Chapter 4
Hazard Identification, Assessment, and Mapping

Hazard Analysis

Recognition of the presence of active or potential slope movement, and of the types and causes of the movement, is essential to landslide mitigation. Recognition depends on an accurate evaluation of the geology, hydrogeology, landforms, and interrelated factors such as environmental conditions and human activities. Only trained professionals should conduct such evaluations. However, because local governments may need to contract for such services, they should be aware of the techniques available and their advantages and limitations.

Techniques for recognizing the presence or potential development of landslides include:

- map analysis
- analysis of aerial photography and imagery
- analysis of acoustic imagery and profiles
- field reconnaissance
- aerial reconnaissance
- drilling
- acoustic imaging and profiling
- geophysical studies
- computerized landslide terrain analysis
- instrumentation

Map Analysis

Map analysis is usually one of the first steps in a landslide investigation. Maps that can be used include geologic, topographic, soils, and geomorphic. Using knowledge of geologic materials and processes, a trained person can obtain a general idea of landslide susceptibility from such maps.

Analysis of Aerial Photography and Imagery

The analysis of aerial photography is a quick and valuable technique for identifying landslides, because it provides a three-dimensional overview of the terrain and indicates human activities as well as much geologic information. In addition, the availability of many types of aerial imagery (satellite, infrared, radar, etc.) make this a very versatile technique.

Analysis of Acoustic Imagery and Profiles*

Profiles of lake beds, river bottoms, and the sea floor can be obtained using acoustic techniques such as side-scan sonar and subbottom seismic profiling. Surveying of controlled grids, with accurate navigation, can yield three-dimensional perspectives of subaqueous geologic phenomena. Modern, high resolution techniques are used routinely in offshore shelf areas to map geologic hazards for offshore engineering. Surveying and mapping standards for outer continental shelf regions are regulated by the U.S. Minerals Management Service.

Field Reconnaissance

Many of the more subtle signs of slope movement cannot be identified on maps or photographs. Indeed, if an area is heavily forested or has been urbanized, even major features may not be evident. Furthermore, landslide features change over time on an active slide. Thus, field reconnaissance is necessary to verify or detect many landslide features.

Aerial Reconnaissance

Low-level flights in helicopters or small aircraft can be used to obtain a rapid and direct overview of a site.

Drilling

At most sites, drilling is necessary to determine the type of earth materials involved in the slide, the depth to the slip surface and thus the thickness and geometry of the landslide mass, the water-table level, and the degree of disruption

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of the landslide materials. It can also provide samples for age-dating and testing the engineering properties of landslide materials. Finally, drilling is needed for installation of some monitoring instruments and hydrologic observation wells.

Geophysical Studies

Geophysical techniques (the study of changes in the earth's gravitational and electrical fields, or measurement of induced seismic behavior) can be used to determine some subsurface characteristics such as the depth to bedrock, zones of saturation, and sometimes the ground-water table. It can also be used to determine the degree of consolidation of subsurface materials and the geometry of the units involved. In most instances these methods can best be used to supplement drilling information. Monitoring of natural acoustic emissions from moving soil or rock has also been used in landslide studies.

Computerized Landslide Terrain Analysis

In recent years computer modeling of landslides has been used to determine the volume of landslide masses and changes in surface expression and cross section over time. This information is useful in calculating the potential for stream blockage, cost of landslide removal (based on volume), and type and mechanism of movement. Very promising methods are being developed utilizing digital elevation models (DEMs) to evaluate areas quickly for their susceptibility to landslide/debris-flow events (Filson, 1987; Ellen and Mark, 1988). Computers are also being used to perform complex stability analyses. Software programs for these studies are readily available for personal computers.

Instrumentation

Sophisticated methods such as electronic distance measuring (EDM); instruments such as inclinometers, extensometers, strain meters, tiltmeters, and piezometers; and simple techniques such as establishing control points using stakes can all be used to determine the mechanics of landslide movement and to warn against impending slope failure.

Anticipating the Landslide Hazard

One of the guiding principles of geology is that the past is the key to the future. In evaluating landslide hazards this means that future slope failures will probably occur as a result of the same geologic, geomorphic, and hydrologic situations that led to past and present failures. Based on this assumption, it is possible to estimate the types, frequency of occurrence, extent, and consequences of slope failures that may occur in the future. However, the absence of past events in a specific area does not preclude future failures. Man-induced conditions such as changes in the natural topography or hydrologic conditions can create or increase an area's susceptibility to slope failure (Varnes and the International Association of Engineering Geology, 1984).

In order to predict landslide hazards in an area, the conditions and processes that promote instability must be identified and their relative contributions to slope failure estimated, if possible. Useful conclusions concerning **increased probability** of landsliding can be drawn by combining geological analyses with knowledge of short- and long-term meteorological conditions. Current technology enables persons monitoring earth movements to define those areas most susceptible to landsliding and to issue "alerts" covering time spans of hours to days when meteorological conditions known to increase or initiate certain types of landslides occur. Alerts covering longer periods of time become proportionately less reliable.

Translation of Technical Information to Users

According to Kockelman (personal communication, 1989), the successful translation of natural hazard information for nontechnical users conveys the following three elements in one form or another:

(1) likelihood of the occurrence of an event of a size and location that would cause casualties, damage, or disruption;

(2) location and extent of the effects of the event on the ground, structures, or socioeconomic activity;

(3) estimated severity of the effects on the ground, structures, or socioeconomic activity.

These elements are needed because usually engineers, planners, and decision makers will not be concerned with a potential hazard if its likelihood is rare, its location is unknown, or its severity is slight.

Unfortunately, these three pieces of information can come in different forms with many different names, some quantitative and precise, others qualitative and general. For a product to qualify as "translated" hazard information, the nontechnical user must be able to perceive likelihood, location, and severity of the hazard so that he or she becomes aware of the danger, can convey the risk to others, and can use the translated information directly in a reduction technique.

Maps are a useful and convenient tool for presenting information on landslide hazards. They can present many kinds and combinations of information at different levels of detail. Hazard maps used in conjunction with land-use maps are a valuable planning tool. Leighton (1976) suggests a three-stage approach to landslide hazard mapping. The first stage is regional or reconnaissance mapping, which synthesizes available data and identifies general problem areas. This small-scale mapping is usually performed by a state or federal geological survey. The next stage is community-level mapping, a more detailed surface and subsurface mapping program in complex problem areas. Finally, detailed site-specific large-scale maps are prepared. If resources are limited, it may be more prudent to bypass regional mapping and concentrate on a few known areas of concern.

Regional Mapping

Regional or reconnaissance mapping supplies basic data for regional planning, for conducting more detailed studies at the community and site-specific levels, and for setting priorities for future mapping.

These maps are usually simple inventory maps and are directed primarily toward the identification and delineation of regional landslide problem areas and the conditions under which they occur. They concentrate on those geologic units or environments in which additional movements are most likely. Such mapping relies heavily on photogeology (the geologic interpretation of aerial photography), reconnaissance field mapping, and the collection and synthesis of all available pertinent geologic data (Leighton, 1976).

Regional maps are most often prepared at a scale of 1:24,000, because high-quality U.S. Geological Survey topographic base maps at this scale are widely available, and aerial photos are commonly of a comparable scale. Other scales commonly used include 1:50,000 (county series), 1:100,000 (30 x 60 minute series), and 1:250,000 (1 x 2 degree series).

Community-Level Mapping

Community-level mapping identifies both the three-dimensional limits of landslides and their causes. Guidance concerning land use, zoning, and building, as well as recommendations for future site-specific investigations, are also made at this stage. Investigations should include subsurface exploratory work in order to produce a large-scale map with cross sections (Leighton, 1976). Map scales at this level vary from 1:1,000 to 1:10,000.

Site-Specific Mapping

Site-specific mapping is concerned with the identification, analysis, and solution of actual site-specific problems. It is usually undertaken by private consultants for landowners who propose site development and typically involves a detailed drilling program with downhole logging, sampling, and laboratory analysis in order to procure the necessary information for design and construction (Leighton, 1976). Map scales vary, but are usually not larger than one inch equal to 50 feet.

Types of Maps

The three types of landslide maps most useful to planners and the general public are (1) landslide inventories, (2) landslide susceptibility maps, and (3) landslide hazard maps.

Landslide inventories

Inventories identify areas that appear to have failed by landslide processes, including debris flows and cut-and-fill failures. The level of detail of these maps ranges from simple reconnaissance inventories that only delineate broad areas where landsliding appears to have occurred (Figure 20) to complex inventories that depict and classify each landslide and show scarps, zones of depletion and accumulation, active versus inactive slides, geological age, rate of movement, and other pertinent data on depth and kind of materials involved in sliding (U.S. Geological Survey, 1982; Brabb, 1984b) (Figure 21).

Simple inventories give an overview of the landslide hazard in an area and delineate areas where more detailed studies should be conducted. Detailed inventories provide a better understanding of the different landslide processes operating in an area and can be used to regulate or prevent development in landslide areas and to aid the design of remedial measures (U.S. Geological Survey, 1982). They also provide a good basis for the preparation of derivative maps such as those indicating slope stability, landslide hazard, and land use. Wieczorek (1984) described how to prepare a landslide inventory map that can be used by planners and decision makers to assess landslide hazards on a regional or community level. The process consists of using aerial photography with selective field checking to detect landslide areas, and then presenting the information in map form using a coded format. The maps show any or all of the following: state of activity, certainty of identification, dominant types of slope movement, estimated thickness of slide material, and dates or periods of activity.

Landslide susceptibility maps

A landslide susceptibility map goes beyond an inventory map and depicts areas that have the potential for landsliding (Figure 22). These areas are determined by correlating some of the principal factors that contribute to landsliding, such as steep slopes, weak geologic units that lose strength when saturated, and poorly drained rock or soil, with the past distribution of landslides. These maps indicate only the relative stability of slopes; they do not make absolute predictions (Brabb, 1984b).

Landslide susceptibility maps can be considered derivatives of landslide inventory maps because an inventory is essential for preparing a susceptibility map. Overlaying a geologic map with an inventory map that shows existing landslides can identify specific landslide-prone geologic units. This information can then be extrapolated to predict other areas of

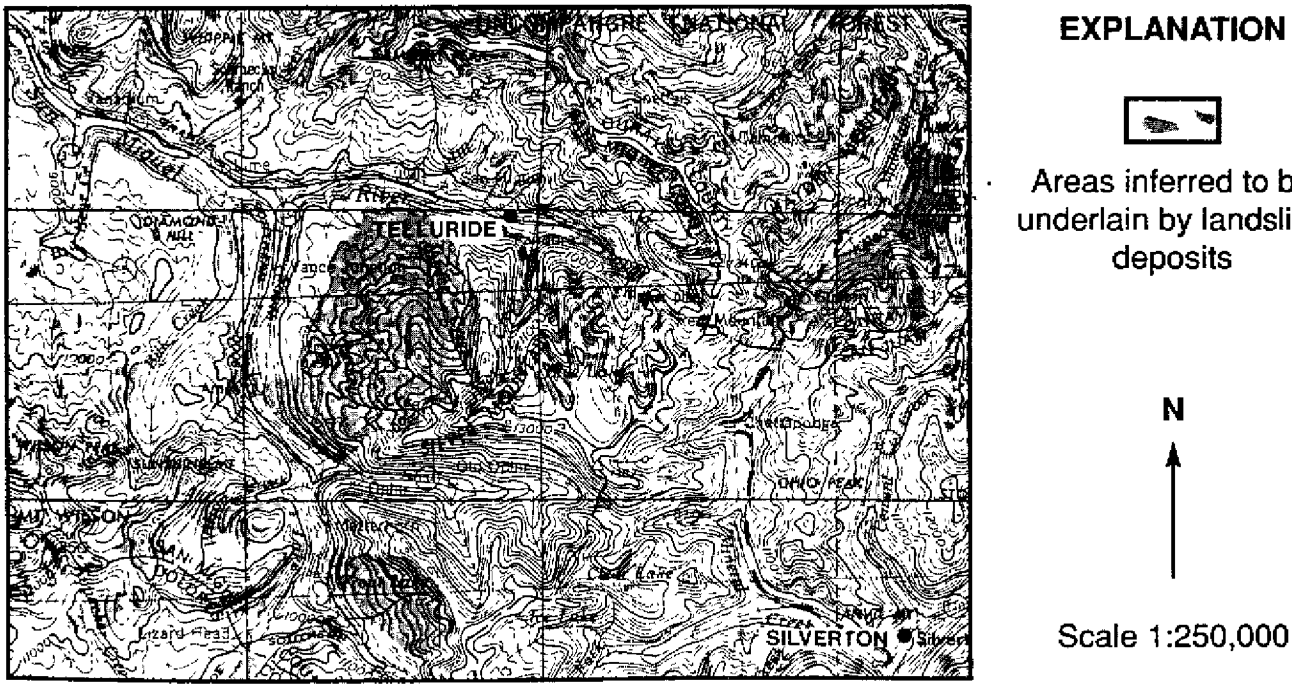


Figure 20. Detail from the landslide inventory map of the Durango 1 x 2 degree map, Colorado (Colton et al., 1975).

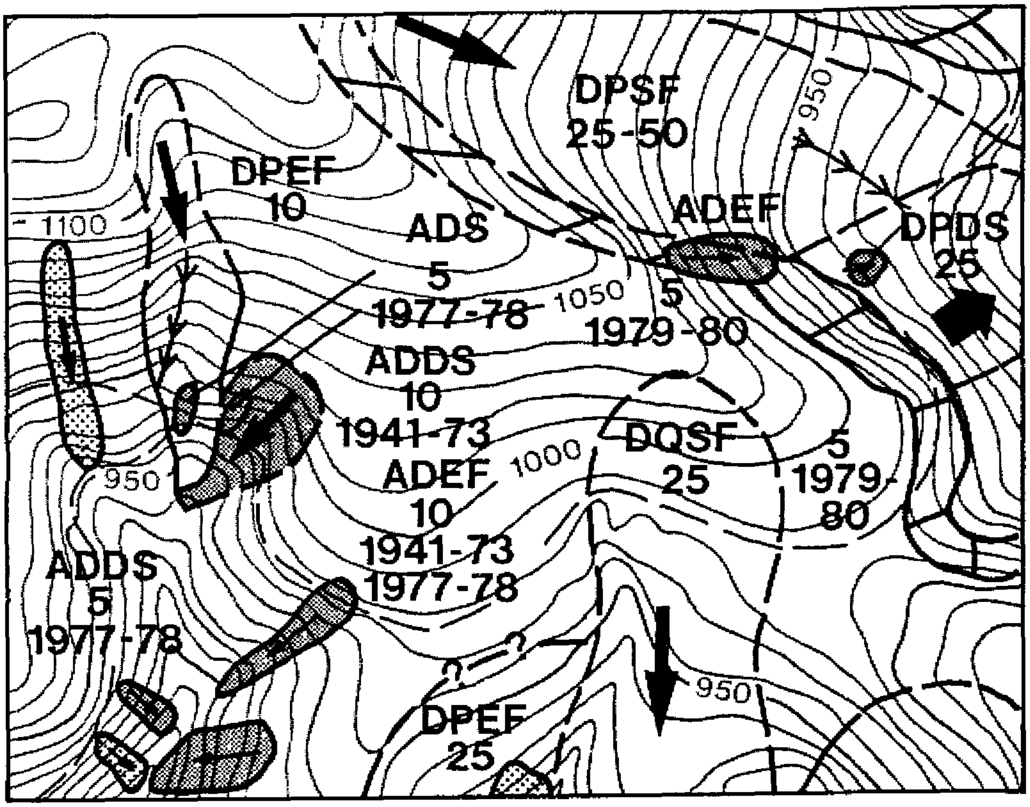
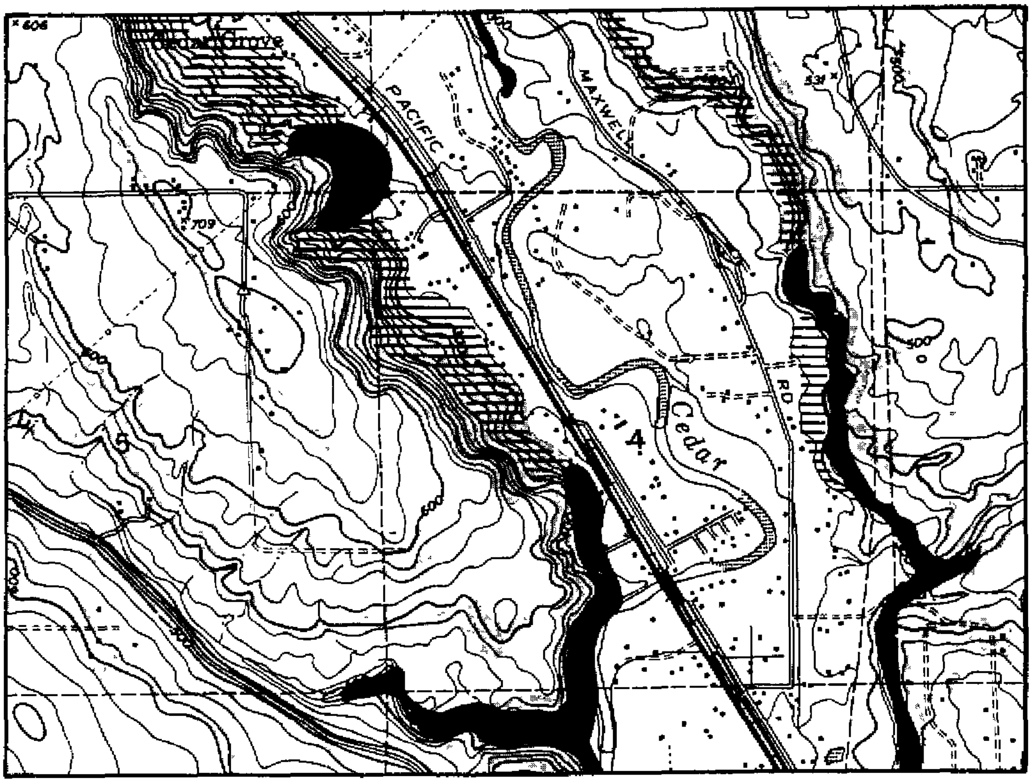


Figure 21.
Detail from map showing recently active and dormant landslides near La Honda, central Santa Cruz Mountains, California. Information shown on this map includes: state of activity, dominant type of slope movement, direction of movement, scarp location, depth and date of movement. See map for detailed explanation. (Wieczorek, 1982.)



EXPLANATION

- Stable slopes
- Normally stable slopes
- Unstable slopes
- Old landslide deposits

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Scale 1:24,000

Figure 22. Detail from map showing relative slope stability in part of west-central King County, Washington (Miller, 1973).

potential landsliding. More complex maps may include additional information such as slope, angle, and drainage.

Landslide hazard maps

Hazard maps show the areal extent of threatening processes: where landslide processes have occurred in the past, where they occur now, and the likelihood in various areas that a landslide will occur in the future (Figure 23). For a given area, they contain detailed information on the types of landslides, extent of slope subject to failure, and probable maximum extent of ground movement. These maps can be used to predict the relative degree of hazard in a landslide area.

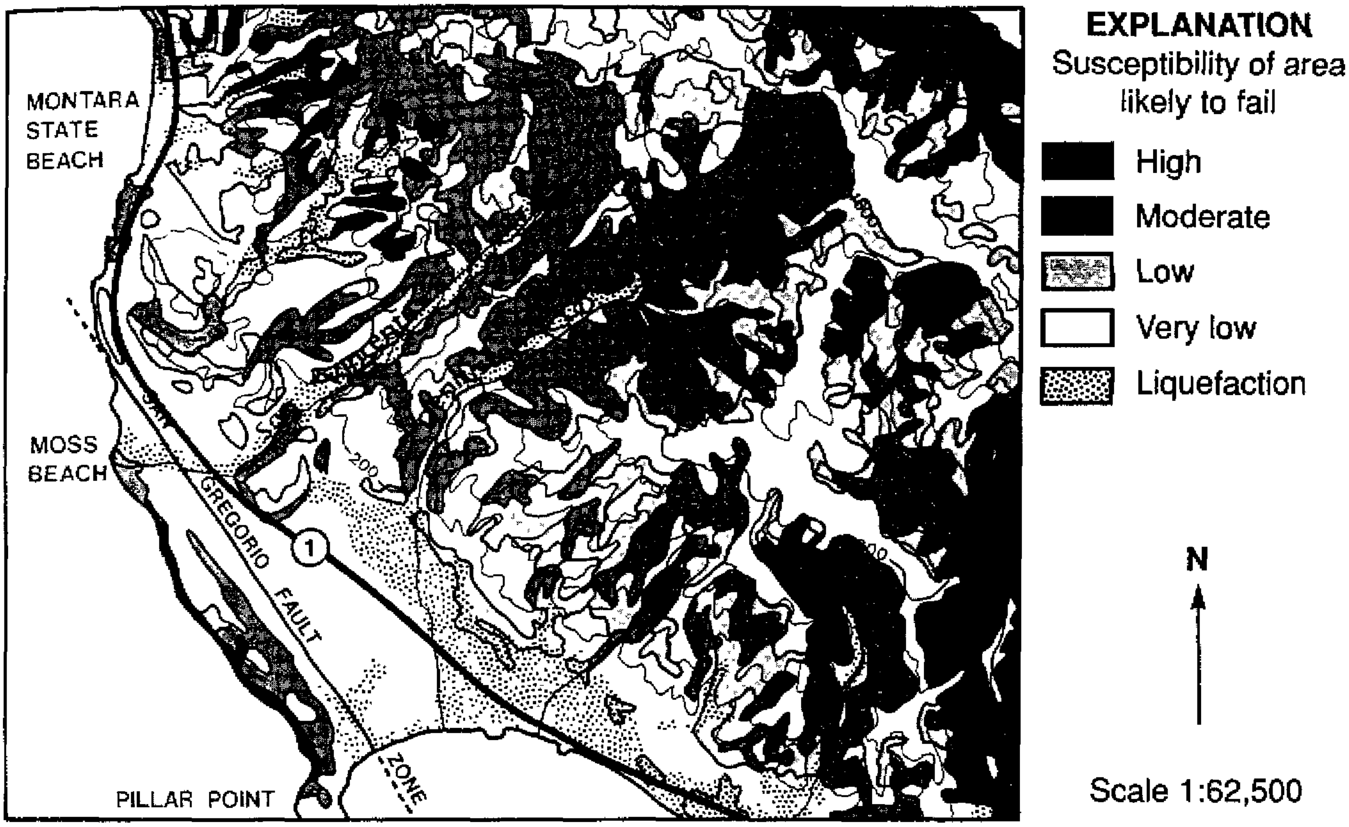

Figure 23. Detail from map showing slope stability during earthquakes in San Mateo County, California (Wieczorek et al., 1985).