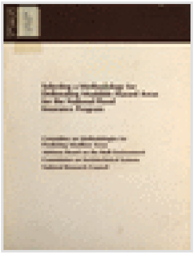

Selecting a Methodology for Delineating Mudslide Hazard Areas for the National Flood Insurance Program (1982)

Pages
49

Size
8.5 x 10

ISBN
0309328004

Committee on Methodologies for Prediction Mudflow Areas; Advisory Board on the Built Environment; Commission on Sociotechnical Systems; National Research Council

Selecting a Methodology for Delineating Mudslide Hazard Areas for the National Flood Insurance Program

Committee on Methodologies for
Predicting Mudflow Areas

Advisory Board on the Built Environment

Commission on Sociotechnical Systems

National Research Council

NATIONAL ACADEMY PRESS
Washington, D.C. 1982

NOTICE

The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the Committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

THE NATIONAL RESEARCH COUNCIL was established by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purpose of furthering knowledge and of advising the federal government. The Council operates in accordance with general policies determined by the Academy under the authority of its Congressional charter of 1863, which establishes the Academy as a private, nonprofit, self-governing membership corporation. The Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in the conduct of their services to the government, the public, and the scientific and engineering communities. It is administered jointly by both Academies and the Institute of Medicine. The National Academy of Engineering and the Institute of Medicine were established in 1964 and 1970, respectively, under the charter of the National Academy of Sciences.

THE COMMISSION ON SOCIOTECHNICAL SYSTEMS is one of the major components of the National Research Council and has general responsibility for the cognizance over those program areas concerned with physical, technological, and industrial systems that are or may be deployed in the public or private sector to serve societal needs.

THE ADVISORY BOARD ON THE BUILT ENVIRONMENT is that unit of the Commission on Sociotechnical Systems with a responsibility for managing advisory networks of government, private sector, and international organizations and individuals that are concerned with the scientific and technological issues which impact the design, production, and management of buildings and communities.

This report was prepared under Contract Number EMW-C-0375 between the National Academy of Sciences and the Federal Emergency Management Agency.

For information regarding this document, write the Executive Director, Advisory Board on the Built Environment, National Research Council, 2101 Constitution Avenue, Washington, D.C. 20418.

Printed in the United States of America

TABLE OF CONTENTS

ADVISORY BOARD ON THE BUILT ENVIRONMENT

COMMITTEE ON METHODOLOGIES FOR PREDICTING MUDFLOW AREAS

Chairman
RUSSELL H. CAMPBELL, U.S. Geological Survey, Reston, Virginia

Members
PAUL BOCK, Department of Civil Engineering, University of Connecticut, Storrs, Connecticut
F. BEACH LEIGHTON, Leighton and Associates, Inc., Irvine, California
JAMES K. MITCHELL, Department of Geography, Rutgers University, New Brunswick, New Jersey
DAVID PRIOR, Coastal Studies Institute, Louisiana State University, Baton Rouge, Louisiana
DWIGHT A. SANGREY, Department of Civil Engineering, Carnegie-Mellon University, Pittsburgh, Pennsylvania
WADE G. WELLS, II, Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, Glendora, California

Liaison Representative
WILLIAM R. LOCKE, Federal Emergency Management Agency, Washington, D.C.

ABBE Staff
JOHN P. EBERHARD, Executive Director
JAMES R. SMITH, Acting Executive Director until August 1981
ABRAM B. BERNSTEIN, Program Manager
DEBORAH D. LANGE, Editorial Consultant
CATHERINE E. ALLISON, Secretary
DELPHINE D. GLAZE, Administrative Secretary

FOREWORD

This report presents the results of one of four studies on flooding conducted by the Advisory Board on the Built Environment (ABBE) during 1981-1982. The client for these studies was the Federal Emergency Management Agency (FEMA), which administers the National Flood Insurance Program (NFIP). This report addresses the problem of how to map areas of mudslide hazard. The other three studies are (1) an assessment of the conduct of flood insurance studies, (2) an evaluation of computer models for the hydrodynamics of erodible channels, and (3) an evaluation of a computer model for coastal flooding from hurricanes.

The present report is a sequel to a report prepared by a panel of the Building Research Advisory Board (predecessor to the Advisory Board on the Built Environment) in 1974. Both reports address essentially the same problem: how to delineate areas prone to mudslides and identify the degree of risk in a manner compatible with other hazard mapping conducted for the NFIP. A major purpose of the present report is evaluation of a methodology developed by the Los Angeles County Flood Control District for use in delineating areas of mudslide hazard in the San Gabriel Mountains.

The study committee was selected after consultation with a number of experts in government, industry, and academia, as well as within the National Academy of Sciences. The committee was chosen to include experts in geology, hydrology, geography, and geotechnical engineering --the technical disciplines related to floods, mudslides, and similar phenomena occurring in mountain drainage basins. The chairman of the committee is an engineering geologist who served on the 1974 panel. The committee also includes one other geologist, two hydrologists, one geotechnical engineer, one geographer, and one geographer-geologist. Two committee members are from southern California and have had extensive experience with floods and landslides in the Los Angeles area. The remaining five members are from Connecticut, Pennsylvania, New Jersey, Virginia, and Louisiana and have expertise in landlides, slope stability, mudslides, water resources planning, and community response to natural hazards. Two committee members are with federal agencies, one is with a private consulting firm, and four are on university faculties.

Fifteen additional experts from universities, private companies, and federal, state, and local agencies met with the committee in a one-day workshop to discuss various aspects of flood and landslide hazard mapping. The committee also spent a day touring flood control works and sites of past mudslides in the Los Angeles area. In addition, personnel of the Los Angeles County Flood Control District briefed the committee on their methodology.

The committee did not include experts in the economics of flood and mudslide damage or in the actuarial determination of insurance rates, since these topics were beyond the scope of this study.

John P. Eberhard
Executive Director
Advisory Board on the Built Environment

PREFACE

This report is the result of a study carried out by the Committee on Methodologies for Predicting Mudflow Areas. Its purpose is to advise the Federal Emergency Management Agency (FEMA) on methods for mapping areas of mudslide hazard as part of the National Flood Insurance Program (NFIP).

The time available for this study and for preparation of a report was short, and the committee was asked for a general overview rather than a detailed analysis. In keeping with that request, this report presents the committee's evaluation of several key aspects of the problem of delineating areas of mudslide hazard, but it is not an exhaustive treatment of the subject. This report does not recommend any one approach to mudslide hazard mapping. There are several approaches that can probably serve the purposes of the NFIP. Selection of one requires a clear decision by FEMA of which phenomena are to be included in the NFIP and which are to be excluded.

In writing this report, the committee has avoided highly technical discussions wherever possible. For example, there is no technical discussion of the Newtonian and non-Newtonian flow mechanisms that provide a basis for differentiating between what we call in this report "mud floods" and "mud flows."

I. SUMMARY

INTRODUCTION

The technical problems faced by the Federal Emergency Management Agency (FEMA) in administering the mudslide provisions of the National Flood Insurance Program (NFIP) stem from a need to identify and map areas of potential mudslide hazard. The NFIP was created in 1968 for the dual purpose of (1) easing individual flood-loss burdens by spreading costs among the population at risk, and (2) reducing future losses by encouraging sound land-use management of flood-prone areas. A key element of the program is the mapping of areas prone to flooding. These maps are used to identify areas in which appropriate land use management measures are required. They are also used in establishing insurance rates. The flood hazard maps currently prepared identify the extent and depth of the so-called 100-year flood, i.e., the flood that has a one percent chance of being equaled or exceeded in any given year. The 100-year flood is the base flood used in delineating flood-prone areas.

The original program covered only floods. Mudslides were added in 1969. An unambiguous, technically acceptable definition of mudslides was not provided at that time, although an attempt was made, a few years later, to clarify the term "mudslide" by the addition of the phrase "i.e., mudflow." Moreover, no standard procedure existed for identifying mudslide-prone areas and calculating the degree of mudslide risk. As a consequence, although mudslide coverage is included in the Standard Flood Insurance Policy, no mudslide hazard maps have been published, nor has a formal system of mudslide management and mitigation been established. Insurance premiums are based entirely on the risk of flood and do not reflect presence or absence of mudslide risk. The processing of claims for mudslide damage is often complicated by difficulty in determining whether the occurrence responsible for the damage was actually a mudslide. Some claims have been paid; others have been denied. Some lawsuits have resulted.

In 1979, the Los Angeles County Flood Control District (LACFCD) developed a methodology for mapping areas of mudslide[1] hazard along

---

[1] The Los Angeles County Flood Control District uses the term "mudflow."

the southern flank of the San Gabriel Mountains and used it to identify areas of mudslide hazard in the City of Sierra Madre, California. FEMA then asked the National Academy of Sciences to (1) examine this methodology and assess its validity, (2) determine whether it could be applied in other geographic areas, (3) identify any other mudslide prediction methodologies that might exist, and (4) make recommendations concerning methods for delineating areas of mudslide hazard.

The study committee directed its attention to three areas:

- Definition of the terms used to describe mudslides and related phenomena.
- Methodologies for delineating areas prone to mudslides and related hazards.
- Strategies for developing methods for delineating areas prone to mudslides.

The committee did not propose a definition for the term "mudslide," believing that to be FEMA's responsibility. In this report the term "mudslide" is used only in discussing the history, purpose, statutes, regulations, and status of the NFIP. In discussing the physical processes that take place in mountain drainage basins, the committee uses the terms "mud flood" and "mud flow." The term "mudflow," as a single word, is not used in this report except when another source is being quoted.

DEFINITIONS

Floods and landslides fall within a continuum of natural processes. Distinctions within this continuum can be made. For application in the NFIP it is useful to define two principal categories and four subcategories.

"Floods" is a general class of phenomena that includes both "clear water floods" and "mud floods." Clear water floods may carry small amounts of sediment, but damage is caused primarily by the water. Mud floods are flood flows in which large quantities of mud and debris are carried by water, which acts as the transporting agent. Damage may be caused by the mud and debris as well as by water.

"Landslides" is a general class of phenomena associated with instability of slopes. It includes "mud flows" and "other landslides." Mud flows are a subset of landslides involving a flow mechanism in which water, clay, silt, sand, and boulders are so mixed as to constitute a fluid having sufficient density and viscosity to be self-transporting. "Other landslides" includes landslides with other movement mechanisms, such as slides, topples, and falls.

Mud floods generally occur in stream channels. Mud flows generally originate on hillslopes and sometimes flow into stream channels. Mud floods and mud flows can occur as separate and distinct events. They can also occur simultaneously as a result of the same triggering event. Within a single drainage channel, the movement of water and material may at times have the character of a mud flood and at times that of a mud flow.

It is possible for a geologist, hydrologist, or other trained professional with appropriate experience to distinguish between mud floods and mud flows during and after the event. To a certain extent, the potential for occurrence of these two kinds of flow can be distinguished before the event on the basis of the geomorphic setting.

METHODOLOGIES

Methodologies have been developed in different parts of the nation that can be used to delineate flood-prone and landslide-prone areas. While there is a generally accepted approach that can be used to map riverine floodplains throughout the nation, there is no single nationally applicable methodology for delineating areas specifically prone to mud floods, or for delineating areas prone to mud flows as distinct from other landslides.

The LACFCD methodology was developed for application to the mud floods that occur on the alluvial fans at the foot of the San Gabriel Mountains. It is limited to predicting hazards on the fans and does not apply to either mud floods or mud flows within the Mountain basins above the fans. It appears to work well in the San Gabriel Mountains, although it has not been quantitatively verified with independent data. While the general principles of the LACFCD methodology may be applicable to mud floods in other areas, the details and specific calibration factors are not likely to be transferable. Without a large data base, such as the historical record of debris accumulations in the LACFCD, the potential for development of similar methodologies in other areas is limited.

Methods have been developed for delineating areas of landslide hazard and have been applied in a variety of locations. These methods rely on the judgement of experienced professionals. Although there is no generally accepted procedure for separating mud flows from other landslides, such a procedure could probably be developed without great difficulty.

HAZARD DELINEATION STRATEGIES

Because no one methodology can be used to delineate areas prone to all of the phenomena in the flood-landslide continuum, it will be necessary to use several methodologies in delineating areas prone to more than one kind of hazard. The methodologies for mud floods and mud flows will differ from those currently used for clear water floods in floodplains.

Mud floods, because of their similarities to clear water floods, can best be described using hydrologic methods.

Mud flows, because of their similarities to other landslides, can best be described using slope stability methods. Because hilly regions prone to slope instability are subject to both mud flows and other landslides, it may be technically difficult and economically inefficient to map only areas prone to mud flows, rather than mapping areas prone to all kinds of landslides. This holds true even if mud flows are the only kind of landslide for which insurance coverage is made available and for which mitigation measures are required.

CONCLUSIONS

The LACFCD methodology was developed specifically for the alluvial fans of the San Gabriel Mountains, where a system of debris catchment basins and flood control channels is in place. While the general approach may be applicable to the mapping of mud flood hazards in some other hydrologically similar areas, the specific methodology developed by the LACFCD cannot be used as a general mudslide hazard mapping procedure.

Selection of a more generally applicable mapping strategy and of specific methodologies would be greatly aided by the following:

1. A clear decision by FEMA of which phenomena are to be included under the mudslide provisions of the NFIP and which are to be excluded, with reference to a standard classification scheme for earth movements.

2. Utilization by FEMA of activities that are already being carried out by other federal agencies and can contribute to the mapping of mudslide hazards, with FEMA's own resources being directed toward filling programmatic gaps and adapting other agencies' products to its own needs.

3. Development by FEMA of a means for drawing upon relevant technical expertise in selecting a mudslide mapping strategy and in developing and evaluating specific methodologies.

II. BACKGROUND

ORIGIN OF THE PROBLEM

The National Flood Insurance Program (NFIP) was created by the Housing and Urban Development Act of 1968 for the dual purpose of providing previously unavailable flood insurance to property owners in flood-prone areas and inducing flood-prone communities to adopt floodplain management regulations designed to reduce future flood-related damage. The Act specified that

> . . . the term "flood" shall have such meaning as may be prescribed in regulations . . . and may include inundation from rising waters or from the overflow of streams, rivers, or other bodies of water, or from tidal surges, abnormally high tidal water, tidal waves, tsunamis, hurricanes, or other severe storms or deluge.[1]

The Act was amended to include mudslides in 1969 by adding the following clause to the Declaration of Purpose:

> The Congress also finds that (1) the damage and loss which results from mudslides is related in cause and similar in effect to that which results directly from storms, deluges, overflowing waters, and other forms of flooding, and (2) the problems involved in providing protection against this damage and loss, and the possibilities for making such protection available through a Federal or federally sponsored program, are similar to those which exist in connection with efforts to provide protection against damage and loss caused by such other forms of flooding. It is therefore the further purpose of this title to make available, by means of the methods, procedures, and instrumentalities which are otherwise established or

---

[1] P.L. 90-448, Housing and Urban Development Act of 1968, Sec. 1370 (a)(1).

> available under this title for the purposes of the flood insurance program, protection against damage and loss resulting from mudslides that are caused by accumulations of water on or under the ground.[2]

The following statement was added under "Definitions":

> The term "flood" shall also include inundation by mudslides which are caused by accumulations of water on or under the ground; and all of the provisions of this title shall apply with respect to such mudslides in the same manner and to the same extent as with respect to floods.[3]

It was not clear what range of phenomena the word "mudslide" was intended to identify. The legislation adding the mudslide provisions was introduced immediately following the severe storms of January and February 1969 in southern California. The term "mudslide" has been commonly used by southern California news media to refer to a variety of landslide phenomena that includes mud flows (to be defined in Chapter III). The same news media have been fairly consistent in referring to debris and mud inundations associated with overflows of existing flood control channels and debris basins as flood damage.

Similar phenomena occur in many other parts of the United States. However, news media in other parts of the country do not tend to refer to them as "mudslides." Instead, a broad mix of colloquial, nontechnical, and technical terms such as "skin slides," "popouts," "debris avalanches," "mud flows," "debris flows," "landslips," "landslides," "mud floods," etc., have been used by the news media in various regions of the United States, and have sometimes been used in casual references by technical experts as well.

In its initial approach to implementation of the mudslide provision, The Federal Insurance Administration (FIA) defined a mudslide as

> . . . a general and temporary movement down a slope of a mass of rock, soil, artificial fill, or a combination of these materials, caused or precipitated by the accumulation of water on or under the ground.[4]

---

[2]P.L. 91-152, Housing and Urban Development Act of 1969, Sec. 409(a).

[3]Ibid., Sec 409(b).

[4]Methodology for Delineating Mudslide Hazard Areas, Building Research Advisory Board, National Academy of Sciences, Washington, D.C., 1974, pp. 11-14.

This definition is virtually identical to the usual definition of a landslide,[5] except for the qualification "caused or precipitated by the accumulation of water on or under the ground." This qualification excludes only a few kinds of landslides. The apparent conflict between this definition and the statutory definition of "floods," which seems to define "mudslides" as a type of flood (see p. 6), presented FIA with a serious technical problem concerning just what Congress intended "mudslide" to mean.

ATTEMPTS TO CLARIFY WHAT IS MEANT BY "MUDSLIDE"

In 1973, in order to clarify what was meant by "mudslide," a further amendment inserted the word "proximately" before "caused" in the statutory definition quoted on p. 6. The purpose, as set forth by the Senate Committee on Banking, Housing, and Urban Affairs, was to make clear that claims for damage caused by mudslides would be paid even if there was a landslide already in progress at the time of the mudslide. In its report, the committee stated the following:

> The committee is aware of the difficulties the Federal Insurance Administration has encountered in differentiating mudslides, which the Act covers, from landslides, which are not covered. Because of these difficulties, and on the basis of extensive investigation and advice from technical experts on the subject, FIA has chosen to interpret the word mudslide to mean mudflow; namely, a condition where there is actually a river, or flow, of "liquid mud" down a hillside, usually as a result of a dual condition of loss of brush cover and subsequent heavy rains. Such occurrences are unforeseeable, are less common than earth movement from landslide or erosion, and generally have characteristics markedly similar to those of a flood. Clearly, the committee intended this condition to be covered when it added the mudslide amendment to the Act in 1969.
>
> What has been unclear, however, is whether FIA has consistently provided mudflow coverage in situations where the mudslide was preceded or accompanied by a slow or gradual movement of the earth, sometimes caused or aggravated by the improper use of fill in the construction of new subdivisions, which had already endangered the insured property, and would ultimately result in its destruction, whether or not a mudflow occurred. There have been indications that where a landslide was already in progress at the time the insured obtained coverage, FIA may refuse to pay the claim for a subsequent loss, even if a mudflow actually occurred.

---

[5] Landslides and Engineering Practice, Highway Research Board Special Report 29, National Academy of Sciences, Washington, D.C., 1958.

> The amendment added by the committee is intended to make clear that, just as FIA would be required to pay a sudden flood loss that occurred to an insured property while a gradual landslide was in progress, so too it is expected to pay for mudflow losses that occur unexpectedly while a landslide is in progress, so long as the mudflow and not the landslide is the proximate cause, or sine qua non, without which the damage claimed would not have occurrred.[6,7]

In 1974, a revision of the Standard Flood Insurance Policy contained the term "mudslide (i.e., mudflow)." The term also appeared in the Code of Federal Regulations in 1976. This led to a general substitution of "mudflow" for "mudslide," but did not resolve the question of just what range of phenomena was intended.

---

[6]U.S. Congress, Senate Committee on Banking, Housing and Urban Affairs, Report No. 93-583, 1973, pp. 9-22.

[7]However, this report still does not satisfactorily define "mudslides," and it in fact inadvertently contributes to perpetuation of some misunderstandings. In Chapter III we will define the terms "clear water flood," "mud flood," "mud flow," and "other landslides." The Senate report contains several inaccuracies that are best illustrated using this terminology. First, it asserts incorrectly that mudslides are not landslides. The events commonly called mudslides include mud flows, which are a kind of landslide. Second, it asserts incorrectly that the "dual condition of loss of brush cover and subsequent heavy rains" is the "usual" cause of mudslides. That condition is a cause, but not the usual cause. Mud flows can be triggered by heavy rain on bare slopes. They also commonly originate from landslides in which the mass movement provides the thorough mixing of water and detritus necessary for the development of the flow mechanism unique to mud flows. Heavy rains on recently burned slopes are more likely to generate debris-laden mud floods than mud flows. These mud floods may become clear water floods as they flow downstream and debris is deposited. Third, the characterization of such occurrences as "unforeseeable" is misleading. Clear water floods and mud floods on the alluvial fans of many mountain drainage basins are eminently foreseeable. Areas susceptible to mud flows can be recognized by experienced geologists and engineers. Fourth, mudslides are not everywhere less common than other landslides. In many areas mud flows are a common process of erosion, and in some areas they are the most common erosive mechanism. Fifth, mud flows do not "generally" have the characteristics of floods. Some mud flows do flow in stream channels and cause damage by inundation as floods do, and both mud flows and mud floods can be caused by heavy rain, sudden snowmelt, or dam failure. However, many other features set floods and mud flows apart. Their flow characteristics, triggering mechanisms, and usual geomorphic settings are different.

The regulations that guide administration of the program today include the following definitions:

> "Flood" or "Flooding" means:
> (a) A general and temporary condition of partial or complete inundation of normally dry land areas from:
> (1) The overflow of inland or tidal waters.
> (2) The unusual and rapid accumulation or runoff of surface waters from any source.
> (3) Mudslides (i.e., mudflows) which are proximately caused or precipitated by accumulations of water on or under the ground.
> (b) The collapse or subsidence of land along the shore of a lake or other body of water as a result of erosion or undermining caused by waves or currents of water . . . or by an unanticipated force of nature, such as a flash flood or an abnormal tidal surge, or by some similarly unusual and unforeseeable event which results in flooding . . . .
>
> "Mudslide" (i.e., mudflow) describes a condition where there is a river, flow or inundation of liquid mud down a hillside usually as a result of a dual condition of loss of brush cover, and the subsequent accumulation of water on or under the ground preceded by a period of unusually heavy or sustained rain. A mudslide (i.e., mudflow) may occur as a distinct phenomenon while a landslide is in progress, and will be recognized as such . . . only if the mudflow, and not the landslide, is the proximate cause of damage that occurs.[8]

In 1973, the Federal Insurance Administration (FIA) asked the National Academy of Sciences to recommend a method for delineating mudslide-prone areas and associated hazard risks. The resulting report[9] pointed out the practical difficulties of distinguishing between mudslide-prone areas and areas susceptible to other kinds of landslides. A methodology for mapping areas of potential landslide hazard was developed, and the report recommended that distinctions between mudslides and other kinds of landslides not be made in delineating areas of potential mudslide hazard. The recommended approach is very similar to that used by the U.S. Geological Survey in an experimental delineation of potential landslide hazards in the San Francisco Bay Region. The recommended methodology has not been tested by FIA.

---

[8] 44 CFR 59.1.

[9] Methodology for Delineating Mudslide Hazard Areas, Building Research Advisory Board, National Academy of Sciences, Washington, D.C., 1974.

As the NFIP is administered today, mudslide risks are not identified on hazard maps prepared for insurance and floodplain management purposes. Even so, flood insurance policies, which automatically cover mudslide losses, are available to all property owners in communities that participate in the NFIP. For property located outside the designated flood hazard zone the premiums are very low, since they are based entirely on the risk of flood. The presence or absence of mudslide risk does not affect the premium that a policy owner pays. Land use management measures directed toward mudslides are not required.

THE PRESENT STUDY

In 1979, the Los Angeles County Flood Control District (LACFCD) developed a method for determining mudslide[10] hazards in the San Gabriel Mountains[11] and used that methodology to delineate areas of mudslide hazard in Sierra Madre, California.[12] The Federal Emergency Management Agency (FEMA), to which FIA was transferred in 1978, then asked the National Academy of Sciences to look again at the problem of identifying areas of mudslide hazard, and specifically to (1) assess the validity of the LACFCD methodology, (2) determine whether that methodology, if valid, is likely to be applicable in other geographic areas, (3) identify any other mudslide prediction methodologies that may exist, and (4) make recommendations concerning methods for delineating areas of mudslide hazard.

The Academy established the Committee on Methodologies for Predicting Mudflow Areas under the aegis of the Advisory Board on the Built Environment (formerly the Building Research Advisory Board). The Committee was asked to

1. Identify and categorize the various phenomena that might be considered to be mudslides, including, but not limited to, drainage phenomena in mountain canyons and alluvial fans and landslide-type slope instability phenomena. For each category, assess the technical feasibility and the difficulties of identifying areas of mudslide hazard and of determining the mudslide risk.

2. Examine the mudslide methodology developed by the LACFCD and used to determine the mudslide hazard in Sierra Madre, California. Determine which of the categories

---

[10]The LACFCD uses the term "mudflow" rather than "mudslide."

[11]"Engineering Methodology for Mudflow Analysis," unpublished paper, Los Angeles County Flood Control District, Los Angeles, California, 1979.

[12]"Mudflow Study--City of Sierra Madre, Los Angeles County, California," unpublished paper, Los Angeles County Flood Control District, Los Angeles, California, 1979.

of mudslide phenomena this methodology addresses, and assess its validity and its suitability for purposes of the NFIP. Consider the likelihood that this methodology is suitable for application in other geographic regions.

3. Seek to identify any other methodologies that might be applicable to the determination of mudslide risks, including methodologies developed for underwater mudslides, volcanic slope flows, mine tailings and impoundments, landslides, and floodborne sediments.

4. Identify possible approaches that might be used to delineate areas of mudslide hazard and to determine the associated mudslide risk. For each of these, assess the adequacy of the present technical base and the suitability of the approach for purposes of the NFIP. Identify any problems that might arise in the operational use of these approaches, and identify the criteria that an operational mudslide prediction methodology should satisfy.

It was clear to the committee that damage to structures resulting from (1) hydraulic forces associated with flow of water, (2) inundation by flood water, (3) impact from debris carried in a flooding stream, and (4) deposition of sediment from a flooding stream are all ordinarily considered effects of a flood. Indeed, to redefine any of these effects as damage from mudslides would be inconsistent with accepted technical usage.

Yet the Declaration of Purpose of the National Flood Insurance Act, as amended, suggests that Congress intended to include some additional set of phenomena, termed "mudslides," among the risks to be covered by the Act, and that these phenomena were sufficiently different from those ordinarily included in the term "flood" that they would not otherwise be considered covered risks under the flood provisions of the Act. Therefore, it appears likely that Congress intended that the risks covered under the NFIP should include a discrete subset of the broad range of landslide phenomena--distinct from the risks of erosion, inundation, and sedimentation that would otherwise be covered as intrinsic parts of flood phenomena.

To make a rational decision concerning a methodology for mapping hazard-prone areas for the NFIP, it is necessary (1) to define terms in a way that reflects the nature of the physical processes associated with floods and mudslides, the locations in which they occur, and the kinds of damage they can produce, (2) to determine which of these phenomena are covered under the NFIP, and (3) to determine which of these phenomena the available hazard-mapping methodologies address.

The committee believes that it is FEMA's responsibility to determine which phenomena are meant by "mudslide." In this report, the processes that are triggered by heavy rains in mountain drainage basins are described in a way designed to assist FEMA in making this decision. The committee does not use the term "mudslide" in describing these processes. The term "mudslide" is used only in discussing the history, purpose, statutes, regulations, and status of the NFIP. The term "mudflow," as a single word, is not used except when another source is being quoted.

III. DEFINITIONS OF MUD FLOWS AND RELATED PHENOMENA

INTRODUCTION

The purpose of this chapter is to define a set of terms applicable to floods, mudslides, landslides, and related phenomena. Emphasis is placed on terms used to distinguish various groups of phenomena within a continuum of natural processes. Central aspects of this terminology are (1) the geologic-hydrologic settings where the phenomena originate and through which the material is transported, (2) the character of the moving material, and (3) the transporting mechanisms. The geologic-hydrologic settings can be described in the context of the different parts of a river system, from headwaters to deltas, passing from mountain drainage basins across alluvial fans, and then through lowland valleys to the sea. The character of the moving material and the mechanisms by which it moves through the system can be described in terms of (1) the relative amounts of earth materials and water and (2) the complex processes of slope instability and water flow by which these materials are made available, mixed, and transported in river systems.

The usual image associated with the term "flooding" is overbank flooding of a river and inundation of the adjacent floodplain. The flooding may be preceded by a long, slow rise of water level, and may be predictable weeks in advance from knowledge of rain or snowmelt in distant upstream drainage basins. Alternatively, a river may rise to flood level in a short period of time, depending on rainfall and basin characteristics. Overbank flooding generally results in inundation by water and the deposition of silt over part or all of the flood plain.

Coastal regions, particularly river deltas, may also experience this kind of flooding. In addition, they are subject to inundation from the sea caused by high astronomical tides, storm tides, storm surges associated with extreme weather events such as hurricanes, and earthquake sea waves (tsunamis).

In mountain drainage basins, sudden, severe thunderstorms may produce flash floods capable of transporting large boulders and trees as well as clay, silt, and sand. In many steep, hilly areas, debris-bearing floods have repeatedly occurred when persistent, heavy rain falls in mountain basins. This is a particular problem where slopes are denuded of vegetation by brush fires. Such floods have the potential for causing severe damage to structures by impact of water and debris, by water inundation, and by burial under coarse debris.

MOUNTAIN DRAINAGE BASINS

Mountain drainage basins are generally areas of steep stream gradients, where erosion has been the dominant process in recent geologic time. Many streams emerge abruptly from mountainous or hilly regions onto relatively low lying areas where deposition and erosion are in dynamic equilibrium, with the coarsest sediment (boulders, gravel, and coarse sand) being deposited as an alluvial fan. Much of the finer material (sand, silt, and clay) is transported farther downstream in well-established stream channels through lowland valleys and across delta regions, eventually reaching the sea, a salt lake, or a playa (dry lake).

Within a drainage basin, available water moves down the slopes as runoff to collect in streams and ultimately emerge from the basin onto the slopes below. Likewise, available solid material (loose soil, rocks, and plant debris) may be carried downslope, either by the water itself or by landslides, to ultimately enter the stream channel and be carried downstream. The character of the flow emerging from the mouth of the basin is strongly influenced by the relative proportions of available water and detritus. Where detritus is lacking or is bound to the substrate by vegetation, excessive rainfall results chiefly in clear water floods. Where detritus is abundant and easily eroded, the same amount of rainfall can result in a flood that is laden with sediment and debris. In areas of extremely high relief, such as the canyons of the San Gabriel Mountains, boulders, trees, and mud may be carried out of the basins and onto the alluvial fans. Culverts, bridges, and sewers may clog, diverting flow onto streets and into homes, causing considerable damage from impact. As such floods move downstream, gradients diminish, especially near the mouths of the mountain basins, and deposition of coarse mineral and plant debris, rather than impact by boulders and other debris, becomes the more important damaging effect.

Hillslope failures are major sources of detritus. The same rainstorm that causes a flood in a mountain basin can also trigger landslides on the slopes in the basin, increasing the available loose earth materials. Subsequent runoff from continued rainfall can so modify the moving rock and soil masses that they become inseparable components of a single flood event.

LANDSLIDE TERMINOLOGY

The term "landslide" is in common technical use to refer to all kinds of slope movements as a general class. In Landslides and Engineering Practice[1] the term "landslide" is defined as the downward

---

[1]Highway Research Board Special Report 29, National Academy of Sciences, Washington, D.C., 1958.

and outward movement of slope-forming materials: rock, soils, artificial fills, or combinations of these materials. In technical classification schemes, terms such as "rock slide," "mud flow," or "earth fall" are used to describe specific kinds of landslides. The suffix "slide" in the word "landslide" does not refer to a restricted mechanism of movement in the way that the terms for more specific events, such as "rock slide" or "debris slide," refer specifically to movement by "sliding." Falls, topples, spreads, and flows are other mechanisms of landslide movement. Some experts now prefer to substitute terms such as "slope movement" or "slope failure" for the term "landslide."

Individual landslides commonly involve several slide and flow phases. However, it is common practice to simplify the nomenclature by emphasizing the dominant parent materials, the dominant mechanism of transport, and the dominant rates of transport. The classification scheme developed recently by D. J. Varnes[2] is widely accepted. In this scheme flows, along with lateral spreads, slides, topples, and falls, are recognized as major mechanisms for transporting earth materials and varying amounts of water downslope and downstream.

Flows are defined as movements of earth material with a distribution of velocities resembling that of viscous fluids. They may carry a wide variety of materials, self-supported by the density and viscosity of the flowing mass. Varnes subdivides flows according to the predominant kind and particle size of the material being transported; for example, rock fragment flow, debris flow, sand flow, and mud flow. Varnes distinguishes between mud flow and debris flow on the basis of the relative abundance of coarse particle sizes. Both mud flows and debris flows contain fine particles (i.e., sand, silt, and clay) as essential constituents. "Debris flow" is the term Varnes uses when 50 percent or more of the particles are larger than sand in size, "mud flow" when the majority are sand size or smaller. Many users do not make this distinction, and the terms "mud flow" and "debris flow" are often used interchangeably along with other terms such as "debris avalanche," "flowslide," and "earthflow." Ambiguity can be avoided by referring to a single classification scheme.

For the purposes of this report, it is sufficient to divide the flood-landslide continuum into four subcategories: clear water floods, mud floods, mud flows, and other landslides.

CLEAR WATER FLOODS AND MUD FLOODS

The term "clear water flood" refers to inundation by clear water or water carrying some sediment, generally fine grained. Such a flood typically occurs when a river or stream overflows onto adjacent areas.

---

[2]David J. Varnes, "Slope Movement Types and Processes," Chapter 2 in Landslides: Analysis and Control, Transportation Research Board Special Report 176, National Academy of Sciences, Washington, D.C., 1978.

The term "mud flood" refers to a flood in which the water carries heavy loads of sediment (as much as 50 percent by volume), including coarse debris.[3] Mud floods typically occur in drainage channels and on alluvial fans adjacent to mountainous regions, although they may occur on floodplains as well.

While both clear water floods and mud floods cause damage associated with rising water levels and deposition of fine sediment, mud floods also cause impact damage associated with their heavy burden of mud and debris.

Clear water floods and mud floods are hydraulic flows. They can be described and predicted using standard hydrologic techniques. Both fall under the NFIP definition of floods. Current NFIP mapping of potential flood areas covers only floodplains; no comparable maps have been made for hazards from clear water floods and mud floods in steep-gradient mountain basins and on alluvial fans.

MUD FLOWS AND OTHER LANDSLIDES

The term "mud flow" refers to a specific subset of landslides whose dominant transporting mechanism is that of a flow having sufficient viscosity to support large boulders within a matrix of smaller-sized particles.[4] Mud flows may be confined to drainage channels or

---

[3] Transport of sediment by water in channels involves both suspension of fine particles due to turbulence and bedload transport by creep and saltation. These processes are intricately dependent upon water velocity characteristics. For example, a decrease in water velocity due to a reduced channel gradient causes deposition of portions of the transported debris. The layering of particles of different sizes in the deposits reflects the water velocity at the time of deposition. The actual amount of sediment in transport in any given channel section, while dependent primarily on velocity, is also a function of sediment availability.

[4] The key characteristic in differentiating between mud floods and mud flows is that a mud flow possesses a combination of density and strength that will support inclusions of higher density than water, such as boulders, both during transport and when the mass comes to rest. The ability to support an inclusion during transport stems from a velocity-dependent strength (the matrix viscosity), and a velocity-independent strength (the shearing resistance of the mass). When the flow comes to rest, the velocity-dependent strength goes to zero. However the high density inclusion does not sink in the mass because it is supported by the static shearing resistance. A mud flood, in contrast, does not have a static shearing resistance. Transport of inclusions is possible only because of the strength provided by the motion of the fluid. When the fluid velocity goes to zero, the strength also goes to zero and the supporting capability of the mass is lost. All inclusions of higher density than the fluid (water, in most cases) then sink.

may occur unconfined on hillslopes.

The term "other landslides" refers to downslope movements of masses of earth materials by mechanisms other than flow: mechanisms such as falling, toppling, sliding, and spreading. The masses may be wet or dry and can occur unaccompanied by heavy rain, melting snow, or flooding. However, they are often triggered by such events and can become mud flows.

RELATIONSHIPS AND DISTINGUISHING CHARACTERISTICS

The relationships between clear water floods, mud floods, mud flows, and other landslides is shown schematically in Figure 1. It is important to emphasize that a heavy rainstorm in a mountain drainage basin may give rise to all four kinds of processes: clear water floods, mud floods, mud flows, and other landslides. Moreover, transformations may occur. For example, the addition of sediment and debris can cause a clear water flood to become a mud flood or even a mud flow. More commonly, the reverse occurs--from other landslide to mud flow to mud flood to clear water flood--as rain continues to add water to the total flow.

During an event it is possible to distinguish between mud floods and mud flows by observing the velocity, flow patterns, and characteristics of particle transport. These indicate the viscosity of the moving material, which determines whether it is a mud flood or a mud flow. It is also possible to distinguish between mud flows and other landslides during an event. In contrast with mud flows, which are viscous fluids consisting of relatively uniform mixtures of particles and water, other landslides are relatively solid and move as discrete blocks or groups of blocks by sliding, falling, or toppling.

Debris deposits left by the different processes can be used to identify the process after the event. The pattern of sorting by sizes within a mud flood deposit is distinctly different from the pattern

Class of Phenomenon	Event	Location		Covered by NFIP	Status of Hazard Mapping
FLOODS	Clear Water Floods	Floodplains	Drainage Channels and Alluvial Fans	Yes	Now Mapped
	Mud Floods				Not Now Mapped
LANDSLIDES	Mud Flows	Hillslopes			
	Other Landslides			No	

FIGURE 1 Flood and landslide phenomena: the locations in which they occur and their status under the National Flood Insurance Program (NFIP).

within mud flow debris. Similarly, mud flow deposits can generally be distinguished from deposits left by other landslides.

Although these distinctions between the different processes can be made, they depend upon professional judgment based upon experience and applied to a particular local event. These distinctions are not particularly useful for determining the potential for each type of event in a particular location.

IV. METHODOLOGIES FOR MUDSLIDE HAZARD ASSESSMENT

SUMMARY

The methods used to delineate areas of potential flood hazard for NFIP purposes are directed primarily toward riverine and coastal floodplains. These areas are subject to overbank and tidal flooding, but are not areas of potential mud flow hazard. Mountain basins and the alluvial fans at their mouths, not generally mapped at the present time, are subject to floods (especially flash floods and mud floods) and mud flows. Hillslope areas generally have a much higher potential for mud flows and other landslides than for floods. No methodology now in use is adequate to delineate all the areas of potential hazard from floods, mud floods, and mud flows.

The Los Angeles County Flood Control District (LACFCD) methodology for the delineation of mudslides[1] on alluvial fans in the San Gabriel Mountains extends clear-water flood-control methodology to debris-laden torrential floods (mud floods), and perhaps to some mud flows, that overtop debris basins at the mouths of mountain canyons, choke downstream flood-control channels with debris deposits, and divert flows from those channels to cause flooding on adjacent parts of the alluvial fan. The methodology is specific to, and appears to be valid for, the alluvial fans of the San Gabriel Mountains. It is not applicable to hillslope mud flows or to mud floods that occur above the debris catchment basins.

Several methods for identifying areas of potential landslide hazard have been applied in land-use planning and regulation. Some simply identify all hillside areas as having the potential for landslides and require special engineering-geology study or engineering design to assure slope stability before grading and construction permits are issued. Others provide special maps showing hazard areas for land-use planning and for evaluation of engineering designs before issuing construction permits.[2] Still other methodologies for landslide

---

[1]The LACFCD uses the term "mudflows."

[2]Some mud flows leave deposits that superficially resemble flood deposits. These mud flows have not always been recognized and included in the landslide maps. However, there is sufficient understanding of these flows to permit their inclusion in landslide maps provided sufficient care to do so is exercised by the mappers.

hazard assessment are currently under development by several federal, state, and local agencies.

THE LOS ANGELES COUNTY FLOOD CONTROL DISTRICT METHODOLOGY

The methodology devised by the Los Angeles County Flood Control District (LACFCD) is an extension of standard flood-control engineering methods for clear-water flooding. It delineates areas of what the LACFCD calls "mudflow" hazard. However, it addresses only a very narrow band within the wide range of mud flow phenomena, and is primarily applicable to flash floods and mud floods that spill onto alluvial fans.

The LACFCD flood control system uses debris catchment basins constructed at the mouths of natural mountain drainage basins to contain debris-laden flows long enough for most of the debris to deposit. Relatively clear water then spills from the debris basins, through intake towers or over spillways, into concrete-lined flood channels designed to accommodate clear water runoff. The sediment trapped in the debris basin is excavated and trucked away to a disposal site to prepare for the next storm.

When the storm runoff from a mountain drainage basin is heavily laden with silt, sand, gravel, and other debris, the total flow can be twice the volume of the equivalent clear-water flow. If a debris catchment basin fills and is overtopped, the debris-laden flow can enter the downstream channels. The flow may exceed the capacity of a channel, or debris deposits may block the channel. Either of these conditions can force the flow out of its regular channel, flooding nearby areas on the alluvial fan.

The LACFCD debris basins are designed to contain the sediment of a 100-year flood and to spill its accompanying water safely into the designated flood channels.[3] The magnitude of the 100-year flood has been calculated for more than 90 basins from about 40 years of data. The Sierra Madre map was constructed by calculating the 100-year and 500-year floods and routing flows too great to be contained by the debris catchment basin down the channels below it.

The methodology involves five distinct elements: (1) determining how frequently given flows occur, (2) estimating the average annual debris production, (3) estimating peak flows, (4) estimating the effects of brush fires, and (5) mapping the hazard area below the debris basins for 100- and 500-year floods.

The methodology uses standard hydrological and statistical techniques, modified to reflect the high sediment loading that typically occurs in this area and to reflect the effects of brush fires. Fires

---

[3]Because of physical or topographic constraints, it is sometimes not possible to build a basin large enough to contain the sediment of a 100-year flood. This is the case for the Sierra Madre dam and reservoir.

dramatically increase the rates of both sediment delivery and clear water flow from the slopes to the channels. The effect is short-lived and the return to normal occurs within three to ten years.

Estimation of average annual debris production is based on six factors: relief ratio, slope, aspect (exposure), vegetation index (a measure of relative ground cover), area, and precipitation.

Peak water flows having 100-year and 500-year recurrence intervals are calculated. The part of these flows that exceeds the capacity of the debris catchment basins is then routed along the channels below, and the area of danger is mapped as for clear-water flows using conventional engineering techniques, taking into consideration in-situ channel geometries, cross-sectional flow areas, and hydraulic properties such as slope and roughness. Areas of potential debris deposition are determined by calculating where flattening of slopes causes decreased stream velocity.

Evaluation

The LACFCD methodology is based on a considerable body of local data, is designed for local conditions, has been developed by engineers with considerble local engineering experience, has been used and tested and modified over the years, and is considered by the LACFCD to be valid for identifying areas of mudslide hazard on the alluvial fans at the base of the San Gabriel Mountains. It appears to yield results within the normal range of accuracy of similar hydrologic flow analyses. However, a systematic verification of the LACFCD method, using data from basins not used in developing the method, has not been undertaken. Until this verification is done, the validity of the method remains in doubt.

Data adjustments were made to account for changes in areas of watershed development, upstream stabilization engineering, watershed burn history, and trap efficiency in the debris basins. These adjustments were made to produce a historical data set whose statistical properties remain unchanged with time. Although it appears likely that these adjustments were made with skill, they permit unknown biases to enter into the final equations. The effect these subjective adjustments would have if the method were applied to other drainage basins is unknown. Moreover, it seems certain that, as urban development continues, there will be changes in watershed character, engineering works, trap efficiency, and watershed burn history.

The method is based on a multiple regression analysis. Regression establishes an associative relationship between the dependent variable and a set of independent variables. Although a regression technique can be useful, it does not lead to cause-effect relationships or to a fundamental understanding of the problem. This limits the usefulness of such techniques to the location and the hydrologic situations used in their development.

It is unlikely that the LACFCD methodology can be applied in other locations. The method is specific to the area where LACFCD has a system of debris catchment basins and downstream flood control channels, as well as an extensive historical data base. Were the approach to be applied elsewhere, new empirical relationships would have to be developed to represent the particular characteristics of the new region. As a practical matter, it appears that few if any areas have a data base as comprehensive as that of the LACFCD. Therefore, the use of regression techniques based on local data is not likely to be productive at this time.

Should an attempt be made to develop an LACFCD-like method for another area, it will first be necessary to undertake a substantial measurement program to construct a long-term data base. Because of the present lack of a mudslide theory, more powerful statistical techniques would have to be used. The six predictor variables used in the LACFCD method may not be appropriate for other areas.

The method is probably a valid one for delineating the potential for mud floods on alluvial fans below debris basins at the mouths of mountain drainage basins on the south flank of the San Gabriel Mountains. However, it is basically a modified clear water flood methodology and is limited to channeled flow across alluvial fans where flood control channels have been built to avoid flooding streets and homes. It may be partly applicable to mud flows in those same drainage basins if the mud flows are large enough to fill a debris basin, overtop the dam, and enter the channels on the alluvial fan. However, since the method is based on assumptions related to water flow, it may not properly describe the behavior of mud flows even when they spill into channels.

LANDSLIDE HAZARD CONTROL METHODOLOGIES

City of Los Angeles and Los Angeles County, California

The grading codes administered by the Department of Building and Safety, City of Los Angeles, and the Department of the County Engineer, Los Angeles County, do not rely on hazard maps but require detailed geological site investigations and reports from property subdividers and site developers who seek to modify hillslopes. These codes have been adopted in stages since 1952. In effect, the method used for delineating areas susceptible to landslides is to identify all hillslope areas as areas where special studies for slope stability are required. The potential for mud flows is evaluated along with the potential for other kinds of landslides. Engineering designs and practices to mitigate potential mud flow hazards include specifying minimum setback of structures from the bases of cuts and natural slopes and using walls to divert flows away from structures at risk.

All hillside grading and construction work must be supervised by a registered soils engineer and an engineering geologist, as well as a registered civil engineer specializing in design. Requirements precedent to issuing building permits include surface and subsurface exploratory work by a soils engineer and an engineering geologist, and reports and recommendations from both consultants for avoidance or correction of all known existing or anticipated geologic hazards, including those related to off-site conditions. Both professional consultants must sign and approve the building plans. The soils engineer and the engineering geologist are required to inspect sites and prepare reports during grading and on completion of construction. All of the reports are submitted for review by a registered soils engineer and an engineering geologist on the staff of the appropriate review department of the agency. The professional consultants must certify that all known geotechnical conditions have been evaluated and that all of the building sites are suitable and safe for construction.

Comprehensive standards for the evaluation of slope stability have been adopted by the two agencies. These standards now apply not only to cut, fill, and buttress-fill slopes, but also to natural slopes associated with hillside development. They take into account the potential for deep-seated and surficial landslides (including mud flows). When existing slopes do not have safety factors (resisting forces divided by driving forces) of at least 1.5, adequate protection systems are required. Special attention is now required for ravines and reentrants of natural slopes, as these areas are commonly the location of erosion and mass movement problems, including mud flows.

On the basis of the reports and their reviews, developers may be required to move lot boundaries away from vulnerable slopes and to take other actions affecting grading and compacting of soils, placement of drains, and installation of building supports.

The effectiveness of the city and county codes relies largely on accurate and thorough investigations and reports by qualified private consultants, and on skillful and conscientious reviews by qualified professional staffs of the agencies. Even then, geotechnical stability problems can affect those areas developed before the 1960s, when the modern codes did not apply and qualified experts were not involved.

The existing grading codes in the Los Angeles area are technically sound and can be effective where rigorously enforced. Similar codes have been adopted in other California cities and counties with varying degrees of success. With some modification, the procedures may be transferable to other parts of the United States.

San Mateo County, California

The San Mateo County Engineering Department uses a variant of the Los Angeles County grading code. Reviews are carried out by a certified engineering geologist employed by the county. The work is greatly facilitated by the existence of a comprehensive landslide susceptibility map of the county (at a scale of 1:62,500) prepared by the U.S. Geological Survey as part of a pilot study in the San Francisco Bay Region.

The map divides the county into areas according to seven categories, ranging from those least susceptible to those most susceptible to landslides. It is a derivative map constructed from three basic data maps: (1) a geologic map showing the distribution of rock and other earth materials, (2) a slope map with six slope intervals, and (3) a landslide map showing nearly 2,000 landslide deposits whose largest dimension ranges from 50 feet to a mile or more.

This map used is for planning purposes and provides a guide to how past landslides have been distributed within the county. It cannot be used to determine the stability of specific building sites, as more detailed investigations by engineering geologists and soils engineers are necessary to assess local foundation stability. However, the map lends itself to preliminary actuarial calculations.

A separate experimental study by the U.S. Geological Survey was made in a 15-square-mile area of the county to determine whether computer techniques could be useful in preparing the derivative landslide susceptibilty map from the same three basic maps. A comparison of the manual and computer-generated maps demonstrated the feasibility of the computer method. The computerized maps can be generated in about the same time and at less cost than comparable manually compiled maps. Additional benefits are less human error and the availability of a data bank for future mapping.

Colorado Geological Survey

State of Colorado legislation requires that proposals for nearly all developments be accompanied by reports on geologic characteristics significantly affecting the proposed land use. The reports and plans must be submitted to the Colorado Geological Survey (CGS) for review and evaluation. The law also requires the CGS to assist local governments in carrying out activities to identify geologic hazard areas and to engineer and administer those areas in a manner that minimizes the danger to health, safety, and property.

In carrying out these functions, the CGS has mapped mud flow* hazard areas in some communities in the course of more comprehensive mapping of a larger spectrum of geologic hazards. These maps identify specific areas susceptible to mud flows. The mapping relies heavily on the judgment of experienced geologists who interpret the origins of terrain features. The 1:24,000-scale maps were prepared rapidly by reconnaissance techniques. They provide an adequate basis for preliminary identification of communities containing areas prone to mud flows, and they might be suitable for preliminary rate zoning. They probably are not accurate enough for zoning on a lot-by-lot basis.

Other Operational Methods

Variations of the Los Angeles County and City codes have been adopted in both Orange and Santa Clara Counties, California. Both counties employ certified engineering geologists for the reviews required by the codes.

Fairfax County, Virginia, has adopted a peer review system in which engineering designs for construction projects are reviewed by a panel of professional engineers and engineering geologists. The reviews are facilitated by the existence of a slope stability map of the County at a scale of 1:48,000 that was prepared by the U.S. Geological Survey as part of a pilot study.

---

*The Colorado Geological Survey uses the term "debris flow."

METHODOLOGIES DISCUSSED BY THE 1973-74 PANEL

Other methodologies that include mud flows as a subset of landslides have been devised, and a few have been tested. Three of these methodologies were evaluated by the 1973-74 Panel on Methodology for Delineating Mudslide Hazard Areas.[5]

California Division of Mines and Geology

In the early 1970s the California Division of Mines and Geology prepared maps (at a scale of 1:24,000) of potential mudslide hazards in southern Ventura County, California, for FIA. A methodology was devised and applied to an area of about 1,100 square miles. The methodology considered slope, geology, soil, vegetation, incidence of fire, and prior incidence of all kinds of landslides. The result was a mudslide risk map showing three zones: "high risk," "intermediate risk," and "little or no risk." The mapping relied heavily on professional judgment to evaluate the factors and to determine their relative influence in the complex combination required for delineating the risk zones.

The Ventura County communities included in the map area have made little use of it in regulations for planning, zoning, or building. FEMA has not used the maps for setting insurance rates.

Advanced Management Systems Study

Advanced Management Systems, Inc., under contract to FIA, studied Allegheny County, Pennsylvania, to develop preliminary methodologies for landslide risk analysis. Based on an analysis of prior landslides with respect to topographic setting, geologic setting, earth-material properties, and vegetation properties, particular locations were determined to be areas of high, moderate, and minimum landslide hazard. The analysis was subjective and relied heavily on the professional judgment of engineers and geologists familiar with the local setting.

The Committee knows of no application of this study by Allegheny County or the municipalities within it. FEMA has not applied the results to the assignment of premium rates for mudslide insurance in the area.

USGS-HUD San Francisco Bay Region Study

As a part of a San Francisco Bay Region environmental resources planning study conducted in cooperation with the Department of Housing

---

[5] Methodology for Delineating Mudslide Hazard Areas, Building Research Advisory Board, National Academy of Sciences, Washington, D.C., 1974.

and Urban Development, the U. S. Geological Survey developed mapping methods to delineate landslide susceptibility. The preliminary work consisted primarily of collecting basic geologic and topographic information. Subsequently, experimental maps having different scales and differing complexity were prepared for selected parts of the region. These ranged from a comprehensive slope stability map (at a scale of 1:62,500) for San Mateo County to regional maps of relative slope stability (at a scale of 1:125,000).

Many of these maps are in current use by county and municipal governments for regional planning purposes. The San Mateo County map, for example, is used as a key reference for reviewing proposals for land uses and engineering designs for development. Code changes have been made by local governments as a result of the available information; however, FEMA has not used these maps to determine mudslide insurance premium rates.

Methodology Proposed by the 1973-74 Panel

The 1973-74 Panel recommended a methodology for conducting mudslide hazard studies based on landslide analyses. The recommended methodology was for construction of a mudslide study map that delineates both boundaries of hazard areas and categories of risks, accompanied by a text describing background for the study and suggestions for remedial practices. The methodology was described in six steps:

- Gather information about the nature of the local landslide problem and assemble available maps and data.
- Prepare three landslide factor maps--topographic, soil, and geologic--and one comprehensive map combining the three factors.
- Map areas of prior landslides and areas believed to have the potential for landslides.
- Undertake field reconnaissance and analysis to confirm mapped indications of landslide history and susceptibility.
- Prepare a mudslide map classifying the entire community according to three levels of mudslide risk.
- Prepare a final report for each community including background information, description of work, discussion of difficulties and remedial suggestions, and bibliography.

The proposed methodology is based on two main conclusions by the panel: (1) The most practical approach to delineating areas susceptible to mudslides is to delineate areas susceptible to landslides without regard to the degree of wet flow likely to be involved, and (2) mapping of potential landslide areas (based on field studies and professional judgment) is more appropriate than attempting probabilistic calculations of landslide risk based on frequency of occurrence. The method was intended to be flexible, accommodating a variety of local geologic settings and a variety of available local expertise for its application. It is not an objective method but one that relies heavily on the professional judgment of the individuals who perform the study in each local community.

Although details might require some updating, the methodology recommended by the 1973-74 panel can be applied today to the problem of mapping areas of potential mud flow hazard.

METHODOLOGIES NOW BEING DEVELOPED

Work is being done in universities and in a number of federal, state, and local agencies to develop more rapid, accurate, and comprehensive methods for mapping areas of potential landslide hazard. Short summaries of several of these efforts are included in USGS Open-File Report 81-987, "Goals, Strategies, Priorities and Tasks of a National Landslide Hazard-Reduction Program."[6] This reflects a growing awareness of the extremely large annual losses from landslides--losses totaling over $1 billion per year. The state of the art in mitigation technology is also growing rapidly. Virtually all the methods currently used or under development begin with the mapping of areas of potential landslide hazard and are aimed at assessment of landslide risk.

The interest of other federal agencies in landslides offers an opportunity for FEMA to coordinate its mapping of potential mud flow hazard areas with the activities of other organizations. Significant savings should be possible if the mud flow hazard mapping is integrated with the landslide hazard mapping of other agencies.

---

[6] Undated report by the U.S. Geological Survey, Reston, Va.; published in 1981.

V. STRATEGIES FOR MAPPPING AREAS OF MUD FLOW AND MUD FLOOD HAZARD

The purposes of the NFIP include (1) providing insurance to property owners in hazard-prone areas, and (2) inducing hazard-prone communities to adopt land-use regulations designed to reduce future losses from floods and mudslides. The maps needed for identifying communities that contain areas subject to mud flows and mud flcods are much less complex and detailed than those needed to delineate specific hazards to individual properties. Naturally, the more complex and detailed the map, the more costly it is to make. Minor adjustments in the premium-rate structure or in the way the program is administered might make major differences in the scale and complexity of the maps needed. The selection and adoption of a methodology for all NFIP hazard maps should consider changes in the regulations and standard policy that might make the mapping simpler and more economical to implement.

Mapping methodologies exist that could be adapted to meet both insurance and land-use needs. However, the adaptations should be carefully tailored to be most cost-effective. Unfortunately, there is only scattered information concerning losses from mud flows and other forms of landslides. Data collection has not been systematic, except in a few local areas. Those data that do exist do not generally distinguish between losses from mud flows and losses from landslides, nor do they always separate mud flow damage from flood (especially mud flood) damage. Similarly, losses caused by mud floods are nearly everywhere subsumed within general riverine flood losses.

SELECTING METHODOLOGIES

Mud flows and mud floods occur on hillsides and adjacent drainage basins throughout the United States. The antecedent conditions, triggering events, and dominant effects are sufficiently varied from place to place and time to time that no single methodology can be used to delineate areas prone to all of the kinds of mud flows and mud flcods. Mapping these hazards requires a range of methodologies that is broad enough and flexible enough to be adjusted for regional variations in the key factors. The methodologies for mud flows and mud floods will differ from those currently used for the clear water flcods that occur in floodplains. The selection of the most appropriate set of methodologies will require, first, a clear distinction between those hazards that are covered under the NFIP and those that are not, and second, an interactive process involving policy officials and technical experts in planning the mapping program and in providing a quality-control review system to assure national uniformity in the final products.

MUD FLOW HAZARD MAPPING

Techniques for mapping areas susceptible to mud flows can be adapted from existing methods for mapping areas susceptible to landslides. Research directed toward landslide hazard mapping is now being undertaken by federal agencies such as the Geological Survey, Forest Service, and Soil Conservation Service, as well as by a number of state and local agencies, and should be monitored by FEMA.

Since areas delineated as landslide-prone are often susceptible to many kinds of landslides, including mud flows, maps showing areas of landslide hazard can often serve as a starting point for making maps of areas of mud flow hazard. In many localities, it is not likely that present hazard mapping techniques can provide a more detailed picture of areas prone to mud flows than is given by the landslide hazard maps. Where more detailed maps of mud flow hazard are required (for example, in communities where much of the landslide-prone area is not prone to mud flows) special mapping studies can be undertaken. A possibly more economical alternative is to carry out special site studies, such as those required by the Los Angeles City and County grading codes, for all hillside areas or for all properties in landslide-prone areas.

MUD FLOOD HAZARD MAPPING

Because mud floods occur more commonly in mountain canyons and on alluvial fans than on riverine floodplains, floodplain maps do not completely depict the distribution of the potential hazard. Techniques for mapping mud flood hazard areas can probably be adapted from standardized flood prediction methods. Adaptations of the LACFCD methodology could be effective in some, but not all, areas that are hydrologically similar to the San Gabriel Mountains, but only after an extensive period of data collection.

Little is known about how different conditions cause variations in the ways mud and debris are produced, transported, and deposited during floods. Regional assessments of areas having high mud flood risk are needed, and a data gathering program for such assessments should begin.

VI. CONCLUSIONS

The LACFCD methodology was developed specifically for mud floods on the alluvial fans of the San Gabriel Mountains, where an extensive system of debris catchment basins and flood control channels is in place, and where there is a long historical record of debris accummulations. The method appears to be valid, although it should be quantitatively verified using independent data. While the general approach may be applicable to the mapping of mud flood hazards in some other hydrologically similar areas, the specific methodology developed by the LACFCD cannot be used as a general mudslide hazard mapping procedure for the NFIP.

Selection of a more generally applicable mapping strategy and of specific methodologies would be materially aided by the following:

1. A clear decision by FEMA as to which phenomena are to be included under the mudslide provisions of the NFIP and which are to be excluded, with reference to a standard classification scheme for earth movements. This is essential both for mapping purposes and for the purpose of insuring nationwide uniformity and consistency in assessing whether losses for which insurance claims are submitted were caused by phenomena covered by the NFIP. This decision must be based not only on technical considerations, but also on considerations involving economics and national policy. This is likely to require an interactive process involving policy officials and technical experts.

2. Determination by FEMA of which NFIP needs can be met by activities that are already being carried out by various federal agencies and which cannot. A number of federal agencies concerned with landslides and soil stability, including the Geological Survey, the Soil Conservation Service, and the Forest Service, are carrying out activities related to landslide hazard mapping that could contribute to FEMA's mudslide mapping needs. FEMA should not duplicate these activities, but should devote its resources toward filling programmatic gaps and adapting other agencies' products to its own needs.

3. Use of appropriate technical expertise to assist FEMA in selecting a mudslide mapping strategy and in developing and evaluating particular methodologies. FEMA should draw on technical expertise in geology, soil science, geotechnical engineering, hydrology, and other relevant fields in selecting a mapping strategy, in formulating criteria to guide contractors in developing specific methodologies, and in evaluating newly developed methodologies. This can be accomplished either by entering into cooperative arrangements with other federal agencies, by establishing technical advisory and review bodies, or by using outside consultants.

APPENDIX: BIOGRAPHICAL SKETCHES OF COMMITTEE MEMBERS

RUSSELL H. CAMPBELL is a geologist with the U.S. Geological Survey and is currently program coordinator for the Ground Failure and Construction Hazards Program at the Survey's national headquarters in Reston, Virginia. He received his B.A. in Geology from the University of California at Berkeley in 1951, and has since worked continuously as a geologist on a variety of research investigations. He is a specialist on debris flows in the southern California region and also has extensive experience in regional geologic structure and stratigraphy in southern California, northwestern Alaska, and southeastern Utah. In addition to project investigations, he has served the Survey as acting chief of the Office of Environmental Geology, and as deputy for geology in the Office of Earthquake Studies. In 1973-74, he served as a member of the Panel on Methodology for Delineating Mudslide Hazard Areas of the Science and Engineering Committee on Prevention and Mitigation of Flood Losses for the Building Research Advisory Board, National Research Council.

PAUL BOCK is Professor of Hydrology and Water Resources at the University of Connecticut. He received his B.S. in Civil Engineering in 1947 from the Massachusetts Institute of Technology and his M.S. in Engineering in 1951 and D.Eng. in 1958 from the Johns Hopkins University. He is a member of the Space Applications Board of the National Research Council and is a member of the National Advisory Committee on Oceans and Atmosphere, a presidentially apppointed committee. He also serves on the editorial board of Remote Sensing of the Environment. In the past he has served on various National Research Council committees dealing with hydrology and remote sensing.

F. BEACH LEIGHTON is President of Leighton and Associates, a geotechnical consulting firm that he founded in 1960. He received his B.S. in Engineering Geology from the University of Virginia in 1946, his M.S. in Geology from the California Institute of Technology in 1949, and his Ph.D. in Geology from the California Institute of Technology in 1951. Dr. Leighton was Chairman of the Department of Geology at Whittier College from 1951-72, and he is presently Adjunct Research Professor in that department. He is principal author and co-author of over thirty geotechnical papers and publications. Dr. Leighton received the National Association of Engineering Geologists Claire P. Holdredge award in 1967 for his paper "Landslides and Hillside Development." He has served on the Engineering Geology Qualifications Boards of the City of Los Angeles and Los Angeles County, on the Geological Society of America Membership Committee, on the National Earthquake Studies Advisory Panel, and as State-of-the-Art Reviewer on Application of Earth Science to Urban Planning from 1972 to 1974.

JAMES K. MITCHELL is Department Chairperson and Professor of Geography at Rutgers University. He received his B.Sc. from Queens University, Belfast, Northern Ireland, in 1965, his M.A. and M.C.P. from the University of Cincinnati in 1967, and his Ph.D from the University of Chicago in 1973. One of his areas of expertise is the management of human responses to environmental hazards, particularly in coastal and marine areas. He chairs the Scientific Committee of the Outer Continental Shelf Advisory Board in the U.S. Department of Interior, and has served on evaluation panels for the National Science Foundation, the U.S. General Accounting Office, and the U.S. Interagency Committee on Ocean Pollution, Research, Development and Monitoring.

DAVID B. PRIOR, Professor in the Coastal Studies Institute of Louisiana State University, is an authority on marine geology, submarine slope instabilities, and various types of terrestrial landslides. Under recent contracts with the U.S. Geological Survey, the Bureau of Land Management, and the Office of Naval Research, and as a consultant to industry, he has been engaged in mapping and identifying shelf and continental slope geology and landslide features, particularly in the northern Gulf of Mexico. His work has involved considerable field experience with state-of-the-art marine survey systems and experience as chief scientist on numerous multisensor cruises. Field work has been conducted in Ireland, France, Denmark, the Caribbean, Canada, Spitsbergen, and Greenland. Dr. Prior has served on the faculty of The Queen's University of Belfast, Northern Ireland, Clark University, and Louisiana State University. He earned his B.A. in 1964 and his Ph.D. in 1968 at the Queen's University of Belfast. He has published approximately fifty scientific papers.

DWIGHT A. SANGREY is Professor of Civil Engineering and Head of the Department of Civil Engineering at Carnegie-Mellon University in Pittsburgh. He received his B.S. in Civil Engineering from Lafayette College in 1962, and he received his M.S. in geotechnical engineering from the University of Massachusetts and his Ph.D. in geotechnical engineering from Cornell University in 1968. Dr. Sangrey taught at Queens University and Cornell University prior to joining Carnegie-Mellon and has worked in private practice. He is the author and co-author of numerous publications including the book Landslides: Analysis and Control published by the National Academy of Sciences in 1978. He recently served as Chairman of the Task Group on Landslides and Other Ground Failures for the National Academy of Sciences and has served as Co-Chairman of the New York State Governors' Special Commission on PCB Contamination of the Hudson River.

WADE G. WELLS II is a research hydrologist with the Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, Glendora, California. He received his B.S. in Forestry and B.S. in Agriculture in 1962 from the University of Idaho. He then served in the United States Army as a Regular Army Officer until 1969. He received his M.S. in Hydrology in 1976 from the University of Arizona. He specializes in flash flooding and erosion processes in mountainous terrain, and has published several papers on these subjects. He is also a member of the research staff of the Environmental Quality Laboratory, California Institute of Technology, Pasadena.