A primary consideration of the planner is the effect of existing land use on landslide activity. Certain types of landslides may be associated with specific land uses. For example, certain slides may only occur in road cuts or excavations. There may even be a critical height-to-inclination relationship for cutslopes below which these landslides will not occur. Field studies can provide insight into how different factors have contributed to failures. In some investigations special

**IN ORDER TO PLAN FOR DEVELOPMENT IN LANDSLIDE
AREAS, A PLANNER NEEDS TO KNOW:**

- Past distribution of landslides
- Types of bedrock
- How steep the slopes are
- Indirect measures of the area's hydrologic characteristics that are available
- Effects development activity can have on landslide susceptibility

forms have been employed to ensure consistent collection of this ancillary information (see Figure 10-4). A summary of observations about landslide conditions and processes are incorporated into each landslide inventory, e.g., as in Pomeroy (1979), and mapped.

b. Bedrock

Bedrock influences landslide occurrence in several ways. Weak, incompetent rock is more likely to fail than strong, competent rock. (See Figure 10-5 for an example of this.) On slopes where weak rock overlain by strong rock is exposed, the difference in strength increases the potential for landsliding in the stronger rock as well since the weak rock tends to erode and undermine the stronger rock.

The strength of a rock mass depends on the type of rock and the presence and nature of discontinuities such as joints or other fractures. The more discontinuities present in bedrock, the greater the likelihood of rock instability. Rock type may exert control on landsliding by influencing the strength of surface material in the area. For example, soils (in the engineering rather than agricultural sense of the term) derived from schists or shales will contain high percentages of clay. These soils will have different strength characteristics than coarser-grained soils such as those derived from granitic bedrock. There are many ways, then, that rock type or structure contributes to the instability, which can be represented on a map.

c. Slope Steepness or Inclination

The influence of slope steepness on landslide occurrence is the easiest factor to understand. Generally, steeper slopes have a greater chance of landsliding (see Figure 10-6). This does not prevent failures from occurring on gentler slopes. Other factors may make a gentle slope especially sensitive to failure, and thus in this situation could be determined to have a relatively high hazard potential.

For example, high ground water conditions occurring in sandy soils may liquefy during an earthquake. This can cause a landslide on a slope as gentle as 5 to 10 percent. Conversely, the steepest slopes may not always be the most hazardous. Steep slopes are less likely to develop a thick cover of superficial material conducive to certain types of landslides. Slope steepness can be mapped using generally available topographic maps.

d. Hydrologic Factor

Water is recognized as an important factor in slope stability--almost as important as gravity. Information on water table levels and fluctuations is rarely available. To represent the hydrologic factor in landslide hazard assessments, indirect measures can be used which can be mapped to show the influence of the area's hydrology, such as vegetation, slope orientation (aspect), or precipitation zones.

The type of vegetation and its density over an area will often reflect the variation in subsurface water. Certain species are water-loving or phreatophytes. Presence of these species shows near-surface water table conditions and springs. In mountainous regions, microclimatic differences produce different hydrologic conditions which in turn result in plant communities that vary according to the moisture available to the slope and its distribution throughout the year.

Slope orientation (aspect) refers to the direction a slope faces. It can be an indirect measure of climatic influence on the hydrologic characteristics of the landscape. Important characteristics associated with landslides are related to such factors as subsurface recharge resulting from prevailing winds and their influence on local frontal storms or accumulated snow. In other cases, a slope may experience more freeze/thaw cycles or wet/dry cycles which can reduce the strength of the soil and make the area more susceptible to landslides. In general, due to the complexity of these factors and existing development

Figure 10-4

INVENTORY AND STATISTICAL ANALYSIS INFORMATION FORM FOR LANDSLIDES

C.N.R. irpi INVENTORY AND STATISTICAL ANALYSIS OF LANDSLIDES									
Sheet		Surveyor's unit and form number		Date		LANDSLIDE		<input type="checkbox"/>	
		Name		Drainage Basin		LANDSLIDE ZONE		<input type="checkbox"/>	
		Township				STREAM EROSION		<input type="checkbox"/>	
						EROSIONAL ZONE		<input type="checkbox"/>	
				MONOLITHIC a <input type="checkbox"/> b <input type="checkbox"/> c <input type="checkbox"/> solid <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> partly solid <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> loose <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> cohesive			LITHOLOGY ALTERATED S <input type="checkbox"/> P <input type="checkbox"/> L <input type="checkbox"/> C <input type="checkbox"/>		
TIPPING downstream <input type="checkbox"/> upstream <input type="checkbox"/> oblique <input type="checkbox"/> VERT <input type="checkbox"/> HORIZ <input type="checkbox"/> <input type="checkbox"/> LAYERING <input type="checkbox"/> JOINTS <input type="checkbox"/> FAULTS				town, village etc. houses n° <input type="checkbox"/> country houses l <input type="checkbox"/> main roads l <input type="checkbox"/> country roads l <input type="checkbox"/> railroad <input type="checkbox"/> aqueduct <input type="checkbox"/> bridge-viaduct <input type="checkbox"/> retaining walls and similar structures <input type="checkbox"/>			great social <input type="checkbox"/> economic implications <input type="checkbox"/>		
ROCK CONDITIONS fresh <input type="checkbox"/> weathered <input type="checkbox"/> fractured <input type="checkbox"/>				barren <input type="checkbox"/> occasionally <input type="checkbox"/> permanently <input type="checkbox"/> sown <input type="checkbox"/> grass <input type="checkbox"/> other <input type="checkbox"/> pasture <input type="checkbox"/> shrubbery <input type="checkbox"/>			vineyard <input type="checkbox"/> trees with sawn <input type="checkbox"/> orchard <input type="checkbox"/> oakgrove <input type="checkbox"/> bush <input type="checkbox"/> forest <input type="checkbox"/> chestnut <input type="checkbox"/> beech <input type="checkbox"/> pine <input type="checkbox"/> other <input type="checkbox"/>		
UNIFORM SLOPE rectilin <input type="checkbox"/> concave <input type="checkbox"/> convex <input type="checkbox"/> slope angle <input type="checkbox"/> NON UNIFORM SLOPE terracettes <input type="checkbox"/> hummocky <input type="checkbox"/>				EXPOSURE N <input type="checkbox"/> NE <input type="checkbox"/> E <input type="checkbox"/> SE <input type="checkbox"/> S <input type="checkbox"/> SW <input type="checkbox"/> W <input type="checkbox"/> NW <input type="checkbox"/>			logging <input type="checkbox"/> fire <input type="checkbox"/> other <input type="checkbox"/> THICK <input type="checkbox"/> THIN <input type="checkbox"/>		
<input type="checkbox"/> EROSIONAL AREA <input type="checkbox"/> sheet pile erosion <input type="checkbox"/> gully erosion <input type="checkbox"/> bad lands <input type="checkbox"/> erosion niches <input type="checkbox"/> lateral erosion <input type="checkbox"/> incision				SHAPE <input type="checkbox"/> circular <input type="checkbox"/> parabolic <input type="checkbox"/> elongated <input type="checkbox"/> other			GROUND AREA from 0 to 5000 <input type="checkbox"/> from 5000 to 10000 <input type="checkbox"/> from 10000 to 25000 <input type="checkbox"/> from 25000 to 50000 <input type="checkbox"/> from 50000 to 100000 <input type="checkbox"/> over 100000 <input type="checkbox"/>		
<input type="checkbox"/> STREAM EROSION related to landslides <input type="checkbox"/>				ELEVATION SLOPE ANGLE <input type="checkbox"/>			MAP AREA		
CAUSES lithology <input type="checkbox"/> climate exposure <input type="checkbox"/> morphology <input type="checkbox"/> slope <input type="checkbox"/> structures <input type="checkbox"/> deforestation <input type="checkbox"/> cultivation <input type="checkbox"/> landslides <input type="checkbox"/>				CORRECTIVE MEASURES groins <input type="checkbox"/> dams <input type="checkbox"/> drainage ditches <input type="checkbox"/> afforestation <input type="checkbox"/> trellis-works <input type="checkbox"/> walls terraces <input type="checkbox"/>			YES <input type="checkbox"/> NO <input type="checkbox"/>		

Source: Carrara, A., and Merenda, L. "Landslide Inventory in Northern Calabria, Southern Italy" in Geological Society of American Bulletin, vol. 87 (1976), pp. 1153-1162