

DISCLAIMER

This document has been reviewed by the Federal Emergency Management Agency and approved for publication. The contents do not necessarily reflect the views and policies of the Federal Emergency Management Agency.

Landslide Loss Reduction:

A Guide for State and Local Government Planning

by:

Robert L. Wold, Jr.

*Colorado Division of Disaster Emergency Services
and*

Candace L. Jochim

Colorado Geological Survey



Contents

FOREWORD	vi
ACKNOWLEDGMENTS	vii
Advisory Committee	vii
CHAPTER 1—Introduction	1
Purpose of this Guidebook.....	3
CHAPTER 2—Landslide Losses and the Benefits of Mitigation	4
The Landslide Hazard	4
Economic and Social Impacts of Landsliding.....	4
Costs of Landsliding.....	4
Impacts and Consequences of Landsliding.....	4
Long-Term Benefits of Mitigation	5
The Cincinnati, Ohio Study.....	6
The Benefits of Mitigation in Japan	6
Planning as a Means of Loss Reduction	6
Local Government Roles.....	7
CHAPTER 3—Causes and Types of Landslides	9
What Is a Landslide?	9
Why Do Landslides Occur?.....	9
Human Activities	9
Natural Factors.....	9
Climate	9
Erosion.....	10
Weathering	10
Earthquakes	11
Rapid Sedimentation.....	11
Wind-Generated Waves.....	11
Tidal or River Drawdown.....	11
Types of Landslides.....	11
Falls	11
Topple.....	11
Slides.....	11
Rotational Slide.....	12
Translational Slide.....	12
Block Slide.....	13
Lateral Spreads.....	13
Flows.....	13
Creep.....	13
Debris Flow.....	13
Debris Avalanche	13
Earthflow.....	14
Mudflow	14
Lahar	14
Subaqueous Landslide.....	15
Interrelationship of Landsliding With Other Natural Hazards (The Multiple Hazard Concept)	15
Landsliding and Dam Safety.....	15
Landsliding and Flooding.....	17
Landsliding and Seismic Activity	18
Landsliding and Volcanic Activity.....	19
CHAPTER 4—Hazard Identification, Assessment, and Mapping	20
Hazard Analysis.....	20
Map Analysis.....	20
Analysis of Aerial Photography and Imagery	20
Analysis of Acoustic Imagery and Profiles.....	20
Field Reconnaissance.....	20
Aerial Reconnaissance	20
Drilling.....	20
Geophysical Studies.....	21
Computerized Landslide Terrain Analysis	21
Instrumentation	21
Anticipating the Landslide Hazard	21
Translation of Technical Information to Users.....	21
Regional Mapping	22
Community-Level Mapping.....	22
Site-Specific Mapping	22
Types of Maps.....	22
Landslide Inventories	22
Landslide Susceptibility Maps	23
Landslide Hazard Maps.....	25
CHAPTER 5—Transferring and Encouraging the Use of Information	26
Information Transfer	26
Users of Landslide Hazard Information.....	27
Developing an Information Base: Sources of Landslide Hazard Information	28
CHAPTER 6—Landslide Loss-Reduction Techniques	30
Preventing or Minimizing Exposure	

Contents Continued

to Landslides	30	Local Needs	39
Land-Use Regulations	30	Step 6 - Formulation of Goals and	
Reducing the Occurrence of Landslides		Objectives	40
and Managing Landslide Events	30	Local Landslide Hazard	
Building and Grading Codes	30	Mitigation	40
Emergency Management	31	Development of Mitigation	
Controlling Landslide-Prone Slopes		Projects	40
and Protecting Existing Structures	31	Step 7 - Establishment of a	
Precautions Concerning Reliance		Permanent State Hazard	
on Physical Methods	32	Mitigation Organization	41
Design Considerations and Physical		Step 8 - Review and Revision	43
Mitigation Methods	33	CHAPTER 8—Review and Revision of	
CHAPTER 7—Plan Preparation	35	the Plan and the Planning Process	44
Determining the Need for a State Plan	35	Inventory of Landslide Costs	44
Federal Disaster Relief and		Evaluation of Mitigation Projects and	
Emergency Assistance Act		Techniques	44
(Section 409)	35	Examples of Innovative Mitigation	
The Planning Team	36	Approaches	45
The Planning Process	37	Analyses of Local Mitigation Programs	45
Step 1 - Hazard Analysis	37	CHAPTER 9—Approaches for Over-	
Step 2 - Identification of Impacted		coming Anticipated Problems	46
Sites	37	Organizational Problems	46
Step 3 - Technical Information		Management Problems	46
Transfer	38	Financial Problems	46
Step 4 - Capability Assessment	38	Coordination Problems	47
Step 5 - Determination of Unmet		REFERENCES CITED	48

Figures

1a. Map showing relative potential of different parts of the conterminous United States to landsliding	1	15. Debris fan formed by debris flows.....	15
1b. Potential landslide hazard in Maine	2	16a. Earthflow	15
2. Major damage from debris flow, Farmington, Utah	5	16b. Roan Creek Earthflow, DeBeque, Colorado.....	15
3. "Bucket brigade," Farmington, Utah	5	17. Damage from Slide Mountain landslide, Nevada.....	16
4. Landslide losses in Japan 1938-1981.....	6	18. Jackson Springs landslide, Franklin D. Roosevelt Lake, Washington state	17
5. The relationship of people, landslides, and disasters	7	19. Aerial view of the Thistle landslide, Utah	18
6. Aerial view of the Savage Island landslide, Washington state	10	20. Landslide inventory map, Durango, Colorado.....	23
7. Ruins of home destroyed in Kanawha City, West Virginia	10	21. Landslide inventory map, La Honda, California.....	24
8a. Rockfall	11	22. Landslide susceptibility map, King County, Washington	24
8b. Rockfall on U.S. Highway 6, Colorado.....	11	23. Earthquake landslide hazard map, San Mateo County, California	25
9a. Topple.....	12	24. Hazardous area warning sign	31
9b. Topple, western Colorado.....	12	25. Warning system schematic	32
10a. Rotational slide	12	26. Rudd Creek debris basin, Farmington, Utah	32
10b. Rotational slide, Golden, Colorado.....	13	27. Retaining wall, Interstate 70, Colorado	33
11. Translational slide	13	28. Executive Order establishing Colorado Natural Hazards Mitigation Council.....	42
12. Block slide	13		
13a. Lateral spread	14		
13b. Lateral spread, Cortez, Colorado	14		
14a. Creep.....	14		
14b. Creep, Mt. Vernon Canyon, Colorado	14		

Tables

1. Estimates of minimum landslide damage in the United States, 1973-1983	2	information	26.
2. Techniques for reducing landslide hazards	8	4. Potential users of landslide hazard information	27
3. Examples of resources available for obtaining/transferring landslide		5. Examples of producers and providers of landslide hazard information	29
		6. Physical mitigation methods	33
		7. Capability assessment checklist	38

Foreword

There is a need for a comprehensive program to reduce landslide losses in the United States that marshals the capability of all levels of government and the private sector. Without such a program, the heavy and widespread losses to the nation and to individuals from landslides will increase greatly. Successful and cost-effective landslide loss-reduction actions can and should be taken in the many jurisdictions facing landslide problems. The responsibility for dealing with landslides principally falls upon state and local governments and the private sector. The federal government can provide research, technical guidance, and limited funding assistance, but to meet their responsibility for maintaining the public's health, safety and welfare, state and local governments must prevent and reduce landslide losses through hazard mapping, land-use management, and building and grading controls. In partnership with public interest groups and governments, the private sector must also increase its efforts to reduce landslide hazards.

Dramatic landslide loss reduction can be achieved. The effective use of landslide building codes and grading ordinances by a few state and local governments in the nation clearly

demonstrates that successful programs can be put into place with reasonable costs. Numerous examples of responsible landslide hazard planning and mitigation by private developers exist but are usually overshadowed by improper development that ignores the hazard.

Transfer of proven governmental and private sector landslide hazard mitigation techniques to other jurisdictions throughout the nation is one of the most effective ways of helping to reduce future landslide losses. This guide, prepared by the State of Colorado for the Federal Emergency Management Agency, builds upon the impressive efforts taken by Colorado state and local governments in planning for and mitigating landslide losses. The Federal Emergency Management Agency hopes that this guide and the accompanying plan for landslide hazard mitigation will stimulate and assist other state and local governments, private interests, and citizens throughout the nation to reduce the landslide threat.

Arthur J. Zeizel
Project Officer
Federal Emergency
Management Agency

Acknowledgments

This project was funded in part by the Federal Emergency Management Agency (FEMA), the Colorado Division of Disaster Emergency Services (DODES), the Colorado Geological Survey (CGS), and the U.S. Geological Survey (Grant No. 14-08-0001-A0420).

The document was written and prepared by **Robert L. Wold, Jr.** (DODES) and **Candace L. Jochim** (CGS). Staff contributors included: **William P. Rogers**, **Irwin M. Glassman**, and **John O. Truby**. Additional contri-

butors included: **David B. Prior** of the Coastal Studies Institute of Louisiana State University and **William J. Kockelman** of the U.S. Geological Survey. Project management was provided by **Arthur Zeizel** (FEMA) and **Irwin Glassman** (DODES).

Other essential project personnel included: **Cheryl Brchan** (drafting and layout), **Nora Rimando** (word processing), and **David Butler** (editing).

Advisory Committee

John Beaulieu, *Deputy State Geologist, Oregon*
John P. Byrne, *Director, Disaster Emergency Services, Colorado*
William J. Kockelman, *Planner, U.S. Geological Survey, California*
Peter Lessing, *Environmental Geologist, West Virginia Geological Survey*

George Mader, *President, William Spangle and Associates, California*
Dr. Robert L. Schuster, *U.S. Geological Survey, Colorado*
Dr. James E. Slosson, *Chief Engineering Geologist, Slosson and Associates, California*
Darrell Waller, *State Coordinator, Bureau of Disaster Services, Idaho*