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ASSESSMENT OF REGIONAL EARTHQUAKE HAZARDS AND RISK ALONG THE WASATCH FRONT, UTAH
VOLUME IV

EDITOR
PAULA L. GORI
U.S. GEOLOGICAL SURVEY
RESTON, VIRGINIA 22092

OPEN FILE REPORT 90-225

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Reston, Virginia
1990

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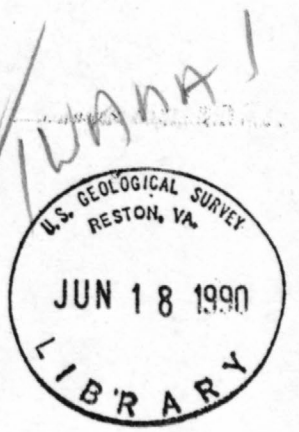

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FOREWORD

This report represents an ongoing U.S. Geological Survey effort to transfer accurate earth science information about earthquake hazards along the Wasatch front, Utah to researchers, public officials, design professionals, land-use planners, and emergency managers in an effort to mitigate the effects of earthquake hazards. This report is a preview of the future U.S. Geological Survey professional paper on regional earthquake hazards and risk along the Wasatch front.

Currently State and local governments, private institutions, and individuals are implementing earthquake hazards reduction measures in Utah. The success of their efforts will depend, in part, on the availability of accurate earth science information. The timeliness and importance of the multidisciplinary research contained in this report and the need for its utilization has made it imperative to release the information in the form of an open-file report while the process of publishing the professional paper is being completed.

The report is organized into four volumes. Volume I contains chapters on the tectonic framework and earthquake potential of the Wasatch front area. Volume II contains chapters on the ground shaking hazards and aspects of loss estimation, as well as, chapters on the use of hazards information for urban and regional planning and development. Volume III contains chapters on loss estimation which were unavailable at the time Volume II (Open-File 87-585) was published. Volume IV contains chapters on implementation of earthquake hazards information. Many of the chapters are in draft format and, therefore, the figures follow the text.

The information contained in this report is the latest and most accurate information available on earthquake hazards along the Wasatch front and may be used and cited until such time as the Professional Paper on "Regional earthquake hazards and risk along the Wasatch front," is published.

Paula L. Gori
Editor

ASSESSMENT OF REGIONAL EARTHQUAKE HAZARDS AND RISK ALONG THE WASATCH FRONT, UTAH

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THE CRUCIAL CONNECTION BETWEEN RESEARCHERS AND PRACTITIONERS

by

William J. Kockelman
U.S. Geological Survey
Menlo Park, California

ABSTRACT

Translation and transfer of complex scientific and engineering studies to nontechnical users are necessary for their use in reducing earthquake hazards in Utah. Three elements are needed for effective translation: likelihood of occurrence, location, and severity of potential hazards. Several examples of translated information for Utah are described and illustrated. Three elements are needed for effective transfer to nontechnical users: delivery, assistance, and encouragement. Numerous examples of transfer techniques in Utah are described and illustrated. The importance of evaluating and revising earthquake-hazard reduction programs and their components is emphasized. Over thirty evaluations of various natural-hazard reduction programs and techniques are introduced.

This report was prepared for research managers, funding sources, and evaluators of the Utah earthquake-hazard reduction program who are concerned about effectiveness. It provides an overview of the Utah program for those researchers, engineers, planners, and decisionmakers -- public and private -- who are committed to reducing human casualties, property damage, and interruptions of socioeconomic systems.

INTRODUCTION AND PURPOSE

Effective comprehensive programs having earthquake-hazard reduction as a goal need five components, each a prerequisite for its successor:

1. Conducting scientific and engineering studies of the physical processes of earthquake phenomena -- source, location, size, likelihood of occurrence, severity, triggering mechanism, path, ground response, structure response, and equipment response.
2. Translating the results of such studies into reports and onto maps at an appropriate scale so that the nature and extent of the hazards and their effects are understood by nontechnical users.
3. Transferring this translated information to those who will or are required to use it, and assisting and encouraging them in its use through educational, advisory, and review services.
4. Selecting and using appropriate hazard reduction techniques -- legislation, regulations, design criteria, education, incentives, public plans, and corporate policies.
5. Evaluating the effectiveness of the hazard reduction techniques after they have been in use for a period of time and revising them, if necessary. Evaluation and revision of the entire program as well as the other components -- studies, translation, and transfer -- may also be undertaken.

These five components (fig. 1) encompass a broad range of activities which are often described or divided differently. Examples include: 48 resolutions by the United Nations Educational, Scientific, and Cultural Organization (1976), six general topics and 37 issues by the U.S. Office of Science and Technology Policy (1978), 48 detailed initiatives recommended by the California Seismic Safety Commission (1986), and 171

action items at a state governor's conference on geologic hazards (Utah Geological and Mineral Survey, 1983).

FIGURE 1 NEXT PAGE

The purpose of this report is to emphasize the crucial connection between scientific and engineering studies and their ultimate use for hazard reduction by Utahans. The connection consists of two of the five components shown in figure 1 -- translation and transfer. Emphasis on this crucial connection is provided by a discussion of the problem -- failure to translate and transfer -- and efforts toward making the connection in Utah. Translation and transfer are defined, described, and then illustrated, first by the use of general examples and then by the use of specific examples in Utah.

Scientific and Engineering Studies

A prerequisite for a successful Utah earthquake-hazard reduction program is the production by researchers of adequate and reliable scientific and engineering information about potential earthquake hazards -- surface fault rupture, ground shaking, liquefaction, landsliding, seiches, tsunamis, subsidence, and their effects. Actual hazards occur when land uses, or structures, or equipment are located, constructed, or operated in such a way that people may be harmed, their property damaged, or their socioeconomic systems interrupted.

Numerous geologic, geophysical, seismologic, and engineering studies are necessary to assess potential earthquake hazards in Utah. These studies are concerned with the physical process of earthquakes -- source, location, size, likelihood of occurrence, triggering mechanism, path, and

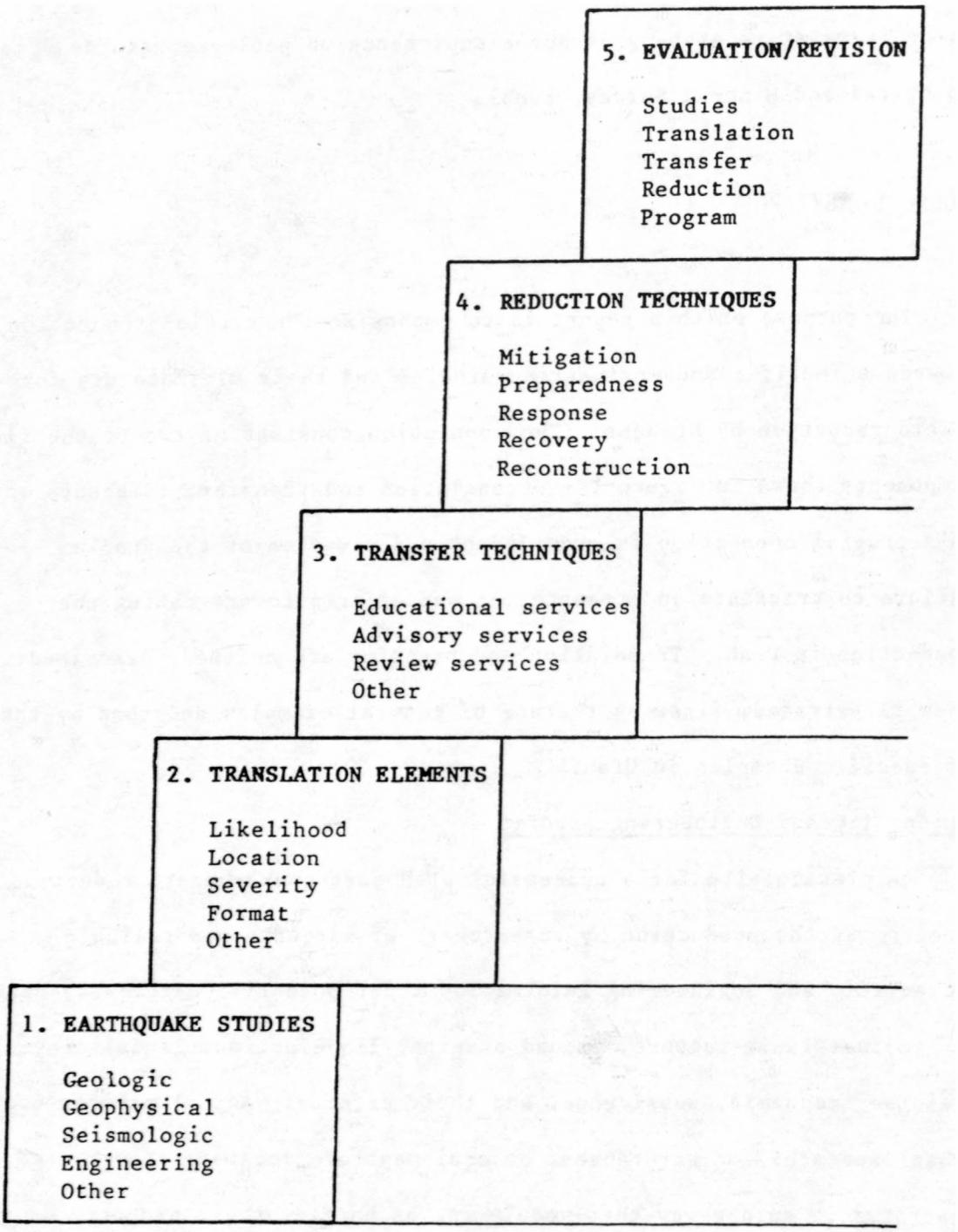

FIGURE 1. -- Five components needed for an effective comprehensive earthquake-hazard reduction program depicted as steps or building blocks, each a prerequisite for its successor.

severity of effects on a site, structure, or socioeconomic activity. These studies can be divided in several ways. To give the nontechnical reader an overview, some of the studies and the knowledge derived are shown in list 1.

LIST 1 NEXT PAGE

A description of many of these studies can be obtained from perusing various scientific and technical reports and texts, such as: Richter (1958), Wallace (1974), Borcherdt (1975), Applied Technology Council (1978), Hays (1980), Ziony (1985), Power and others (1986), Evernden and Thomson (1988), and Schwartz (1988). Most of these studies are complex and interconnected, have limitations because of lack of data, and require special technical skills.

Many of these studies were envisioned and are described in the "Regional Earthquake Hazards Assessments" draft work plan for the Wasatch Front. This plan was reproduced in a workshop proceedings edited by Hays and Gori (1984, p. 17-44). The results of those studies may be seen in a two-volume report edited by Gori and Hays (1987) or in the first volume (ck) of this professional paper.

Such studies are vital, because in the words of a former U.S. Geological Survey director, Walter C. Mendenhall: "There can be no applied science unless there is science to apply." It has been my experience that it is not prudent for planners to develop land-use regulations, engineers to design structures, and lenders and public works directors to adopt policies reducing earthquake hazards without reliable scientific and engineering assessments. Hanks (1985, p. 3) observes that "implementation

List 1

Examples of scientific and engineering studies necessary to assess earthquake hazards [1/]

Types of Studies [2/]	**Knowledge Derived**
Geologic	
Detailed geologic mapping Lithologic investigations Stratigraphy Borehole sampling Trenching Paleontology Scarp analysis Stream offsets Geomorphologic studies Structural geology	Fault slip rates, physical properties, fault length, fault age, fault geometry, bedrock strength, zones of deformation, amplification of ground motion, lateral and vertical offsets, earthquake recurrence intervals, earthquake sources, depth to ground water, fault location, bedrock types, deformation patterns, plate tectonics context, driving forces, and other knowledge concerning surface rupture, ground shaking, landsliding, liquefaction, seiches, tsunamis, and subsidence.

1/ These studies are just some of the ones necessary to assess earthquake "hazards;" many other types of studies are necessary to evaluate "vulnerable" structures, "secondary" hazards (fires, floods, and toxin spills), people "exposed," and socioeconomic activities "at risk."

2/ The term "studies" is loosely used here to include experiments, measurements, investigations, observations, models, techniques, analyses, mapping, monitoring, or testing. Many of the seismologic studies are a special type of geophysical research.

List 1 (continued)

Examples of scientific and engineering studies necessary to assess earthquake hazards [1/]

Types of Studies [2/]	**Knowledge Derived**
Geophysical/Geochemical	
Geodetic leveling and trilateration Field monitoring: Stress and strain Tilt and creep Electrical changes Radon/helium emissions Water chemistry changes Water-well levels Electromagnetic soundings Gravity, electrical, and magnetic studies Seismic refraction and reflection profiling Radiometric dating	Precursor detection, ongoing deformation, fault zone properties, recurrence intervals, shear wave velocity, stress accumulation, crustal anatomy, crustal properties, wave attenuation, crustal velocity model, ground-motion characteristics, deformation patterns, buried faults or structure locations, and three-dimensional crustal geometry.

List 1 (continued)

Examples of scientific and engineering studies necessary to assess earthquake hazards

Type of Studies	Knowledge Derived
Seismologic	
Historical seismicity Earthquake monitoring Strong ground-motion monitoring networks Ground response Seismic wave propagation Segmentation analyses Wave propagation Rupture process	Asperity locations, velocity, severity of shaking, acceleration, displacement, seismic gaps, source zones, fault mechanism, rupture direction, seismic direction, recurrence interval, epicenters, epicentral intensity, fault type, fault length, fault width, maximum probable magnitude, seismic hazard zones, rupture characteristics, seismic moment, stress drop, local amplification, duration of shaking, focal mechanism and depth, and response spectrum.

List 1 (continued)

Examples of scientific and engineering studies necessary to assess earthquake hazards

Type of Studies	Knowledge Derived
Engineering	
Structural mechanics Engineering characteristics Risk analysis Monitoring of structures Damage inventories Soil-structure interaction Structural vulnerability Soil mechanics Rock mechanics Soil/rock acoustic impedance Standard penetration tests	Seismic risk maps, structural performance, hysteretic behavior, strength of materials, stiffness degradation, structural strength, structural reliability, design criteria, material properties, response spectra, seismic intensities, nonlinear behavior, inelasticity, ductility, damping, energy absorption, bearing capacity, soil properties, amplification levels, shear wave velocity, shear modulus, failure limits, load limits, ultimate load limits, and foundation design.

Note: Robert Brown, geologist, Robert Simpson, geophysicist, Allan Lindh, seismologist, and Mehmet Celebi, structural engineer, U.S. Geological Survey, provided critical comments and valuable suggestions that have refined and improved this list. However, because of its abbreviated form, the author remains responsible for its omissions and any errors.

plans may not mean much if they are not based on the best scientific knowledge and data available."

Hazard Reduction Techniques

Numerous earthquake-hazard reduction techniques are available in Utah to engineers, planners, and decisionmakers, both public and private. These techniques have the following specific objectives: awareness of, avoidance of, accommodation to, or response to, the effect of the earthquake phenomena on people and their land uses, structures, and socioeconomic systems. The general goal of these objectives is to reduce human casualties, property damages, and socioeconomic interruptions.

Many of the reduction techniques are also complex, interconnected, and require special skills -- legal, financial, legislative, design, economic, communicative, educational, political, and engineering. To give the reader an overview, examples of specific reduction techniques are shown in list 2. These techniques can be divided in other ways, for example:

- o Pre-event mitigation techniques, which may take 1 to 20 years.
- o Preparedness measures, which may take 1 to 20 weeks.
- o Response during and immediately after an event.
- o Recovery operations after an event, which may take 1 to 20 weeks.
- o Post-event reconstruction activities, which may take 1 to 20 years.

These estimated time periods vary depending upon the postulated or actual size of the earthquake, its damage, the reduction techniques in place, and the resources available to the State of Utah, its communities, its corporations, and its families.

LIST 2 NEXT PAGE

List 2

Examples of techniques for reducing earthquake hazards in Utah

Incorporating hazard information into plans and programs

Community-facilities inventories and plans

Economic-development evaluations and plans

Land-subdivision layouts

Land-use and transportation inventories and plans

Public-safety plans

Redevelopment plans (pre-disaster and post-disaster)

Utility inventories and plans

Regulating development

Placing moratoriums on building

Reviewing annexation, project, and rezoning applications

Enacting building and grading ordinances

Adopting design and construction regulations

Requiring engineering, geologic, and seismologic reports

Requiring investigations in hazard zones

Enacting subdivision ordinances

Creating special hazard-reduction zones and regulations

Siting, designing, and constructing safe structures

Reconstructing after a disaster

Reconstructing or relocating community facilities

Reconstructing or relocating utilities

Securing building contents and nonstructural components

Evaluating specific sites for hazards

Siting and designing critical facilities

Training design professionals

List 2 (continued)

Examples of techniques for reducing earthquake hazards in Utah

Discouraging new development in hazardous areas

Disclosing potential hazards to real-estate buyers

Adopting lending policies that reflect risk of loss

Adopting utility and public-facility service-area policies

Requiring nonsubsidized insurance related to level of hazard

Posting public signs that warn of potential hazards

Making a public record of potential hazard locations

Clarifying the legal liability of builders and property owners

Strengthening, converting, or removing unsafe structures

Condemning and demolishing unsafe structures

Creating nonconforming land uses

Repairing unsafe dams or lowering their water levels

Retrofitting bridges and overpasses

Strengthening or anchoring buildings

Acquiring or exchanging hazardous properties

Reducing land-use intensities or building occupancies

Preparing for and responding to emergencies and disasters

Estimating damages and losses from an earthquake

Preparing damage scenarios for critical facilities

Providing for damage inspection, repair, and recovery

Conducting emergency or disaster training exercises

Operating monitoring, warning, and evacuation systems

Initiating public and corporate education programs

Preparing emergency response and recovery plans

Creating community recovery information clearinghouses

Many of the hazard reduction techniques identified in this report have been discussed and illustrated by Blair and Spangle (1979), Kockelman and Brabb (1979), Brown and Kockelman (1983), Kockelman (1985, 1986), Jochim and others (1988), Mader and Blair-Tyler (1988), Blair-Tyler and Gregory (1988), and the United Nations Office of the Disaster Relief Coordinator (Lohman and others, 1988).

Utah's Draft Work Plan

A collective partnership of Utahans and others in 1983 created a unique state earthquake-hazard reduction program. The formulators of the draft work plan for the Wasatch Front not only envisioned the use of scientific and engineering studies to reduce the hazard, but provided for an "implementation" component having three priorities: (1) determining the needs of users, (2) producing translated information that meets the need, and (3) fostering an environment for use of research results by local government. For the purpose of this report, users are defined as those who are interested in or who have responsibility for reducing earthquake hazards.

Examples of specific techniques to reduce hazards (list 2) and potential users of earthquake-hazard information (list 3) were compiled. The reduction techniques most appropriate for Utah were to be selected by these users. These techniques and users were included in the draft work plan reproduced by Hays and Gori (1984, p. 37-44). The adopted work plan provides a bench mark for evaluating its accomplishments.

LIST 3 NEXT PAGE

List 3

Examples of potential users of earthquake hazard information in Utah

City, county, and multicounty government users

City building, engineering, zoning, and safety departments

County building, engineering, zoning, and safety departments

Mayors and city council members

Multicounty planning, development, and preparedness agencies

Municipal engineers, planners, and administrators

City and county offices of emergency services

Planning and zoning officials, commissions and departments

Police, fire, and sheriff's departments

Public works departments

County tax assessors

School districts

State government users

Department of Community and Economic Development (Community Services Office, Economic and Industrial Development)

Department of Business Regulation (Contracts and Real Estate divisions)

Department of Financial Institutions

Department of Health (Environmental, Health Care Financing)

Department of Insurance

Department of Natural Resources

Department of Public Safety

Department of Social Services

Department of Transportation

Division of Comprehensive Emergency Management

Division of Risk Management

List 3 (continued)

Examples of potential users of earthquake hazard information in Utah

Division of Water Resources

Division of Water Rights

Facilities Construction and Management

Geological and Mineral Survey

Legislative Fiscal Analyst

Legislative Research and General Counsel

Legislature and legislators

National Guard

Office of the Governor

Planning and Budget Office

Public Service Commission

Science Advisor

State Board of Regents

State Fire Marshall

State Tax Commission

State Office of Education

State Planning Coordinator

Private, corporate, and quasi-public users

Civic, religious, and voluntary groups

Concerned citizens

Construction companies

Consulting planners, geologists, architects, and engineers

Extractive, manufacturing, and processing industries

Financial and insuring institutions

Landowners, developers, and real-estate salespersons

List 3 (continued)

Examples of potential users of earthquake hazard information in Utah

News media

Professional and scientific societies (including geologic, engineering, architecture, and planning societies)

Utility companies

University departments (including geology, civil engineering, structural engineering, architecture, urban and regional planning, and environmental departments)

Implementation Underway

Descriptions and illustrations of the reduction techniques are beyond the scope of this report. However, many of them were selected, successfully used, or are pending in Utah. Descriptions of some of them may be seen in the previous volume (ck) or in the volumes edited by Gori and Hays (1987, 1988). One of them -- a model natural-hazards reduction ordinance drafted by the Salt Lake County planning staff (Barnes, 1988a, b) -- has been adapted and adopted by the city of Washington Terrace.

In addition, geologists, engineers, and planners -- public and private -- are evaluating the location or design of developments in relation to earthquake hazards, for example: rezonings and annexations by Utah and Juab counties' geologist R.M. Robison (written commun., 1985, 1986); subdivision layouts, apartment project locations, fire station design, and aqueduct relocation by Salt Lake County geologist C.V. Nelson (1988; written commun., 1985, 1986); and long-range environmental plans, subdivision layouts, and critical facilities, including water tanks, fire stations, jails, and waste disposal by Weber and Davis counties' geologist Mike Lowe (written commun., 1989).

According to Utah Geological and Mineral Survey geologist W.F. Case (written commun., 1988), a residential development in Ogden was scrutinized because it was proposed to be located in a rockfall-hazard area shown on his map. The developer then hired an engineering firm to determine the extent of the hazard and to reduce it.

Previously adopted techniques to reduce losses from natural hazards can be revised to include the latest earthquake research information. Examples of regulations that can or have been revised include: the site development regulations of the Salt Lake City Council (1981), Emigration

Canyon master plan adopted by the Salt Lake County Commission (1985), multihazard mitigation plan for Ogden City and Weber County prepared by the Utah Multi Hazards Mitigation Project Administrative Review Committee (1985), and the critical environmental zone created by the Mapleton City Council (1985).

Others include: seismic risk reduction recommendations for primary and secondary schools by Taylor and Ward (1979), hillside site development regulations by the Spanish Fork City Council (1980), regulations governing dam safety by Hansen and Morgan (1982), structural seismic resistance regulation by the Ogden City Council (1983), sensitive area overlay zone ordinance by the Ogden City Council (1985), hillside development standards and sensitive lands development ordinance by the Provo Municipal Council (1985), seismic-hazard area regulations by the Orem City Council (1986), structural directives of the Headquarters Structural Engineering Staff (1987), development overlay zone by the Washington Terrace City Council (1988), emergency training exercises by the Utah Division of Comprehensive Emergency Management (Tingey and May, 1988), and the emergency recovery plans proposed by the Financial Institution Emergency Preparedness Committee (James Tingey, written commun., 1988).

TOWARD THE CONNECTION IN UTAH

Sometimes planners, engineers, and decisionmakers fail to fully use the research information available. The connection between research (list 1) and its use to reduce hazards (list 2) simply is not made. According to several experienced and perceptive observers (McKelvey, 1972; Jacknow, 1985, p. 18; Reilly, 1987; Szanton, 1981, table 3-1, p. 64; Yin and Moore, 1985, p. 18-19; and Petak, 1984, p. 456), the reasons vary. They may be restated simply as: not all of the research information is in a language or format understandable or directly usable by nontechnical users, or is not effectively transferred to them.

Utah's User Needs

In Utah, nontechnical users -- government officials, corporate planners, land developers, and private citizens -- have needs that differ from those of scientists, engineers, and other technical people. The nontechnical users in list 3 do not constitute a homogeneous group. Rather, they differ widely in the kinds of information they need and in their capabilities to use that information. Thus, detailed technical information prepared by scientists or engineers often is unsuitable for and unusable by nontechnical users. For example, most professional land-use planners and local officials do not have the training or experience to directly apply earthquake-hazard research information (U.S. Office of Science and Technology Policy, 1978, p. 170). Few academic programs train students of planning or public administration to avoid, reduce, or design for natural hazards.

Although many land use planners and local officials in Utah have some experience with natural hazards, such experience is usually with floods, landslides, or soil problems. Without translating and transferring the

earthquake research information, the effective user community is limited to scientists and engineers. At the other extreme, if the users do not become familiar with and proficient in using research information, it is likely to not be used or worse, misused!

Problem Recognized

Both researchers and users of research information have recognized the problem and the needs of nontechnical users -- decisionmakers (Alexander, 1983, p. 49); state and local governments (Council of State Governments, 1976); city, county, and multicounty planners (Kockelman, 1975, 1976b, 1979); nonspecialists (Wenk, 1979); potential user groups (Yin and Moore, 1985); journalists (Peterson, 1986), nontechnical users (White and Haas, 1975), and the general public (Petak, 1984).

From the beginning of their five-year focused effort in 1983, both the Utah Geological and Mineral Survey (UGMS) and the Utah Division of Comprehensive Emergency Management (CEM) were aware of and concerned about the problems of research information being effectively used by nontechnical persons. For example, during a Utah Governor's conference on geologic hazards held in 1983, most of the 36 working groups identified specific problems or needs of nontechnical users as:

- ... officials need risk maps ....
- ... lack of knowledge concerning... expertise... available ....
- ... not aware of the availability ... of hazards information.
- Most local government ... requires technical assistance ....
- ... State and local agencies need a central data bank ....
- ... mechanism is needed to ... transfer ... information ....
- Lack of hazard susceptibility maps ....

According to UGMS deputy director D.A. Sprinkel (written commun., 1986),

"most of the research scientists feel the amount of data collected can and should be translated into products for the public and disseminated as soon as possible."

Part of the solution to the problem has been widely recognized as simply one of adequate translation for, and effective transfer to, nontechnical users. International agencies (United Nations Educational, Scientific, and Cultural Organization, 1976), federal agencies and committees (Wallace, 1974; NEHRP Expert Review Committee, 1987), and state agencies (Utah Seismic Safety Advisory Council, 1981; California Seismic Safety Commission, 1986) have all addressed the need for translation and transfer of research information.

Recommendations for translation and transfer have been included in hazard-reduction programs for natural hazards other than earthquakes; for example, coastal area hazards (White and others, 1976), flood hazards (National Science Foundation, 1980), landslide hazards (U.S. Geological Survey, 1982), and for the major natural hazards considered by the Advisory Committee on the International Decade for Natural Hazard Reduction (1987).

Utah's Work Plan

Two of the five components (fig. 1) in the work plan adopted by Utahans directly relate to the connection between research and its use. The work plan clearly identifies "translated" scientific information as a prerequisite to its transfer to a user and its use for earthquake-hazard reduction. It then specifically addresses those actions likely to improve effective use of scientific information by nonscientists, particularly as part of the implementation component, namely:

- Identify the hazard maps and reports needed for hazard reduction measures and ensure that new information is prepared in detail and at the scales needed by the users.
- Make special efforts to present the information in a format and language suitable for use by engineers, planners, and decisionmakers.
- Design the communications program after an assessment of potential users' needs and capabilities.
- Select the most effective educational, advisory, and review services appropriate to the targeted users.
- Design the communications program so that information can be effectively disseminated (including use of the scientists and investigators to help communicate).

According to Atwood and Mabey (previous volume (ck); 1987, p. S30), achieving this "requires communication of translated scientific information to responsible officials and interested parties seeking to reduce losses from the hazards. This is a major challenge to the program because many of the products of scientific research are not directly usable by responsible officials and the public. To accomplish this goal, it is essential to involve the user of the information early in the program."

In their book, In Search of Excellence, management consultants Peters and Waterman (1982, p. 145) observe: "Finally, and most important, is the user connection ... we will simply say that much of the excellent companies' experimentation occurs in conjunction with a lead user." A social scientist (Drabek, 1986, p. 416) remains "convinced that the quality of disaster research will be improved immeasurably if the interaction between practitioners and researchers is increased." A comprehensive review of the use of research (Yin and Moore, 1985, p. 70)

includes a conclusion that "the most consistent pattern leading to utilization was the prevalence of rich and direct communication between knowledge producers and users throughout the design and conduct of the research project." Taylor (1979, p. 278) notes that "if users participate in the research process -- most especially at the beginning when the problem is defined -- then they are likely to identify with the research project and with its outcome."

One of the ways for ascertaining nontechnical users' needs is that of arranging for a dialogue between researchers and users of hazard information (list 3). In the case of Utahans, this was done in several ways -- conferences, workshops, and special sessions. Each required careful preparation, good-faith effort, and skillful facilitating. Three examples are discussed in more detail in the following subsections.

Governor's Conference

The conference was sponsored by the Utah League of Cities and Towns, Utah Association of Counties, Utah State Legislature, Federal Emergency Management Agency (FEMA), U.S. Geological Survey (USGS), and the University of Utah; it was coordinated by the UGMS and the Utah Division of Comprehensive Emergency Management (CEM). It was held on August 11 and 12, 1983, on the campus of the University of Utah.

The purpose of the conference was to bring together scientists and engineers, elected and appointed officials, leaders of business and private organizations, and private citizens to discuss geologic hazards and to recommend appropriate actions to all levels of government. The first day of the conference was designed to provide information on the principal geologic hazards in Utah. During the second day, 36 working groups met in half-day sessions to develop recommendations for actions by

all levels of government to reduce the geologic hazards in Utah.

The working groups recommended 171 actions that they felt should be taken to reduce the impacts of geologic hazards on the lives of Utahans. They concluded that although much of the information needed to make site-specific decisions has not yet been developed, sufficient information exists on which to base public policy. The working groups determined that the primary support for research on geologic hazards should come from the Federal Government, and that the State should take a major role in identifying research priorities and applying research results. The working groups also concluded that information collection and dissemination is the role of State agencies, and that local governments should take a more active role in identifying their information needs and providing matching assistance. An excerpt from one of the working groups follows:

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33. HAZARDS INFORMATION FOR PLANNERS

Chairperson: James P. McCalpin, Geologist, Utah State University

Topic c: Interpretation of information

Problem: Planners are often unable to interpret available geologic hazards information and therefore cannot use it effectively in land-use planning or regulation. This problem has two related aspects: the data are presented in too technical and specialized a format for planners, or planners have insufficient geologic background.

Action: (1) Offer natural hazard information in derivative or interpretive maps .... Such interpretive maps would assess hazards directly with some kind of rating system (e.g., serious, moderate, slight)

.... (2) Educate planners via technical workshops ... to train them in hazard interpretation from existing geologic maps and forthcoming interpretive maps, or (3) Local governments in critical hazard areas should hire a full- or part-time geologist to identify local hazards and to help draft local government ... regulations.

The results of the conference -- suggestions for action, remarks of the Governor, action items of the working groups, and a summary of the questionnaire -- were published by the Utah Geological and Mineral Survey (1983). The dialogue between researchers and the users of geologic hazard information had begun!

Earthquake Hazards Workshops

The first of five workshops was held on August 14-16, 1984, in Salt Lake City. The workshop was sponsored by USGS, FEMA, UGMS, CEM, and the University of Utah. One hundred and fifteen participants having varied backgrounds in earth science, social science, planning, architecture, engineering, and emergency management participated in the workshop. They represented various industries, volunteer agencies, and academic institutions in Utah, as well as representatives of local and State governments of Utah, other states, the private sector, and the Federal Government.

The two primary objectives of the workshop were to: (1) strengthen the capability of the scientific and technical community to compile and synthesize geologic, geophysical, and engineering data needed for evaluating earthquake hazards, and (2) work with public officials in fostering an environment for implementation of research results, creating

partnerships, and providing high-quality scientific information that can be used by local government to reduce hazards.

Four discussion groups were created, each composed of both researchers and users of hazard information. Two of the groups recommended translation and transfer activities. An excerpt from the "information systems" group moderated by a USGS research geographer reads:

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2) An extraordinary effort should be made to communicate. Possible actions include:

b) Devising outreach activities to involve a wide range of groups. These activities could use strategies such as workshops, small group meetings, exchange of technical information, demonstration of products and results of research neighborhood meetings, and generation of special information packets and audiovisual materials to give them a stake in the process.

An excerpt from the "implementation options" group moderated by a FEMA emergency manager reads:

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3) County geologists -- Local governments need to attain the capability to take the products (data, maps, reports, etc.) produced ... and apply them to solve problems in their jurisdictions. This application is the only way that the ultimate goal of reducing the loss of life and property from earthquakes will be attained. The Wasatch front counties ... are the places to start. The county geologists are the key resource. Such a process is needed now.

The results of this innovative workshop and recommendations of the discussion groups were published in the proceedings edited by Hays and Gori (1984). The results of the 1986 workshop were published in the proceedings edited by Hays and Gori (1987). These workshops resulted in early release of research findings, continued dialogue between researchers and practitioners, and an increased awareness of the earthquake hazard by the public.

User Needs Session

A special session was held in the evening following the workshop discussed above. The purpose of this session (convened and moderated by the Utah State Geologist and the USGS earth-sciences applications planner) was to carry on a dialogue in order to determine needs of users for earth-science information and to identify any obstacles to its use. This special session was designed to provide an opportunity for users of earth-science information to communicate their needs to the UGMS, USGS, universities, consultants, and others who produce such information.

Invitations to participate in this session were sent to over 70 city, county, and State officials, planners, engineers, and university researchers and educators. Representatives of the Utah League of Cities and Towns, League of Women Voters, American Planning Association (Utah Chapter), Wasatch Front Regional Council, The Western Planner, and the Southeastern Utah Association of Governments also attended.

Seven speakers experienced in determining or meeting user needs made presentations that were prepared specifically for this session. The speakers' collective experience included conducting studies of user-needs, translating scientific information for nontechnical users, communicating information to nontechnical users, or using earth-sciences information to

reduce hazards. Briefing materials emphasizing the needs of users were provided to participants.

Six panelists representing important city, county, State, and private planning and decisionmaking agencies participated. The panelists were selected on the basis of their experience in the use of earth-sciences information and on their need to have research information translated, transferred, and used. The panelists began the "brainstorming" session by commenting on the usefulness to their organizations of the techniques presented by the speakers. They were asked to list types of information that they felt rated the highest priorities.

The meeting then was thrown open to the nontechnical participants. A "brainstorming" approach was scrupulously followed and resulted in a blackboard filled with items needed. The items listed were organized into five categories: (1) scientific research topics, (2) translation of science for use by nontechnical users, (3) transfer of the information to the users, (4) use of the translated information to reduce hazards, and (5) evaluation of the uses of the information to ensure effectiveness.

After the items were organized, the moderators asked for a weighting of the importance of each need by a simple showing of hands. The users were then asked whether they would actually use the information if it were available. Both information producers and users fully understood that a "no" vote did not mean that the information was not necessary or useful to someone else, but rather that this particular group of users did not think that they would use the information. The spontaneous voting by only the user attendees resulted in a rating on a scale of 1 to 10. The number 10 indicating that virtually all the users present felt that their organizations needed and would, or should, use a specific type of information.

Some of the needs (and weights assigned) follow:

- o Site-specific geologic reports that are legally and politically defensible (10).
- o Early warning "red flag" maps, scales 1:9600 (10).
- o Structure types susceptible to failure by shaking (8).
- o Location of surface fault rupture zones (7).
- o Maps showing multihazards, scales of 1:2400 or more detailed (10).
- o Maps showing susceptibility to damage or hazard (10).
- o Retain five staff geologists to serve 10 counties (9).
- o "Red-flag" hazard maps for counties at a scale of 1:100,000 (6).
- o Maps interpreting research for ... nontechnical persons (10).
- o Education of local planning commissioners (10).
- o Increased awareness of hazards (10).
- o Educational materials explaining earthquake processes and their effects ... meant for adults but can be understood by sixth-graders (5).
- o Advisory services (10).
- o Training for local government ... including planners (10).
- o Protypical community training exercises (9).

The names of the session's speakers, panelists, and participants, along with the papers, briefing materials, and the complete results of the "brainstorming" are included in the workshop proceedings edited by Hays and Gori (1984, p. 606-674). This session provided the researchers with the specific translation and transfer needs of the nontechnical users.

Researchers and Translators

Various views have been expressed concerning who is responsible for translating and transferring research information to nontechnical users. The following examples concerning the responsibility of researchers and

translators are from several experienced and perceptive observers:

- ... identify user groups, ... meet their needs, and plan on producing a major product aimed directly at users. (Yin and Moore, 1985, p. ix-x)
- ... be prepared to make their analyses of earthquake danger comprehensible in common sense terms by frequent and imaginative use of metaphors and examples from common experience. (Turner and others, 1981, pt. 10, p. 96)
- ... not only be willing to face the adverse reactions but also to persist in finding truly effective ways of conveying information that is important to societal needs ... (Peterson, 1986, p. 245)
- ... sees user problems as interesting and worthy of serious intellectual commitment beyond the theoretical implications for other scientists in the field. (White and Haas, 1975, p. 152)
- ... much greater direct participation by geologists and by planners with better training and understanding of the significance and application of earth-science information ... (Nichols, 1982, p. 290)

In identifying problems and opportunities as experienced by USGS, Bates (1979, p. 29) in his Transferring Earth Science Information to Decision-makers concluded that the entire earth-science community must mobilize to provide specialized, technical information in a form and language understandable to the intelligent citizen; and to engage in the educational, advisory, and review services necessary to assist the public and its representatives in making effective use of that information. The unusual and remarkable efforts taken in Utah to translate and transfer research information to nontechnical persons will be seen in subsequent sections of this report.

Other Aspects

Translation and transfer activities considered in this paper are only part of the solution to the problem of lack of effective earthquake-hazard reduction. Other aspects must be considered; the following have been noted:

- Perhaps the most telling factor acting against adoption of earthquake-risk reduction measures is that Utah has not experienced a highly destructive earthquake in a heavily populated area. (Atwood and Mabey, previous volume (ck); 1987, p. S19)
- Utah needs trained people to analyze the technical data bases, to extrapolate beyond the limits of the data, and to translate the basic data into maps and other products that can be applied in the community .... (Hays, previous volume (ck); 1987, p. R8)
- ... the research begins with approval of the effort by those top officials who have power to see that results are utilized. (White and Haas, 1975, p. 152)
- Lack of leadership due to competing, day-to-day problems, lack of interest or commitment, potential citizen opposition, and inadequate educational programs. (Perkins, 1986, p. 3)
- ... the public lacks knowledge of and underestimates the hazardous quality of their environment ... these underestimations reflect busy people ... occupied with their own life priorities -- day-to-day issues of living. (Drabek, 1986, p. 320)

Hays (1988b, p. 100-101) emphasizes that the risk management process in every nation depends on seven factors: a perceived need for risk reduction, informed internal advisors, strong external champions, credible products, user-friendly products, balanced political, legal, and economic

considerations, and a window of opportunity. Sprinkel (1988) in his review of the earthquake assessment program in Utah asks "Will Utah meet the challenge?" and then answers that question in the affirmative by noting the existence of the following key factors:

champions	challenge
symbiotic relationship	true believers
strong partnership	key players
early planning	long-time advocates
mutual buy-in	brimming with enthusiasm
credibility of the program	excellent media coverage
commitment of funds	translation expedited
talented people	potential devastating earthquake

TRANSLATION FOR PRACTITIONERS

The objective of translating hazard information for practitioners is to: make them aware that a hazard exists which may affect them or their interests; provide them with information that they can easily present to their superiors, clients, or constituents; and provide them with materials that can be directly used in a reduction technique (list 2). The Utah work plan is quite specific as to what is expected of translated information:

- o ... users will have easy access to data in media, scales, and formats, that will be most useful to them.
- o ... selection of standard base maps and mapping scales ....
- o ... interpreted information derived from basic scientific data.
- o ... make it easy for local government, engineers, architects, planners, ... and emergency responders to use the technical information ....
- o ... information in a format and language suitable for use by engineers, planners, and decisionmakers.

Definition

Much has been said about the need for and objectives of translation. No clear concise definition or criterion has been offered, nor can it be found in the literature except by inference or by an analysis of what is actually used by practitioners. However, various researchers, translators, and users of earthquake research information are specific about what is needed by nontechnical users. They range from Steinbrugge (1982, p. 13) "Knowledge of the distribution of earthquakes in time, location, and size is essential for insurance ratings and underwriting purposes," to Keaton and others (1987, p. 73) "Successful translation of science must 1) show hazard locations on maps at suitable scales, 2) provide some sense of the

damage likely to result from occurrence of a hazardous event, and 3) provide some sense of when a hazardous event is likely to occur."

My experience with reducing potential natural hazards (primarily atmospheric, floods, soils, landslides, and earthquakes) indicates that hazard information successfully used by nontechnical users has the following three elements in one form or another:

1. Likelihood of the occurrence of an event that will cause human casualties, property damage, or socioeconomic disruption.
2. Location of the effects of the event on the ground.
3. Estimated severity of the effects on the ground, structure, or equipment.

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

However, concern varies widely with the individual user, the cost of hazard reduction, and who or what might be affected. For example, a pedestrian might prepare for a fifty-percent probability of rainfall tomorrow by carrying an umbrella; a lender might require flood insurance if the mortgaged property is within a 100-year-recurrence-interval flood zone; and a regulatory agency might curtail construction if a critical facility is being located near a fault that has moved in the last 10,000 years. The reader will note that both location (areal, zonal, or specific) and likelihood of occurrence are conveyed in these three examples; severity is provided in a much different way -- personal experience, documented damage, or fear of a disaster and possible liability.

Unfortunately, these three elements come in different forms and with

different names, some quantitative and precise, others qualitative and general. Several examples follow for each element. In all cases, for a product to be defined as "translated" hazard information, the nontechnical user must be able to perceive likelihood, location, and severity of the hazard so that he or she becomes aware, can convey it to others, and can use it directly in selecting and adopting a hazard reduction technique.

Likelihood of Occurrence

This element can be conveyed for a selected size and location of damaging earthquake by the use of various concepts -- probability, return period, frequency of occurrence, or estimated, average, or composite recurrence interval. Sometimes a specific event is chosen -- design earthquake, hypothetical earthquake, characteristic earthquake, or postulated earthquake. Each of these terms has a specific definition which is beyond the scope of this report. In all cases, each event chosen must be credible; that is, have some likelihood of occurring.

In some cases, an engineering parameter is used for a specific ground failure: "the probability that the critical acceleration would be exceeded in 100 years" for liquefaction by Anderson and others (1986, p. 39) or for landslides by Keaton and others (1987). Algermissen and others (1982) use a map showing probabilistic bedrock peak horizontal ground acceleration that has a 90-percent probability or likelihood of not being exceeded in a 50-year period. In another case, the term "oppor-tunity for liquefaction" was used where "a return period of about 30 to 50 years is anticipated for ground motions sufficient to exceed the liquefaction threshold at a given susceptible site" (Tinsley and others, 1985, p. 315). The period of 30 to 50 yr is selected because it embraces the economic or functional life of most buildings.

No matter what term is used, it must convey a likelihood of occurrence that is important to the user. This likelihood varies widely, depending upon its use. For example, the National Research Council (1986, p. 5) notes that "various public agencies define an active fault as having had displacements (a) in 10,000 yr, (b) in 35,000 yr, (c) in 150,000 yr, or (d) twice in 500,000 yr." The interest of an engineer, planner, or decisionmaker in likelihood of occurrence also varies widely, for example:

Insuring agent	Premium period (1 yr)
Elected official	Term of office (2-6 yr)
Lending officer	Amortization schedule (10-30 yr)
Bridge designer	Structure's life (50-100 yr)
Waste manager	Hazard's life (1,000-10,000 yr)
Pyramid builder	Next world (10,000-10,000,000 yr)

Location and Extent

Once users are convinced of the likelihood of a damaging event, they want to know if their interests might be affected. This information is conveyed by showing the location and extent of ground effects or geologic materials susceptible to failure. These are usually shown on a planimetric map having sufficient geographic reference information to orient the user to the location and extent of the hazard. Topographic maps showing geographic information, such as streams, highways, railroads, and place names, are very helpful. Some maps show streets; others show property boundaries. The scales of such maps vary widely; examples from Utah vary from 1:36,000 (1 in. equals 3,000 ft) to 1:1,200,000 (1 in. equals approximately 3 mi). Compare figures 3 and 4 in next section.

The scale selected depends on the detail and amount of information to

be shown, as well as the users' needs. For example, the seismic zone map of the United States adopted by the International Conference of Building Officials (1988, p. 178) and incorporated into the widely used Uniform Building Code is at a scale of 1:30,000,000; it is based on Algermissen and others (1982) national map which is at a scale of 1:7,500,000. Some building site hazards have been shown at scales of 1:1,200 (1 in. equals 100 ft) or larger. Most hazard maps are a compromise between scale, detail, reliability, difficulty and cost of preparation, and the purpose for which they were designed. There are no "best" scales, only more convenient ones.

Estimated Severity

After the users recognize the likelihood of an event which may affect their interests, their next question is: how severe will be its effects? In other words, is the hazard something that should be avoided, designed for, or should preparations be made to respond during, and recover, repair, and reconstruct after a damaging event. Severity of anticipated effects is best expressed by use of measurable engineering parameters for the various hazards, for example:

- o vertical and horizontal displacements for surface fault ruptures.
- o peak acceleration, peak velocity, peak displacement, frequency, and duration for ground shaking.
- o velocity and volume for landslides.
- o extensional and vertical displacement for liquefaction.
- o vertical displacement for tectonic subsidence.
- o run-up height for tsunamis.

Modified Mercalli or Rossi-Forel intensity scales of observed or estimated damage also show severity. They are used primarily for ground

shaking but can include the effects of surface fault rupture, landsliding, and liquefaction. These scales also include some of the observed or anticipated effects on structures, their occupants, and their contents.

Format

These three elements -- likelihood, location, and severity -- have been combined into various formats, some easy for the nontechnical user, and others requiring additional information or an experienced user to appreciate, adapt, and use in a reduction technique. Sometimes all of the elements are placed on a single map. At other times, information in the report or volume must be combined, or outside supplemental information must be obtained. Sometimes one of the elements (likelihood of occurrence) is one of public knowledge or experience. Sometimes the elements are only available or combined for a demonstration area. When adequate research information is available for other areas, additional translation work can be done. Otherwise new research must be undertaken to cover the user's area of jurisdiction or interest.

At other times, the format is a "seismic-hazards zone" (sometimes called "seismic zonation") showing the location and severity of all the effects from one postulated event. Qualitative terms are often used to show relative susceptability (high, moderate, low, and very low) of geologic or other units to landslides or liquefaction, or to show relative severity (very violent, very strong, strong, and weak) of shaking. Examples of some of these formats follow:

Wesson and others (1975) and Ziony and Yerkes (1985) show location of faults that have, or may generate, damaging earthquakes or surface-fault rupture on index-scale maps. Maps at much larger scales (1:24,000) for surface-fault traces are readily available. Likelihood of occurrence

(estimate of recurrence intervals) and severity (maximum surface displacement) are conveyed by discussions, tables, and graphs in the text accompanying the index maps. Both reports are in a volume that illustrates surface faulting as part of the predicted effects of a postulated earthquake (magnitude 6.5) for a selected fault.

Algermissen and others (1982) show location and severity (in terms of peak velocity and acceleration) by areas on a map for the ground-shaking hazard. Likelihood of occurrence is conveyed by probability (percent) of not being exceeded for various exposure times (10, 50, and 250 yr) in the map caption.

Rogers and others (1985) show location of a demonstration site and severity (mean amplification factor compared with level of shaking at site on rock) by areas on maps for predicted relative ground response. Individual maps are used to show predicted relative ground response in three period-bands having significance to buildings of specific heights (2-5, 5-30, and 30 or more stories). Likelihood of occurrence is conveyed by other papers in the same volume.

Wieczorek and others (1985) show location and extent (levels of susceptibility), and percentage of area likely to fail on a map for slope stability during earthquakes. Likelihood of occurrence is conveyed by a discussion of a lower-bound hypothetical (or "design") earthquake large enough to trigger landslides (Richter magnitude 6 or 7, depending on location of the earthquake). Severity is conveyed by a discussion on the map by noting that "structures generally cannot withstand more than 10 to 30 cm of movement without damage ...." and then by selecting 5 cm (2 in.) as a conservative design threshold.

Tinsley and others (1985) show location and extent (levels of

relative susceptibility) of liquefaction on a map. Likelihood of occurrence (return period of liquefaction opportunity) for magnitude 5 or larger earthquakes is shown by contours on a separate map. Severity is partially conveyed by photographs showing liquefaction damage to three critical facilities -- causeway, juvenile hall, and an earth-filled dam. Their report is in a volume that illustrates liquefaction-related ground failure as part of the predicted effects of a postulated earthquake for a selected fault; the text also conveys severity.

Agnew and others (1988) show conditional probability of large earthquakes on a map for selected segments. Probabilities are based on expected recurrence times, and calculated for the likelihood of occurrence during the next 30 yr. Severity is generally conveyed by the expected magnitude of a major earthquake, which is provided for each segment.

In some cases, the use of lists of damaging events, photographs of damage, or diagrams of effects on ground or buildings for similar events are used to convey severity. Examples include Youd and Hoose (1978) for ground failure, Ziony (1985) and Borcherdt (1975) for earthquake hazards, and Hays (1981) for several geologic and hydrologic hazards.

This type of information is an important part of the researcher's observations, but when used in translated information becomes an effective transfer technique, namely, communicating possible effects -- casualties, damage, and socioeconomic interruptions. Sometimes this can be misleading because of differences in the user's environment and that depicted -- earthquake location and size, ground conditions, structure's vulnerability, people exposed, and reduction techniques already implemented.

Successful Translation

One of the best ways to confirm that these elements -- likelihood,

location, and severity -- are needed is to look at information that has been prepared for, and successfully used by, engineers, planners, and decisionmakers to reduce earthquake hazards.

Many examples of the use of translated (and of course transferred) earthquake research information for specific reduction techniques can be cited. In other words, the connection between research and its use in hazard reduction techniques is being made. Selected examples follow:

- Shaking intensity maps for major fault systems (Everenden and others, 1981) used for anticipating damage and interruptions to critical facilities and preparing for emergencies by utilities and local, multicounty, and state government agencies (Davis and others, 1982; Steinbrugge and others, 1987).
- Fault-rupture zone maps by various federal, state, university, and consultant researchers (Brown and Wolfe, 1972; Sarna-Wojcicki and others, 1976) used for statewide legislation, city and county regulations, and real-estate seller disclosures (Hart, 1988).
- Fault-rupture, tsunami, liquefaction, shaking, and landslide hazard information combined by computer and used for county seismic safety plans (Santa Barbara County Planning Department, 1979).
- Maximum credible ground acceleration on bedrock map (Greensfelder, 1972) used to assign priorities and to design for strengthening of highway overpasses by a state transportation agency (Mancarti, 1981).
- Maximum earthquake intensity map (Borcherdt and others, 1975) used for estimating cumulative damage potential for different building types by a multicounty agency (Perkins, 1987).
- Numerous studies of ground shaking acceleration, losses, and predicted intensities used as a basis for inventorying unreinforced masonry

buildings and requiring the strengthening or demolishing of unsafe ones (Los Angeles City Council, 1981).

- Probabilistic intensity (Algermissen and others, 1982) and local site amplification (Hays and others, 1978) maps used to estimate loss and replacement cost for various building types in Salt Lake City (Algermissen and Steinbrugge, 1984, p. 12-22).
- Continuous monitoring and analysis of earthquake precursor information for a specific fault segment used to warn local governments, the public, and the press via a governor's office of emergency services (Bakun and others, 1986).

Discussions and illustrations of some of these and other examples can be found in Blair and Spangle (1979), Kockelman and Brabb (1979), Brown and Kockelman (1983), Kockelman (1985, 1986), Jochim and others (1988), Mader and Blair-Tyler (1988), and Blair-Tyler and Gregory (1988).

Comment

These examples of translation vary as to scale, area covered, format, postulated or probable occurrence, single- or multiple-hazards, limitations, and supplemental information required. What they all have in common is that they convey the likelihood of the occurrence of a damaging event, show location and extent of the hazard on a map, and provide some indication of severity of effects on the ground.

Some of these examples have gone, or can easily be taken, a step further to show potential response of structures, occupants, and equipment. This next step is actually using translated information in a reduction technique (list 2); for example, development regulations, loss estimates, overpass retrofits, preparedness scenarios, and warning systems as seen in the above examples. This step requires the collection,

analysis, and use of new information -- type, age, and condition of vulnerable structures, characteristics of exposed populations, sensitivity of equipment, and importance of the socioeconomic systems at risk.

Numerous benefits are derived from translating earthquake-hazard research for nontechnical users; for example:

- Reports and maps designed for one common user group -- intelligent and interested citizens -- provide a common basis for discussion during public meetings.
- Researchers are relieved from repetitive requests for translation.
- Numerous nontechnical transfer agents are available to transfer nontechnical information.
- Transfer and use occur more rapidly and more correct and appropriate use is made of the research.
- Researchers become more sympathetic to users and their needs, and users become more appreciative and supportive of the researchers.

EXAMPLES OF SUCCESSFUL TRANSLATION IN UTAH

An unusual effort is being made in Utah to translate earthquake research information for nontechnical users. During 1986, the Utah State Geologist convened several meetings to discuss and develop criteria for "translated" research and to identify potential translators. D.A. Sprinkel, UGMS Deputy Director (written commun., December 24, 1986), reported that a common understanding was established, a logical progression from the research to its use was identified, and a tentative definition of translation was developed, namely, occurrence, location, and consequences.

Translators in Utah include university, state, and federal researchers, geotechnical consultants, and county geologists. Hazards being addressed include surface fault rupture, ground shaking, and failures induced by shaking -- liquefaction, landslides, rockfalls, tectonic subsidence, and dam failure. An example and illustration of translated information from Utah for each of these hazards follow.

Surface Fault Rupture

Machette and others (previous volume (ck); 1989) have prepared a report on surface fault rupture for the segments in the Wasatch fault zone. Their text includes a discussion of recurrence of large earthquakes; includes a table giving the number of faulting events on seven of the segments; and introduces the idea of a composite-recurrence-interval between 340 and 415 yr. See figure 2. Personius (1988) shows the location of faults that offset the surficial material on a topographic map (scale 1:50,000). Similar maps are being prepared for the urbanized portion of the Wasatch Front.

FIGURE 2 NEXT PAGE

[All values for age and time intervals (columns A-C) are rounded to the nearest 100 years. Ages based on calendar-corrected radiocarbon dates and thermoluminescence analyses. The average recurrence interval is determined by dividing the sum of time intervals (column C) by the sum of intervals between faulting events (column D). Time intervals (column C) for some segments include time between the oldest (undated) event at a site and the age of the datum; thus, some values in column C are maximum values. N/A indicates a value that is not applicable to the calculation]

Fault segment	Trench site	A: Oldest event (t) or datum (d) (years ago)	B: Estimated time since most recent faulting (years)	C: Time interval (A-B) (years)	D: Number of faulting events (and intervals) Events	Intervals
Brigham City..	Brigham City	4,700t	3,600	1,100	2	1
Weber.....	East Ogden..	4,000t	500	3,500	4	3
Salt Lake City	Dry Creek...	5,500t	1,500	4,000	2	1
American Fork.	AF-1, AF-2..	5,300t	500	4,800	3	2
Spanish Fork..	Mapleton....	3,000t	600	2,400*	2*	1*
Nephi.....	North Creek.	5,300d	400	4,900	3	2
Levan.....	Deep Creek..	7,300d	1,000	>6,300 N/A	1	0
Totals* (based on five segments; segments 1-4, 6).....				18,300	14	9
Totals (based on six segments; segments 1-6).....				20,700	16	10

Calculated recurrence intervals (in years) for segments of the WFZ having repeated Holocene movement#	Minimum value	Maximum value
Average recurrence interval (RI) on a single segment.....	2035	2070
Average composite recurrence interval (CRI).....	340	415

Notes: t—Time of oldest well-dated faulting event.
d—Age of datum from dating, stratigraphic, or tectonic considerations (rounded to nearest 100 years).
*—For a five segment model we use only the number of events and intervals from American Fork for the Provo segment).
#—Three significant figures are used to compute average values of recurrence from the totals in columns C and D. Values are rounded to nearest 5 years. Minimum values calculated from 20,700 years, 10 intervals, and 6 segments. Maximum values calculated from 18,300 years, 9 intervals, and 5 segments. The latter model (maximum value) is based on our preferred model of segmentation.

FIGURE 2. -- Example of a table showing average recurrence interval on a single segment and average composite recurrence interval for several segments by Machette and others (1989, table 2).

In an earlier report, Machette and others (1987) conclude that "recurrence intervals vary widely" on some segments, that some "earthquakes tend to occur in clusters," and that "recurrence intervals within clusters may be as short as 100 years" (revised to 180 yr). They suggest that the lack of faulting events in the past 400-500 yr, and the relatively imprecise dating (± 100 yr) of the most recent events, may indicate that "a major surface-rupturing earthquake is overdue on one or more of the segments." They include displacement, slip rates for the segments, and length of surface rupture from recent large earthquakes in the northern Basin and Range province.

Machette and others (1987) begin their report: the "heavily urbanized part of the Wasatch Front -- between Ogden and Provo --coincides with the part of the fault zone that shows the highest slip rates, shortest recurrence intervals ... , and most recent fault activity" and conclude that major earthquakes have struck the central, heavily urbanized section of the Wasatch fault zone on an average of once every 310 yr (revised to 415 yr) during the last 4,000-8,000 yr; that a form of temporal clustering of earthquakes has been (and may still be) active; and that lack of movement along the Brigham City segment during the late Holocene (past 3,600 yr) is somewhat ominous.

Their work on recurrence intervals is applicable to, and frequently provides the likelihood of occurrence element for, the Wasatch Front hazards which are discussed in the following subsections. In addition, McCalpin (1987) has analyzed the geometry of near-surface ground breakage across some normal faults, and defined reasonable setback distances.

The three county geologists serving Davis, Juab, Weber, Salt Lake, and Utah counties are combining this and other information to show a

surface fault rupture study zone on county maps (see fig. 3). In addition, they are transferring this map information to nontechnical users by use of texts that discuss and illustrate fault characteristics, segments, boundaries, recurrence intervals, displacement, and suggesting use of the maps for hazard reduction. For example, Robison (this volume (ck.); 1988a) summarizes displacement per event for each of the segments.

FIGURE 3 Page AA-46

Ground Shaking

Youngs and others (1987, fig. 37, p. M88) show location and severity (peak ground acceleration) by areas on a map for ground shaking. Likelihood of occurrence is conveyed by probability (percent) of being exceeded for various exposure times (10, 50, and 250 yr) in their figure caption.

Tinsley (this volume (ck.)) has prepared a report and map showing increased shaking due to ground conditions in the Salt Lake Valley. Figure 4 is a generalized version of this map at an original scale of 1:200,000. Location of increased ground shaking on unconsolidated deposits is shown by contour lines on the map. Severity is conveyed by use of Modified Mercalli intensity (MMI) units representing an increase in damage intensities to that which would occur on the underlying bedrock.

FIGURE 4 Page AA-47

The size and location of a credible earthquake can be obtained by referring to Machette and others (1987). A map of MMI on bedrock for such

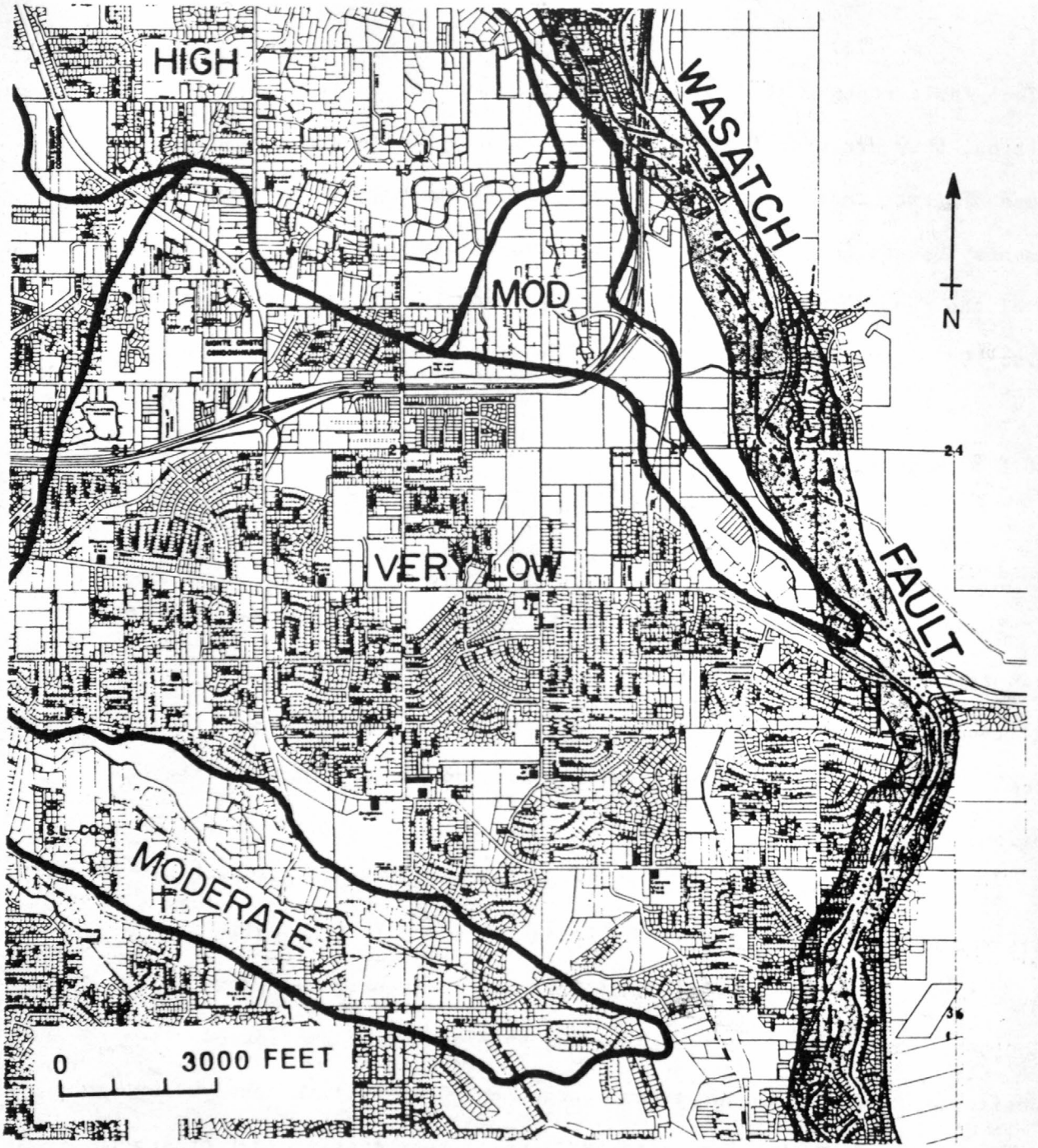

FIGURE 3. -- Part of a cadastral map (original scale 1:36,000) of Salt Lake County upon which Nelson (1987) shows a surface fault rupture zone and potential liquefaction areas. Fault traces are indicated by a solid line where location is known from scarps or trenching; dashed where approximately located or inferred; dotted where concealed. Bar and ball symbol indicates downthrown side. Shaded area indicates where site specific studies addressing surface rupture should be performed prior to construction. Areas labeled high, moderate, and very low indicate their potential for liquefaction during an earthquake.

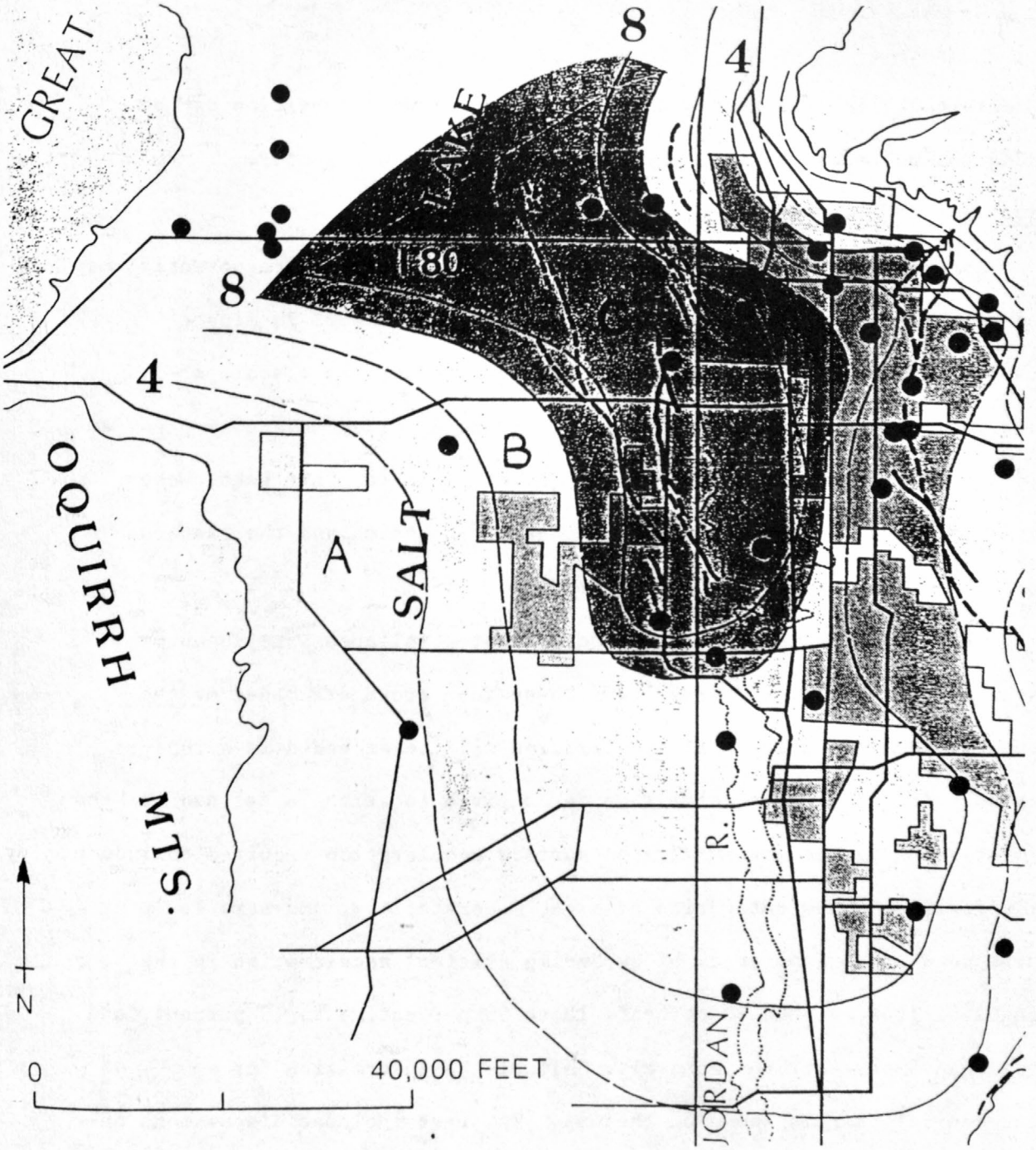

FIGURE 4. -- Map (original scale 1:200,000) showing three levels of ground shaking on alluvium relative to bedrock in the period band 0.2-0.7 sec in the Salt Lake Valley by Tinsley (this volume (ck.)). Contours were drawn on the basis of geology and show alluvium/rock spectral ratios recorded and computed by Kenneth King and Robert Williams. Map is preliminary and contours may be modified owing to further analysis of the data. Letters indicate an increase in Modified Mercalli intensity units: A(+1), B(+2), and C (greater than 2).

an earthquake is available and Tinsley's increased intensities can be added to such a map to meet the needs of a nontechnical user.

Liquefaction Potential

Anderson and others (1986) have prepared a liquefaction potential map and report for Utah County. The base map used is a USGS 7½-minute quadrangle showing topography which has been reduced to a scale of 1:48,000 (1 in. equals 4,000 ft). See figure 5. They have also prepared similar maps and reports for other counties -- Davis, Salt Lake, Weber, Cache, Millard, Sanpete, Sevier, and Wasatch counties and the eastern portions of Box Elder and Juab counties.

The boundaries of four liquefaction potential areas are shown -- high, moderate, low, and very low. These four areas are based on the proba-bility that a critical acceleration will be exceeded in a 100-yr period. The critical acceleration for a given location is defined as "the lowest value of the maximum ground surface acceleration required to induce liquefaction." The categories of high, moderate, low, and very low correspond to probabilities of exceeding critical acceleration in the ranges of greater than 50 percent, 10 to 50 percent, 5 to 10 percent, and less than 5 percent, respectively. All of the information for a nontechnical user is shown on the map. The text includes discussions on methods, geotechnical conditions, existing ground failures, and techniques for reducing the susceptibility of site sediments to the liquefaction process.

In addition, Anderson and others (1986) have provided maps showing some information on soils, groundwater, geology, and slope which can be used in combination with the liquefaction potential map (fig. 5) to assess the type of ground failure likely to occur -- loss of bearing capacity,

lateral spreading, landslides, flows, and translational landslides. These maps require further translation which is being done by county geologists.

FIGURE 5 Page AA-50

Landslide Potential

Keaton and others (1987) have prepared an earthquake-induced landslide potential map and report for the urban corridor of Davis and Salt Lake counties. The base map used is a USGS 7½-minute quadrangle showing topography which has been reduced to a scale of 1:48,000 (1 in. equals 4,000 ft). See figure 6.

FIGURE 6 Page AA-51

Boundaries of four landslide potential zones are shown -- high, moderate, low, and very low. These qualitative terms were assigned on the basis of failure criteria, landslide susceptibilities, and acceleration exceedence probabilities. In the text, displacement related to these terms are given; for example, 10 cm or more in a "moderate" zone during a wet condition, 10 cm or more in a "high" zone during a dry condition. Severity is then provided by the sentence: "Such ... displacement would certainly cause substantial damage to structures on ... or utilities buried within a sliding mass" (p. 75).

These four zones depend upon the probability that a critical acceleration will be exceeded in a 100-yr period. The period of 100 yr is arbitrary, but useful for planning, and is the same as that used for liquefaction potential discussed above. The terms -- high, moderate, low,

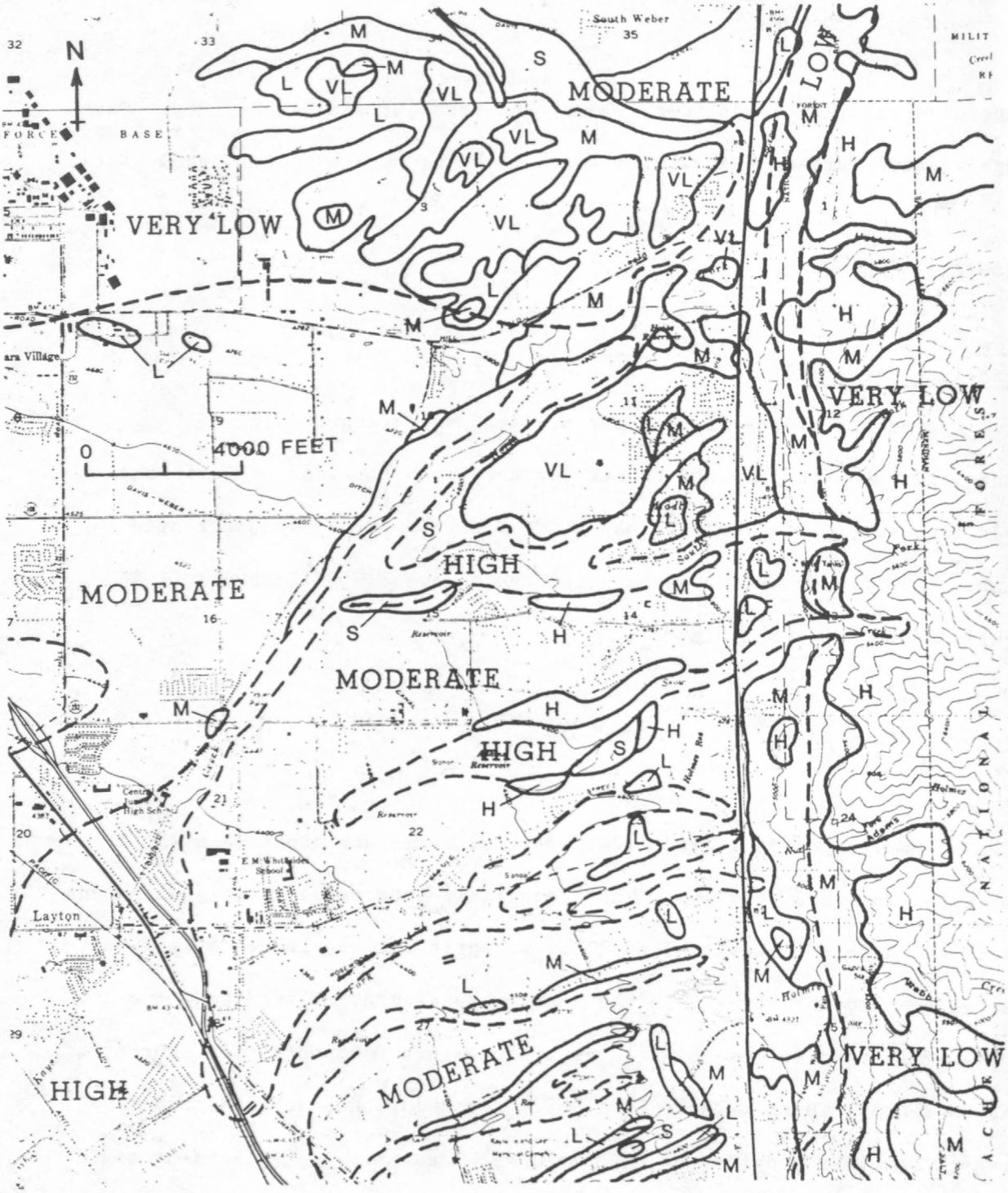

FIGURE 5. -- Part of a topographic map (original scale 1:48,000) of Utah County upon which Anderson and others (1986, plate 4B) show areas with high, moderate, low, and very low potential for liquefaction corresponding to the probability of exceeding a critical acceleration.



FIGURE 6. -- Part of a topographic map (original scale 1:48,000) of Davis County, Utah, upon which Keaton and others (1987, pl. 1b) show potential for earthquake-induced landslides and liquefaction. Letters H, M, L, and VL indicate high, moderate, low, and very low potential for landslides. The letter S indicates existing landslide. Words -- high, moderate, low, and very low -- indicate potential for liquefaction.

and very low -- for these zones are functions of the critical acceleration exceedence probabilities and the groundwater conditions similar to those used for liquefaction potential.

All of the information needed by a nontechnical user is shown on the map. The text includes discussion of method, geology, groundwater, and ground motion; a list of historical earthquake-induced landslides; and maps showing the historical limit of landsliding due to magnitude 7.5 earthquakes for all segments of the Wasatch fault.

Rockfall Susceptibility

Case (1987, p. V1-V36) has prepared a report and map concerning rockfall hazards in the central Wasatch Front between Layton and Draper (including Magna and Tooele) with particular emphasis on earthquake-induced rockfalls. The base map used is a USGS 7½-minute quadrangle map showing topography which has been reduced to a scale of 1:100,000. See figure 7. Field work was at a scale of 1:24,000 and is available from Case. Rockfall source areas are shown but the maximum downslope extent of the hazardous areas are not. According to C.V. Nelson (oral commun., 1988) three county geologists plan to identify such areas using a computer-simulated model program.

FIGURE 7 Page AA-53

Although frequency of rockfall occurrence is not shown on the map, the text contains a table of historic rockfalls and a conclusion based on Keefer (1984) that reads:

> Widespread damage could occur in the Central Wasatch Front area if an earthquake of magnitude 7.0-7.5 should occur. Some of

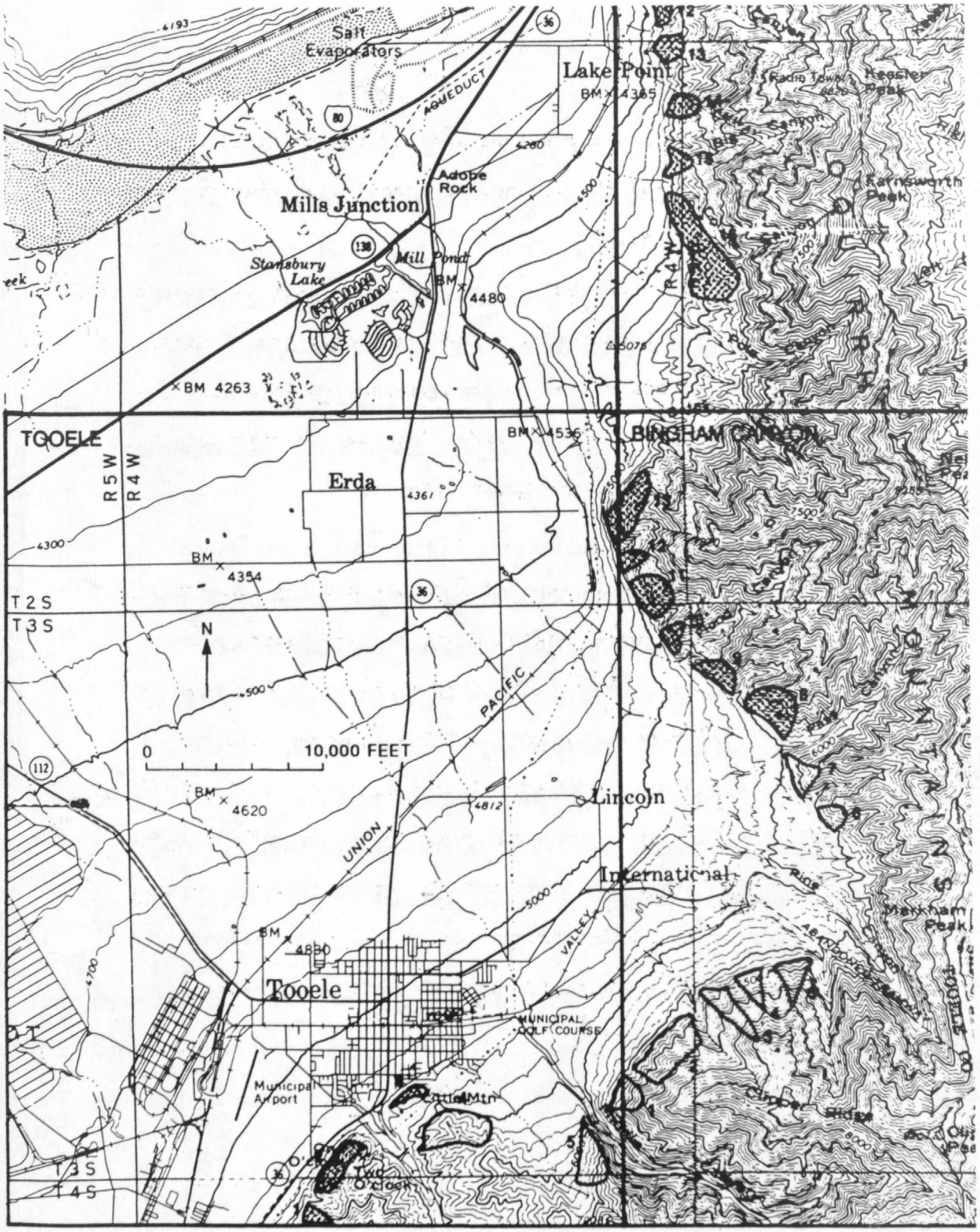

FIGURE 7. -- Part of a topographic map (original scale 1:100,000) of Salt Lake and Tooele counties unon which Case (1987, p. V11) shows mountain spur areas susceptible to rockfalls. Those areas with a rockfall hazard are stippled. Numbers within each USGS 7½-minute quadrangle are referred to in his text.

that damage would be due to thousands of rockfalls that would be the result of ground shaking during the event and aftershocks greater than magnitude 4. The Borah Peak and Hebgen Lake earthquakes are examples of such earthquakes that can be reasonably expected in the future somewhere along the Wasatch Front.

W.F. Case (written commun., 1988) makes the frequency of occurrence quite clear:

> Ground shaking during an earthquake can produce hundreds to thousands of rockfalls over an area of several thousand square kilometers. They are initiated by nearby earthquakes of magnitudes as low as 4. Aftershocks of large earthquakes will continue to produce rockfalls after the main shock, particularly if outcrops were loosened by the main shock. A "characteristic" (magnitude 7-7.5) earthquake anywhere in the Wasatch Front will trigger rockfalls throughout the entire Wasatch Front.

He describes the purpose of his mapping project: to "red-flag" hazardous rockfall areas that need site-specific studies. He then points out that such studies would require additional translation before use by community planners.

Tectonic Subsidence

Keaton (1987) has prepared a report and map on potential consequences of earthquake-induced regional tectonic subsidence. The area covered includes the Great Salt Lake and vicinity from Salt Lake City to Brigham City along the Wasatch Front, Provo and vicinity, and Juab Valley north of Nephi. The base maps used are USGS maps (1:100,000 and 1:125,000 scales)

showing topography. See figure 8.

FIGURE 8 Page AA-56

The location of effects of two earthquake events are shown on the maps: (1) the predicted subsidence that would accompany a "characteristic" Wasatch earthquake of moment magnitude 7.1, and (2) the observed subsidence that accompanied the 1959 Hebgen Lake, Montana, surface wave magnitude 7.5 earthquake. In the report, Keaton (1987, p. 19) restates earthquake occurrence as the "Wasatch fault is ... considered to be capable of generating earthquakes in the range of local magnitude ... 7.5" and "subsidence should be expected to accompany major earthquakes."

Severity is shown on the map by contour lines of subsidence in five-foot increments, by areas of potential ponding, and by areas of potential lake-margin flooding. In addition, the locations of sewage-treatment plants are shown along with directions and amount of tilt. Relatively slight change in hydraulic gradients at plants, outfalls, or other major drain lines will interrupt gravity flows. Such interruptions may cause ponding of sewage and health hazards.

The text contains general discussions of the effects of subsidence on several critical facilities -- transportation, oil refineries, and wastewater treatment plants. Similar critical facilities are likely to be interrupted by the same event reducing system backup and redundancy.

Dam Failure

McCann and Boissonnade (1985) assessed the impact of shaking on the Pineview Dam and its failure on portions of the city of Ogden. The base map used is a USGS 7½-minute quadrangle which has been reduced to a scale

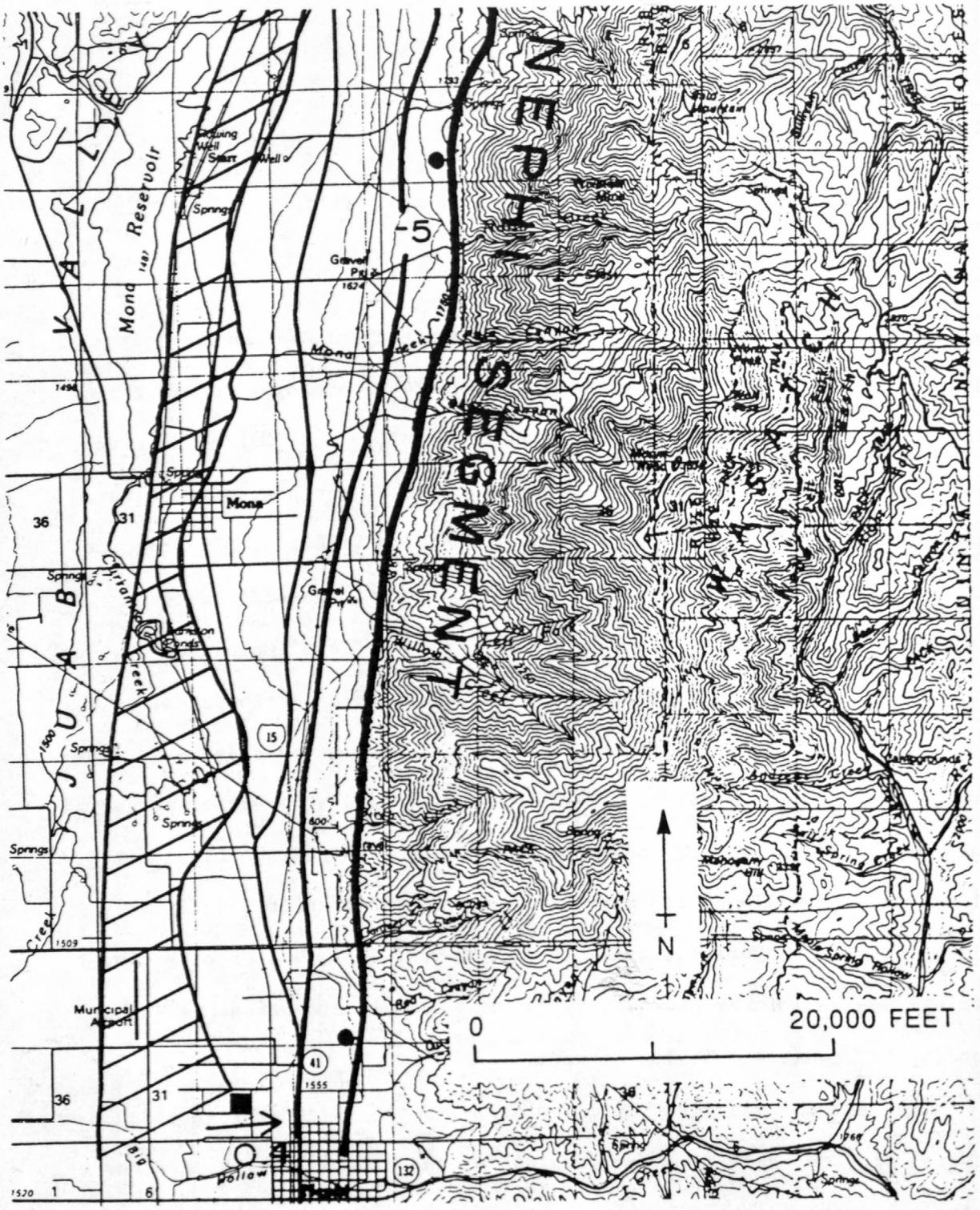

FIGURE 8. -- Part of a topographic map (original scale 1:100,000) of northern Juab Valley, Utah, upon which Keaton (1987, pl. 6) shows potential consequences of tectonic deformation along the Nephi segment of the Wasatch fault. Fault trace is indicated by a heavy line and contours of subsidence in ft by a less heavy line. Cross-hatched area indicates potential ponding of shallow (less than 3 ft) groundwater due to subsidence. Solid square indicates the location of a sewage treatment plant with direction and amount of anticipated tilt (ft/mi) shown.

of 1:48,000. A design earthquake of Richter magnitude 7.5 with an epicenter in downtown Ogden is assumed. Several feet of vertical offset along the 31.5 mi of fault rupture is estimated. Ground acceleration in the range of 50 to 80 percent of gravity at the dam site is estimated. Since the Pineview dam is only 6 mi from the fault trace, they assumed (p. 5-1) that the ground motion exceeds the design basis of the dam and failure occurs.

In the event that Pineview Dam fails, the breach of the dam will release the reservoir. The boundaries of the inundated parts of Ogden for a filled reservoir are shown on a map (fig. 9) with peak flood depths. The flood wave is expected to travel with velocities as high as 20 mph. As part of the study, damage to commercial and residential buildings from the design earthquake and flooding that results from the dam failure is assessed. In addition, casualties from both the earthquake and the dam failure are also estimated.

FIGURE 9 Page AA-58

Even though likelihood, location, and severity are given for the inundation hazard, the example is one of a failure and damage scenario only for the purposes of emergency management planning. McCann and Boissonade (1985, p. 3-2) are careful to point out that "no speculation is made concerning the likelihood that the consequences evaluated ... could occur."

This example is one of the uses of translated research for the purpose of assessing the impact of a secondary hazard (dam failure) as well as earthquake shaking. All dams impounding greater than 20 acre-ft

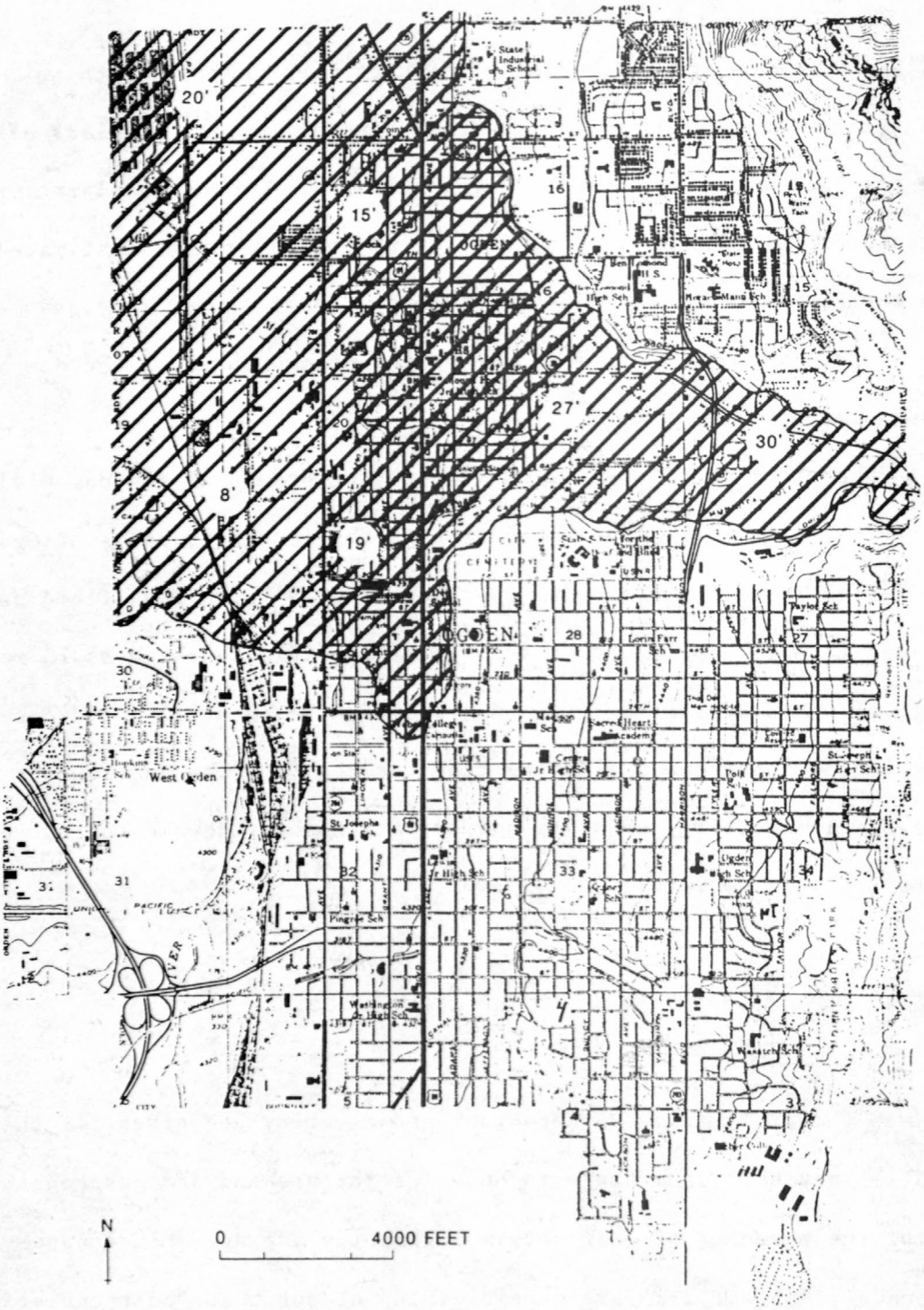

FIGURE 9. -- Topographic map (original scale 1: 48,000) of Ogden/Pineview, Utah, study area upon which McCann and Boissonnade (1985, fig. 3-4a, p. 3-27) show inundation area from a failure of Pineview Dam. Numbers indicate peak flood depths in ft.

of water, and all dams for which dam-failure inundation studies have been completed in Utah have been compiled by Harty and Christenson (1988).

Comment

In all of these Utah examples, the three elements -- likelihood, location, and severity -- may be found, although various scales, parameters, and formats are used. Some require further translation for the nontechnical user. If these examples are easy to understand and use, it means that the researchers/authors are meeting major goals of the Utah work plan.

In some cases, the translators have taken the opportunity to include discussions or illustrations of past casualties or damage. Some include recommendations concerning use of their work for hazard reduction. In other cases, county geologists are transferring this information by providing guidelines for use of the translated information: for debris flows and liquefaction (Lowe, this volume (ck.)); surface fault rupture and tectonic subsidence (Robison, 1988a, b); landslides (Robison, this volume (ck.)); rockfalls (Nelson, this volume (ck.)) and other geologic hazards (Lowe and Eagan, 1987).

Often the simplicity of format and ease of use misleads users to believe that the translated products are easy to produce. A familiarity with the references cited in each report will remind the reader that numerous geologic, geophysical, and engineering studies over many years along with many innovative and creative ideas were necessary to produce these examples.

According to C.V. Nelson (oral commun., 1988), the county geologists and others are performing additional studies or compilations which will result in translated information. For example, nonearthquake-induced

landslide potential information will be combined with the earthquake-induced landslide potential map prepared by Keaton and others (1987) to produce a composite landslide-hazards evaluation. A text has also been prepared discussing other hazards such as failure in sensitive clays, seiches, subsidence in granular materials, and hydrologic changes (Lowe, this volume (ck.)). Emmi (this volume (ck.)) has created maps showing the ground shaking hazard of Salt Lake County using Modified Mercalli intensity scales.

TRANSFER TO NONTECHNICAL USERS

The objective of transferring hazard information is to ensure its use in reducing losses from future earthquakes. Translated hazard information is a prerequisite for transfer to nontechnical users. Its objective has been previously described as: making the users aware that a hazard exists; providing them with information that they can easily present to their superiors, clients, or constituents; and providing them with materials that can be directly used in a reduction technique (List 2). The Utah work plan is quite specific as to what is expected of transfer activities:

- foster the creation and implementation of hazard-reduction measures ....
- ... users will have easy access to data ....
- ... information is released promptly.
- ... most effective educational, advisory, and review services appropriate to the targeted users.
- ... both its transfer and its effective use for hazard reduction.

Definition

Various terms are used to convey "transfer" of information to users, namely, disseminate, communicate, circulate, promulgate, and distribute. Often these terms are interpreted conservatively, for example, merely issuing a press release on hazards or distributing research information to potential users. This level of activity cannot be expected to result in effective hazard reduction techniques or even to make users aware of the hazard.

According to Slovic (1986), communicators must appreciate the limitations of public understanding, namely: 1) people's perceptions are often inaccurate; 2) risk information may frighten and frustrate the pub-

lic; 3) strong beliefs are hard to modify; and 4) naive views are easily manipulated by the format used to present other perspectives. He then suggests that research is needed in the areas of informed consent, information relevance, perceived risk, and the use of the media. Sorensen and Mileti (1987) provide an excellent discussion on the dilemmas of perception, the warning response process, the determinants of senders and receivers, the personalizing of warnings, and the nonbehavioral aspects of response.

No clear concise definition of, or criteria for, "transfer" has been offered, or can be found in the literature except by inference or by analysis of what actually works for those who have developed and adopted reduction techniques. Therefore, I suggest that we use "transfer" to mean the delivery of a translated product in a usable format at a scale appropriate to its use by a specific person or group "interested" in, or responsible for, reducing hazards. To delivery of a product, we must add assistance and encouragement in its use; in other words, an active ongoing learning experience!

This definition of "transfer" is somewhat analogous to the passing of a football or baton. Assume that the football or baton is understandable and in a usable format. Once the hand-off or passing has taken place, the receiver (for various reasons) may not run, win the race, or otherwise act appropriately.

It is the same with a receiver of earthquake-hazard information. The information alone without action will not reduce casualties, damages, and interruptions. Obviously, something else is needed. My experience indicates that effective transfer must include <u>not only delivery but assistance and encouragement</u> in the selection and adoption of an appropri-

ate reduction technique. Only then have the researchers, translators, and transfer agents fulfilled their professional obligation.

Transfer Techniques

Such delivery, assistance, and encouragement can be accomplished through specific transfer techniques which may be categorized into educational, advisory, and review services (list 4). These services were identified and tested by me during the 1960s, successfully used by the Southeastern Wisconsin Regional Planning Commission (1968, 1987), incorporated into the overall program design for the New Mexico State Planning Office (Kockelman, 1970, p. 34-41), brought to the attention of the USGS (Kockelman, 1976a), and incorporated into its national landslide-hazard-reduction program (U.S. Geological Survey, 1982, p. 34, 37-47). In addition, these services are provided by some of the USGS's scientists, engineers, planners, and others as a personal commitment or under various earth-sciences application and public information programs. The remarkable effort in Utah to provide these services can be seen in the following section.

LIST 4 Page AA-64

Educational services range from merely announcing the availability of earthquake-hazard information, through the publishing and distributing of newsletters and brochures, to sponsoring, conducting, or participating in seminars and workshops for potential users.

Advisory services range from explaining or interpreting earthquake-hazard reports and maps, through publishing guidebooks and assisting in the design of regulations based upon the information, to giving expert

List 4

Examples of Techniques for Transferring Hazard Information

Educational services

Providing serial and other types of publications reporting on hazard research underway, reduction techniques in process, and the adoption and enforcement of reduction techniques.

Assisting and cooperating with universities, their extension divisions, and other schools in the preparation of course outlines, detailed lectures, casebooks, and audio or visual materials.

Contacting speakers and participating as lecturers in state and community educational programs related to the use of hazard information.

Sponsoring, conducting, and participating in topical and areal seminars, conferences, workshops, short courses, technology utilization sessions, cluster meetings, innovative transfer meetings, training symposia, and other discussions with user groups.

Releasing information needed to address critical hazards early through oral briefings, newsletters, seminars, map-type "interpretive inventories," open-file reports, reports of cooperative agencies, and "official use only" materials.

Sponsoring or cosponsoring conferences or workshops for planners, engineers, and decisionmakers at which the results of hazard studies are displayed and reported on to users.

Providing speakers to government, civic, corporate, church, and citizen

groups, and participating in radio and television programs to explain or report on hazard reduction programs and techniques.

Assisting and cooperating with state and community groups whose intention it is to incorporate hazard information into school curricula.

Preparing and exhibiting displays that present hazard information and illustrate their use for hazard reduction.

Guiding field trips to disaster areas, damaged structures, and potentially hazardous sites.

Preparing and distributing brochures, TV spots, films, kits, and other visual materials to the news media and other users.

Operating public inquiries offices, sales offices, and clearinghouses.

Advisory services

Preparing annotated and indexed bibliographies of hazard information and providing lists of pertinent reference material to users.

Assisting local, state, and federal agencies in designing policies, procedures, ordinances, statutes, and regulations that are based on, cite, or make other use of hazard information.

Providing explanations of hazard information and reduction techniques during public hearings.

Assisting local, state, and federal agencies in the design of their hazard information collection and interpretation programs and in their work specifications.

List 4 (continued)

Examples of Techniques for Transferring Hazard Information

Providing expert testimony and depositions concerning hazard research information and its use in reduction techniques.

Assisting in the presentation and adoption of plans and plan implementation devices that are based upon hazard information.

Assisting in the incorporation of hazard information into local, state, and federal studies and plans.

Preparing brief fact sheets or transmittal letters about hazard products explaining their impact on, value to, and most appropriate use by local, state, and federal planning and development agencies.

Assisting users in the creation, organization, staffing, and formation of local, state, and federal planning and plan implementation programs so as to ensure the proper and timely use of hazard information.

Preparing and distributing appropriate guidelines and guidebooks relating to natural-hazards processes, mapping, and reduction techniques.

Preparing models for state safety legislation, regulations, and development policies.

Preparing models for local safety policies, safety plan criteria, and hazard reduction techniques.

Advising on and providing examples of the methods or criteria for hazard identification, vulnerability assessments, hazard reduction, and emergency management.

Review services

List 4 (continued)

Examples of Techniques for Transferring Hazard Information

Reviewing proposed programs designed for collecting and interpreting hazard information.

Reviewing local, state, and federal policies, administrative procedures, and legislative analyses that relate to assessing and reducing hazards.

Reviewing studies and plans that are based on, cite, or otherwise use hazard information.

Reviewing proposed regulations, policies, and procedures that incorporate or cite hazard information.

testimony and depositions concerning the information.

Review services include review and comment on policies, procedures, studies, plans, statutes, ordinances, or other regulations, that are based upon, cite, interpret, or apply earthquake-hazard information.

The educational and advisory services should not supplant existing programs or activities of educational institutions, or replace services of private consulting firms or state and local organizations; instead they should supplement them!

The importance of educational and advisory services to accomplish delivery, assistance, and encouragement is obvious. The importance of review services is less obvious. When hazard information is used in a regulatory technique that affects land use and property values, it is eventually challenged in a courtroom or other public forum. At that time the researcher is requested or subpoenaed to explain (or confirm the proper use of) his or her research information.

If the researcher hasn't been given the opportunity to review its use and the opportunity to correct its potential misuse, the regulation will lose validity, the researcher embarrassed, and the user chagrined. It is foolish not to review when the effort to review is compared with the time and scarce resources needed to perform the required scientific and engineering studies (list 1), to translate and transfer them, and to prepare, adopt, and enforce a reduction technique (list 2).

Multiple ways of imparting information should be encouraged. A single exposure to new information, especially if the information is complex or differs from a user's previous knowledge, is often insufficient. Repeated exposure in different formats and through different conduits is needed. This strategy is particularly successful

when new information is provided by persons who are customarily looked to for guidance, such as members of the same professional group. The most effective transfer techniques (list 4) should be selected jointly (if possible) by the translator, transfer agent, and user.

Most public hearings or presentations to decisionmakers allow little time, and the transfer agent is competing with numerous other issues. The most concise, simplest translation and transfer techniques are the most successful. One of USGS's senior scientists (A.H. Lachenbruch, written commun., 1981) with experience in successfully transferring research information to Congress as well as local decisionmakers observed: "Simple maps with a few bright colors are needed ...." Obviously such maps must be derived from larger scale and more detailed information which, if needed to meet a challenge, is readily available.

Transfer Agents

For the purposes of this report, the term "transfer agents" is defined as those who deliver translated research information to potential users and assist and encourage them in selecting and adopting appropriate hazard reduction techniques. In his final report on the County Hazards Geologist Program, Christenson (1988, p. 3) identifies several options for transferring geologic expertise to local governments, namely:

- Permanent, full-time city or county geologist.
- Circuit-rider geologist serving several governments simultaneously.
- Geologist employed by an umbrella agency (regional association of governments, state survey) but dedicated to serving local governments.
- Private consulting geologist on retainer or other under contract with local government.

It should be noted that consultants under contract with a local government may have the appearance of a "conflict-of-interest" if they represent parties other than the local government within its jurisdiction.

Potential transfer agents of earthquake-hazard information in Utah are given in list 5. Many of the users in list 3 will also be transferring such information. Bates (1979, p. 11) notes that: "although both the use of transfer agents and the education of planners in the earth sciences, ... are increasingly important components of the information-transfer system, nothing replaces intensive producer-user interaction ...."

LIST 5 Page AA-71

Of course, geologists, seismologists, and other earthquake researchers may be available to provide some of the educational, advisory, and review services, but to rely solely or heavily on these skilled and scarce resources is unreasonable and would divert them from their work of understanding the process, assessing the hazard, and translating their research.

The role of professional associations -- planners, engineers, geographers, and geologists -- should be emphasized. For example, Petak (1984, p. 457) points out that "hazard and risk assessment must be ... fully supported by the efforts of the geotechnical profession." The professions can not only contribute to identifying user needs, translating and transferring complex information, and fostering an environment for use, but are principal users themselves. The Yin and Andranovich (1987) study on getting research used in the natural-hazard field concluded that

List 5

Potential transfer agents for earthquake-hazard information in Utah

American Planning Association, Utah Chapter

American Society of Civil Engineers, Utah Section

American Society of Public Administrators, Utah Chapter

Association of Engineering Geologists, Utah Section

Bear River Association of Governments

Children's Museum

Church groups, church organizations, and church leaders

Civic and voluntary groups

Consultants (engineers, planners, geologists, and others)

County geologists and extension agents

Educators (university, college, secondary, and elementary)

Governor's Advisory Council on Local Governments

Hansen Planetarium

International Conference of Building Officials, Utah Chapter

League of Women Voters

Local building, engineering, zoning, and safety departments

Local seismic safety advisory groups

Media (journalists, commentators, editors, and feature writers)

Mountainlands Association of Governments

Neighborhood associations

List 5 (continued)

Potential transfer agents for earthquake-hazard information in Utah

Public information offices

Relief Society, Church of Jesus Christ and Latter-day Saints

Researchers, engineers, and planners (local, state, and federal)

Society of American Foresters, Wasatch Front Chapter

Southeastern Utah Association of Governments

Speakers' bureaus (state, local, or project area)

Structural Engineering Board, Church of Jesus Christ and Latter-day Saints

University of Utah Seismograph Stations

Utah Association of Counties

Utah Division of Comprehensive Emergency Management

Utah Department of Social Services

Utah Geological Association

Utah Geological and Mineral Survey

Utah League of Cities and Towns

Utah Museum of Natural History

U.S. Forest Service

U.S. Geological Survey

U.S. Soil Conservation Service

Wasatch Front Regional Council

Western Governors' Policy Office

the role of professional associations "is a diffuse model, in which multiple sources of ideas are mixed with multiple types of users ...." Transfer agents should solicit and use the expertise of those members of the sociological community who are trained and experienced in reducing natural hazards.

Examples of successful transfer agents and their transfer programs follow:

- Circuit-rider geologist in the State of Washington (Thorsen, 1981).
- Planning, reviewing, and enforcing by city and county geologists (McCalpin, 1985; Christenson, 1988).
- Advisory services unit of the California Division of Mines and Geology (Amimoto, 1980).
- Educational, advisory and review services by the Southeastern Wisconsin Regional Planning Commission (1968, 1987).
- Earth-science information dissemination activities of the U.S. Geological Survey (Information Systems Council's Task Force on Long-range Goals for USGS's Information Dissemination, 1987).
- Earthquake-hazard reduction activities of the staff, members, and committees of the California Seismic Safety Commission (1986).

Successful Transfer

One of the best ways to determine which transfer techniques are effective is to closely look at techniques that have been used and which have resulted in the reduction of natural hazards. For over 25 years, a midwestern multicounty planning commission has transferred geologic, hydrologic, and pedologic hazard information to public and private users. The annual project completion report by the Southeastern Wisconsin Regional Planning Commission (1968) shows that almost every educational,

educational, advisory, and review service in list 4 was repeatedly used.

Many other examples of the transfer techniques shown in list 4 including their transfer agents can be cited. Selected examples follow:

- Earthquake-hazard reduction series by the Federal Emergency Management Agency (1985-1988).
- Home guide section on how a house withstands an earthquake in the Chicago Tribune by Kerch (1988).
- Guidebook on reducing earthquake risks for planners by Jaffe and others (1981).
- Isoseismal map users guide by the Central United State Earthquake Consortium (1987).
- Canoe trip to view evidence of probable magnitude 8 or 9 earthquake in the Pacific Northwest by Atwater (1988).
- Introduction to geologic and hydrologic hazards in the United States by Hays (1981).
- Using earth-science information for earthquake-hazard reduction in the Los Angeles region by Kockelman (1985).
- Guidelines for preparing a safety element of the city and county general plan by a governor's office of planning and research (Mintier, 1987, p. 146-153).
- Case studies on strengthening hazardous buildings by the San Francisco Bay Area Regional Earthquake Preparedness Project (1988).
- Guidebook for disaster mitigation for planners, policymakers, and communities by Lohman and others (1988).
- Guidebook on identifying and mitigating seismic hazards in buildings including a model ordinance for rehabilitating masonry buildings by the California Seismic Safety Commission (1987).

- Guidebook on seismic safety and land use planning by Blair and Spangle (1979).
- Handbook on land-use planning for earthquake-hazard mitigation for planners by Bolton and others (1986).
- Analyzing and portraying geologic and cartographic information for land-use planning, emergency response, and decisionmaking in San Mateo County, California, by Brabb (1987).
- Getting ready for a big quake in Sunset Magazine by Lane Publishing Company (1982).
- Landslide-hazard mitigation plan for Colorado by Jochim and others (1988).
- Trail signs describing the 1959 Hebgen Lake earthquake-triggered landslides and vertical displacement along the fault in the Gallatin National Forest, Montana, by the U.S. Forest Service.
- Workshop on the evaluation of regional and urban earthquake hazard and risk in Alaska convened by Hays and Gori (1986).
- Periodical on earthquakes and volcanoes (formerly Earthquake Information Bulletin) by the U.S. Geological Survey (Spall, 1975 to present).
- Bibliography and index to seismic hazards of western Washington from 1855 to 1988 compiled by Manson (1988).
- Review of state landslide-hazard maps by USGS physical scientist W.M. Brown (written commun., 1985).
- Peace of mind in earthquake country -- How to save your home and life by Yanev (1974).
- Selected annotated bibliography of recent publications concerning natural hazards by Morton (1986).

- Washington state earthquake hazards by Noson and others (1988).
- Pilot earthquake education projects in Arkansas, Tennessee, Mississippi, Washington, and South Carolina (Bolton and Olson, 1987b, app. B).
- Steps to earthquake safety for local governments by Mader and Blair-Tyler (1988).

Comment

Many researchers provide educational, advisory, and review services on a limited and informal basis. Federal, state, and university scientists are frequently called upon to assist users. Such services should be formally recognized and included as a work element in any earthquake-hazard reduction program as was done in the Utah work plan.

Many of these services are provided in Utah through cooperative agreements, serial publications, report and map-sales offices, geologic-inquiries staff, public inquiries offices, professional groups, local and State geologists, municipal planners and engineers, and ordinary day-to-day contacts with the public by the researchers and translators of earthquake-hazard information. Specific examples from Utah are given in the following section.

The reader familiar with the successful transfer agents, programs, and techniques cited here will note that they accomplished the following:

- Delivered the information to those who are interested or required to use it.
- Conveyed the hazard in such a way as to result in the users' awareness.
- Provided the user with a wide selection of reduction techniques.
- Suggested a strategy for using the hazard information in a reduction technique through examples.

It is my experience that educational, advisory, and review services must accompany any successful earthquake research, hazard assessment, translation, and transfer program designed for planners, engineers, and decisionmakers.

Several benefits accrue to the transfer agents and those researchers and translators involved in transfer activities. These benefits include:

- Satisfaction that they have discharged their professional obligations and the "ball is now in another court."
- Sense of accomplishment when community safety is improved.
- Perception of how local, state, and corporate decisions are made.
- Awareness of where and how they can now make a civic contribution to encourage appropriate decisions.

EXAMPLES OF SUCCESSFUL TRANSFER IN UTAH

A remarkable effort is being made in Utah to transfer earthquake-hazard information to nontechnical users including real estate salespersons, financial institutions, and church groups. For example, in June 1985 three county geologists began providing educational, advisory and review services to five counties -- Weber-Davis, Salt Lake, and Utah-Juab. They were funded by USGS with other support being provided by the UGMS and the five counties. Financial support by local governments for 1989 is an indication of the success of this type of transfer program.

According to Christenson and others (1987, p. 4), the goals of the county hazards geologist program are to:

- Compile geologic-hazards information and produce maps to be used to delineate hazard areas where site-specific reports should be required.
- Review engineering geologic reports.
- Advise planners regarding hazards ordinances.
- Provide geologic expertise as required.

These geologists are a part of the county planning departments under direct supervision of the planning director; the UGMS provides technical supervision and other support as needed. The geologists are also available to perform the same services to the cities within their county. Some of the services provided over just a six-month period may be seen in the excerpt from the report shown in figure 10. A final report on their data collection, hazards mapping, ordinance reviews, and many other accomplishments has been prepared by Christenson (1988, p. 5-9; this volume (ck.)).

FIGURE 10 NEXT PAGE

Phase II (year 2) -- Wasatch Front County Hazards Geologist Program

Date: June 7, 1987
Grant No. 14-08-0001-G991
Grantee: Utah Geological and Mineral Survey
Don Mabey (principal investigator)
Title: Wasatch Front County Hazards Geologist Program
Grant effective date: February 7, 1985
Grant expiration date: June 7, 1988
Period covered by report: December 7, 1986-June 7, 1987

This report covers the six-month period from December 7, 1986, to June 7, 1987, completing the second year of this three-year program. Phase I (data collection and compilation) and Phase II (basic data map compilation) are complete or nearly complete, and Phase III (preparation of interpretive or translated maps and text) is about to begin. In February, the UGMS and county geologists met with planning directors and others from each county .... All planning directors indicated firm support for the program and will include the geologists in their budgets for 1988. The principal need now is to convey the importance of the program to the county commissions who must approve the budgets. To do this, special presentations and field trips for commissioners and others are planned for June 1987. Also, the UGMS is planning to devote an issue of its quarterly publication, Survey Notes, to the county geologist program, with copies going to commissioners, mayors, and others involved in the decisionmaking. Final budgets must be approved in December 1987, at which time we will know whether or not the counties have decided to maintain the geologists.

Services provided to cities and counties during this report period include aid in developing ordinances, reviews of engineering geologic reports, and memos to planners and developers indicating potential hazards at proposed developments requiring geologic investigations. Major special projects have included preparation of: 1) a gravel resource assessment for county property in Davis County, 2) a surface fault rupture hazard study for a proposed Provo City landfill in Utah County, 5) a review of a proposed county fire station site along the Wasatch fault in Salt Lake County, 6) the engineering geologic section for the Pineview Reservoir Clean Lakes study to control development near the lakeshore to avoid contamination, Weber County, 7) a geologic hazards evaluation of property owned by Payson City proposed for development in Utah County, and 8) an engineering geologic report regarding geologic hazards, slope stability, and potential for ground-water contamination at the North Davis Refuse Dump and new burn plant in Davis County. The county geologists and UGMS have also given talks to various civic groups and governmental organizations, participated in radio talk shows, and been involved in a variety of technical and policy publications ... related to the program.

FIGURE 10. -- Part of a final performance report on educational, advisory, and review services over a six-month period prepared by G.E. Christenson (written commun., 1987). These types of services are identified in list 4.

Much of their work is directed toward reduction techniques (list 2) and therefore is not discussed in this section on transfer techniques. According to county geologist Mike Lowe (unpubl. speech, 1986), examples of such work include the site investigation and hazard evaluation for South Weber City, city of Washington Terrace, city of North Salt Lake, Emigration Canyon (Salt Lake County), and the Lake Mountain and Pine Flat areas (Utah County).

Several Federal, State, and county planners, geologists, and emergency managers identified the "provision of education, advisory, and review services" as one of their most significant accomplishments to date (Christenson and others, 1987, p. 84). Examples of some of the transfer techniques used in Utah follow. Each one can be categorized as an educational, advisory, or review service, or a combination of two or all of the services. In most cases, the transfer agents are not only delivering translated information as defined and illustrated in previous sections of this paper but are assisting and encouraging its use for hazard reduction.

Workshops

During the period from 1984 to 1988, six workshops were held in Utah on assessing and reducing earthquake hazards, two of them in 1985. A field trip followed the one in 1986 and preliminary reports for a professional paper (previous volume (ck.)) were released at the one held in 1987. Each workshop fulfilled a commitment made in 1983 to bring key researchers and users of hazard information together each year for the purpose of providing current information on the earthquake hazard, distributing translated reports and maps, describing how they can be used, and fostering an environment for use of the information for hazard

reduction.

Each workshop had various sponsors including the University of Utah, Utah Geological and Mineral Survey (UGMS), State of Utah Division of Comprehensive Emergency Management (CEM), FEMA, and USGS. Five were attended by as many as 130 earth-scientists, engineers, planners, and emergency managers. One attended by over 400 persons addressed multihazards and comprehensive hazard reduction (May, 1988). An example of some of the topics addressed and reports made at one of these workshops may be seen in figure 11. The proceedings of two of the workshops were edited by Hays and Gori (1984, 1987) and published as open-file reports to ensure early release and delivery. The UGMS compiles examples of interim maps and reports available and uses the workshops as an opportunity to distribute them.

FIGURE 11 PAGE AA-82

Serial Publications

Several serial reports designed to transfer earthquake-hazard information in Utah to nontechnical persons were continued or begun during the past five years. The attractive easy-to-read Survey Notes (fig. 12) is published quarterly by the UGMS (Stringfellow, 1983 to present). It features excellent articles such as the historic and scientific content of earthquake hazards in Utah by Mabey (1985). It reports on UGMS information programs (Smith, 1985a), earthquake activity recorded by the University of Utah Seismograph Stations, hiring of county geologists, new publications, and related activities of interest -- ongoing geologic projects, status of applied geology programs, personnel changes, and how

FOREWARD

Welcoming Remarks at the Workshop on "Earthquake Hazards Along the Wasatch Front": The Honorable Governor Norman H. Bangerter i

BACKGROUND INFORMATION AND SUMMARY OF THE WORKSHOP

Background and Summary of the Workshop on "Earthquake Hazards Along the Wasatch Front, Utah"
Walter Hays and Paula Gori
Introduction 1
1984 Workshop on "Evaluation of Regional and Urban Earthquake Hazards and Risk" 2
1985 Workshops on "Earthquake and Landslide Hazards" 3
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Awards 11
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EVALUATION

Observations on the 1986 Workshop
Peter May 43
Statement Prepared for Presentation to the House Subcommittee on Science Research and Technology, March 10, 1987
Don Mabey 46

REPORTS OF THE RESEARCH AND IMPLEMENTATION TRIADS

Tectonic Framework and Earthquake Potential of the Wasatch Front Area and other Parts of Utah
Michael Machette, Bill Lund, and Walter Arabasz 49
The Ground Shaking Hazard and Various Aspects of Loss Estimation in the Wasatch Front Region of Utah
Delbert Ward, Albert Rogers, and Robert Smith 60
Ground Failure, Rock Falls, and Tectonic Deformation in the Wasatch Front Area
Loren Anderson, T. Leslie Youd, and Earl Brabb 75
Collecting, Compiling, Translating, and Disseminating Earthquake-Hazards Information for Urban and Regional Planning and Development in the Wasatch Front Area, Utah
Gary Christenson, Jerold Barnes, Joseph Moore, Craig Nelson, Robert Robison, Mike Lowe, and William Kockelman 80
Development and Implementation of Loss-Reduction Measures in Utah
Genevieve Atwood, Lorayne Tempest, Gary Johnson and Jerome Olson 87
Integrating Scientific and Engineering Information into Earthquake-Resistant Design in Utah
Lawrence Reaveley, Delbert Ward, and Walter Hays 96

FIGURE 11. -- Part of the table of contents from a workshop proceedings edited by Hays and Gori (1987). This type of workshop is a good example of a successful transfer technique.

UGMS responds to disasters (Atwood, 1983).

FIGURE 12 PAGE AA-84

The Wasatch Front Forum was specially created for the earthquake-hazards program and is published and distributed quarterly by the UGMS (Hassibe 1983-86; Jarva 1987 to present). It features timely articles on neighboring earthquakes (Crone, 1984), prediction in the Wasatch Front (Smith and others, 1985), earthquake-induced soil liquefaction (Keaton, 1986), disruption of critical facilities (Frank, 1987), and earthquake preparedness projects (Tingey, 1986).

This newsletter also reports on the regional earthquake hazards assessment program (Hays, 1984), accomplishments of the ground shaking hazards and loss estimation program (Rogers and others, 1986), Utah County Comprehensive Hazard Mitigation Project (Dewsnup, 1987), progress of geologic, seismologic, and engineering research (Tarr, 1984), earthquake activities recorded by the University of Utah Seismograph Stations, and the results of surveys on the perceptions of risk by residents along the Wasatch Front. Notices of scheduled professional meetings, recent publications, out-of-state workshops of interest, new research programs, and reprints of timely articles such as Rogers (1986) are included on a regular basis. See figure 13.

FIGURE 13 PAGE AA-85

In addition, the Earthquake Information Bulletin (now Earthquakes and Volcanoes) (Spall, 1975 to present) written for nontechnical readers is

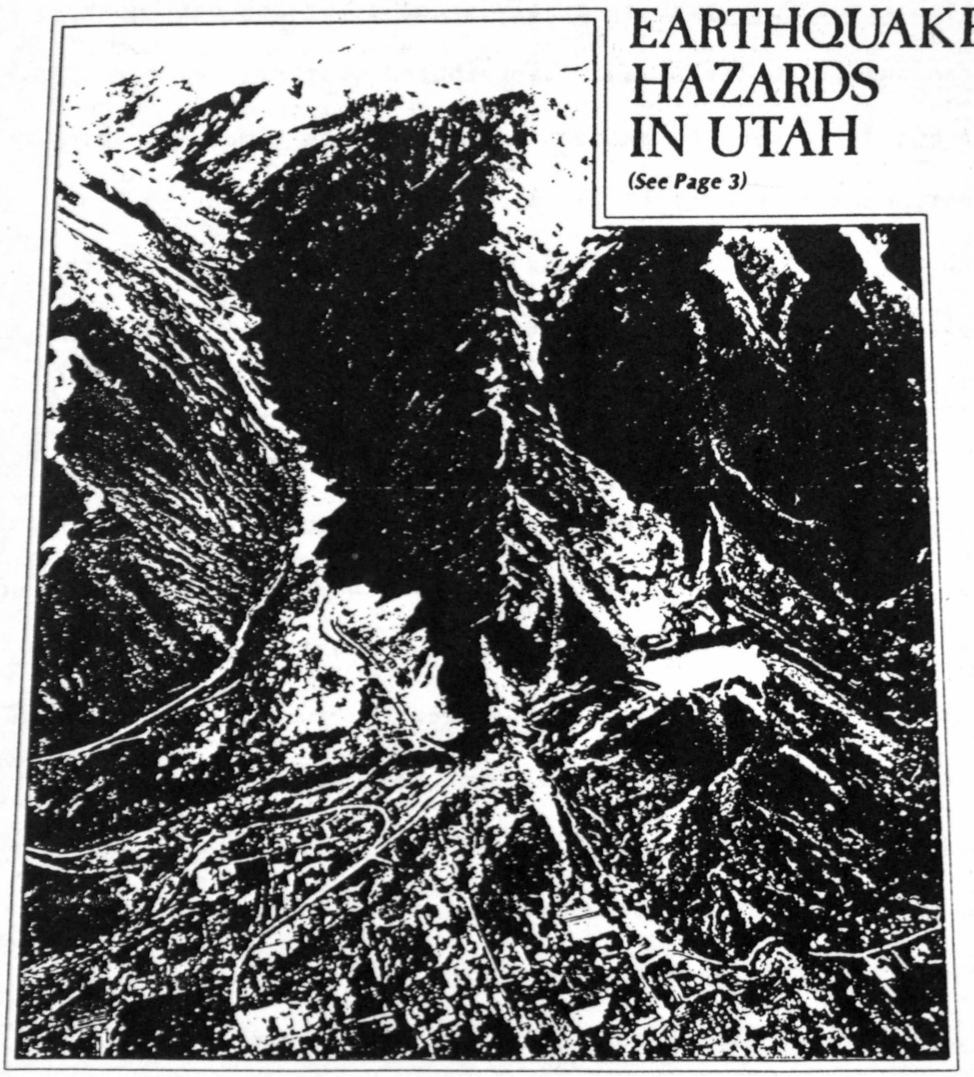
PUBLISHED QUARTERLY BY UTAH GEOLOGICAL AND MINERAL SURVEY

SURVEY NOTES

VOL. 18 NO. 4 SERVICE TO THE STATE OF UTAH WINTER 1985

EARTHQUAKE HAZARDS IN UTAH

(See Page 3)



Wasatch fault at the mouth of Little Cottonwood Canyon, Southeast of Salt Lake City. Latest movement on the fault here pre-dates historic record but the fault has displaced young Quaternary alluvium and glacial moraine probably during the last 1000 years. Photograph courtesy of Lloyd Cluff and George Brogan.

FIGURE 12. -- Typical cover of a serial publication which addresses geologic hazard and resource issues. This type of publication is an excellent example of an information transfer technique identified as an educational service in list 4.

COLLECTING, COMPILING, TRANSLATING, AND DISSEMINATING EARTHQUAKE-HAZARDS INFORMATION FOR URBAN AND REGIONAL PLANNING AND DEVELOPMENT IN THE WASATCH FRONT AREA, UTAH

By Gary Christenson, Jerold Barnes, Joseph Moore Craig Nelson, Robert Robison, Mike Lowe, William Kockelman

MOST SIGNIFICANT ACCOMPLISHMENTS

Much of the work planned under existing programs is in progress but will not be completed for one or two more years. Under the UGMS Wasatch Front County Geologists Program, a series of translated (interpretive) maps (1:100,000) depicting hazards along the Wasatch Front are planned along with a report describing these hazards. Collecting and indexing hazards information and providing technical assistance to planners are being emphasized under this program. Under the UGMS Applied Geology Program, statewide hazard maps (1:750,000) are being completed. Other projects emphasize specific hazards mapping, evaluation of reduction techniques, education, and information dissemination.

Some of the most significant accomplishments to date are:

- Education of planners and decisionmakers in the Wasatch Front area regarding earthquake hazards through meetings, workshops, and placement of geologists on planning staffs in five Wasatch Front counties.
- Creation of county hazard information libraries with ready access to existing hazards information in five county planning department offices.
- Quality control over geotechnical investigations, particularly seismic hazards studies, by providing geological review of reports submitted to local planning agencies.
- Compilation of liquefaction potential maps and reports for three counties.
- Increased communication between earthquake hazards investigators.
- Incorporation of the School Outreach Program into the Museum's overall program,staffing, and budget.
- Provision of educational, advisory, and review services to State and local units of government.

RECOMMENDATIONS AND PRIORITIES FOR THE NEXT TWO YEARS

Because technical and scientific information is a prerequisite for effective implementation, it is recommended that information collected during the first three years be made available for translation and dissemination. It is further recommended that emphasis during the remaining two years of the program be placed on implementation projects. Many of the projects that have been funded will extend into this period, but priority should be assigned to projects which:

- Continue the building excavation inspection program (UGMS staff)

- Continue the compiling of the statewide hazards bibliography (UGMS staff)

- Provide occurrence intervals and severity of various hazards to give planners and decisionmakers a basis for estimating risk (USGS staff and grantees)

- Provide State and local hazards susceptibility maps and reports (County geologists; UGMS staff)

- Develop guidelines for local governments to use in writing earthquake hazard ordinances(UGMS staff)

- Continue providing educational , advisory, and review services aimed at State and local planners and decisionmakers (UGMS staff; County geologists; CEM staff; Museum staff)

- Incorporate collecting, compiling, translating, and disseminating work into ongoing programs of State and local governments.

During the past two years, some additional needs have been identified; the following specific needs should be assigned priority:

- Developing model ordinances, which address earthquake hazards, for local governments

- Collecting examples of reduction techniques for each hazard, and evaluating them for effectiveness

.....

GROUND MOTION ELEMENTS

(from a presentation by Al Rogers at July, 1986 Workshop)

SOURCE

- SIGNIFICANT ACCOMPLISHMENTS

  > Revised segmentation of the Wasatch Front

  > New segmentation slip rates for some segments

  > Suggestion that slip rates are related to paleo-lake level

  > Discovery that some scarps in the Great Basin may be terminated by detachment faults at shallow depths

  > Successful testing of experimental high-frequency reflection techniques for studying Quaternary fault geometry and exploration for Quaternary faults.

  > Discovery of strike-slip faulting in both the geologic and seismic records for a portion of the Colorado Plateau-Basin and Range Transition Zone.

  > Borah Peak
  Reaffirmation of segmentation

- KNOWLEDGE REQUIRED

  > Continued segmentation studies and slip rate estimates

  > Continued studies of active fault geometry

  > Strong ground motion measurements in the vicinity of Great Basin earthquakes.

TRANSMISSION PATH

- SIGNIFICANT ACCOMPLISHMENTS

  > Revised peak acceleration and velocity curves for western Utah based on regression models and a world wide strong motion data set

  > High and Low Q versions

FIGURE 13. -- Typical article reporting on the status of the Utah earthquake-hazard reduction program in the Wasatch Front Forum (v. 2, no. 4, p. 5). This type of newsletter is a unique example of a transfer technique in Utah identified as an educational service in list 4.

published bimonthly by the USGS. It contains feature articles such as "Earthquake Potential of the Wasatch Front" (Spall, 1985), as well as reporting on earthquake activity by states and countries. Notices of state, national, and international workshops and conferences on earthquakes -- research, engineering, preparedness -- and recent publications are also included on a regular basis.

Outreach Programs

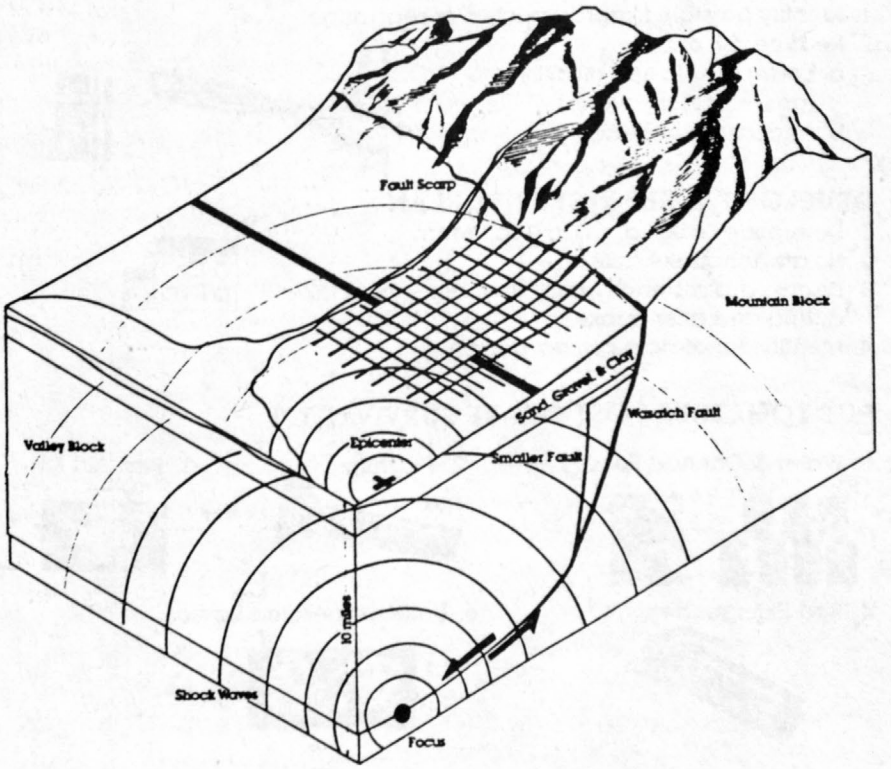
The Utah Museum of Natural History contributes to the geologic education of the general public through exhibits, classes, lecture series, film series, field trips, teaching kits, and teacher workshops. Since the fall of 1985, "Utah Geologic Hazards" has been a popular outreach program.

According to the Museum's earthquake safety instructor, Deedee O'Brien (written commun., 1988), the program has reached 3,000 students and adults for each of two school years (1985-86 and 1986-87). During the following year (1987-88), the outreach program was phased down in favor of training teachers to use the materials (fig. 14) and teach the information to their own classes. Three workshops were held in 1988 with instructors from the Museum, CEM, UGMS, and the University of Utah. Seventy-nine teachers from five Wasatch Front school districts completed the course. They may check out a teaching kit which includes a two-foot square model, cardboard fault blocks, 150 slides with text, and a packet of follow-up earthquake safety activities.

FIGURE 14 PAGE AA-87

In addition to the geologic hazards curriculum, Deedee O'Brien developed an earthquake-safety curriculum appropriate for kindergartens

EARTHQUAKE HAZARDS



A MAJOR EARTHQUAKE (UP TO M 7.5) COULD OCCUR ALONG THE WASATCH FAULT AT ANY TIME!

Such an earthquake could cause:

I. RUPTURE OF THE EARTH'S SURFACE—SCARP FORMATION

A. Distruction of buildings on the scarp
B. Breaking of utility lines that cross scarp
   (1) Disruption of gas, water, & electric services
   (2) Fire hazards
C. Flooding—shifting of the Great Salt Lake and Utah Lake

II. GROUND SHAKING

A. Damage to rigid manmade structures such as buildings, freeway overpasses, dams
B. Liquefaction—soil becomes quicksand, so cannot support buildings
C. Landslides, Rockfalls, Mudflows
D. Falling objects that cause injuries

FIGURE 14. -- Example of materials provided to students, teachers, and the general public under an outreach program by the Utah Museum of Natural History (1985). They are an innovative transfer technique identified as an educational service in list 4.

EARTHQUAKE SAFETY

I. BE PREPARED AHEAD OF TIME

A. EARTHQUAKE PROOF YOUR HOME

1. Identify possible hazards; anchor or rearrange.
2. Reduce risk of fire.
   a. Learn how to turn off utilities. (gas, electricity, water)
   b. Anchor water heater.



B. DEVELOP FAMILY RESPONSE PLAN

1. Determine "safe" areas in each room.
2. Hold earthquake drills.
3. Discuss actions each family member should take during and after quake.
4. Identify out-of-state contact person.



C. PUT TOGETHER POST-QUAKE SURVIVAL KIT

1. Water & Canned Food



2. Flashlight



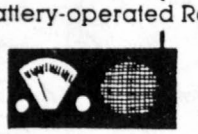
3. First-Aid Kit



4. Fire Extinguisher



5. Battery-operated Radio



II. KNOW WHAT TO DO DURING

A. Stay Calm!

B. DUCK & COVER.

1. If Inside, Stay There.
   Duck under table, or
   stand in door frame, or
   brace yourself in inside corner away from windows.



2. If Outside, Stay There.
   a. Move into open away from buildings & electric wires.
   b. Park car & stay inside until shaking stops.

III. RESPOND AFTERWARD

A. Administer first-aid.

B. Check for utility damage & turn off if necessary.

C. Use telephone only for medical emergency.

D. Be prepared for aftershocks.

FIGURE 14. (cont'd). -- Example of materials provided to students, teachers, and the general public under an outreach program by the Utah Museum of Natural History (1985). They are an innovative transfer technique identified as an educational service in list 4.

through third grades. This has been tested in approximately 30 classrooms and has been offered to teachers in two in-service workshops entitled "Earthquake Safety in the Elementary Classroom." Forty-eight teachers attended. These workshops were cosponsored by CEM. The museum continues to offer earthquake-safety in-service courses annually.

The Utah State Division of Comprehensive Emergency Management (CEM) has developed various hazards outreach programs which include educational and advisory services. A good example is an inexpensive booklet by Tingey (1989) which provides both an awareness of the earthquake hazard and suggested preparations to reduce the hazard. According to Tingey and Findlay (1987, p. T11; previous volume (ck.)), CEM has made many presentations and during one year alone distributed over 730,000 brochures on earthquake hazards and their reduction. One project completed in 1986 was the production of a television program (video format) which succinctly covered the earthquake hazard, risk, and safety concepts specific to the Wasatch Front. Near the end of the project, the local CBS affiliate, KSL Television, produced an excellent half-hour program ("Not If ... But When") which was shown twice, in response to public reaction, during January, 1987. The program won a regional Emmy Award out of 150 entrants from seven western states. Several copies of the video are being used to make presentations to school, church, business, and other interested groups.

Integrated into the video were results of the latest research work on fault surface expression, segmentation, rupture, and geometry; ground shaking and amplification; liquefaction; and loss estimates for postulated events. Translation of this research was performed by CEM, UGMS, scientific and public safety-oriented agencies, and the producer of the

video program. According to Tingey (1988, p. 102), the producer "had a terrific feel for the material" and was able to distill and translate complex ideas into concepts understandable by the nontechnical audience.

The Utah State Office of Education (Burningham, 1983) has produced an inexpensive, well-illustrated comprehensive booklet on natural hazards entitled "I can make the difference -- Emergency preparedness." In chapter 2 (p. 15-28), it addresses earthquake hazards through three personalized scenarios, questions and solutions, a quiz, and a word-hunt game.

The UGMS has provided one-page pass-out sheets for public use, for example, earthquake hazard situation, safety, and faulting in Utah by Kaliser (1984a-c). These sheets address scientific evidence, historic events, population exposed, past damages, expected magnitude, critical facilities vulnerability, retrofitting, topographic expressions, and other aspects of earthquake hazards and their reduction. Cogent, one-sentence "bullets" are used; see figure 15.

FIGURE 15 PAGE AA-91

The county geologists are continually providing various educational services. For example, as county employees, they are available to explain earthquake hazards and the techniques for reducing them to various county officials, staffs, and citizens. They have increased community awareness through a slide-lecture program presented to university students, community councils, civic groups, and other local government organizations such as the Ogden City Seismic Committee, citizens groups in Nephi and Provo (Lowe, personal commun., 1986), Salt Lake Board of Realtors, and



UTAH GEOLOGICAL AND MINERAL SURVEY
606 Black Hawk Way, Salt Lake City, Utah 84108



BUILDING OR BUYING A HOME IN UTAH

Prepared by Bruce N. Kaliser, Chief Engineering Geologist

BEFORE YOU BUY:

- Most geologic hazards such as landslides, floods, ground settling and aggravated earthquake ground motion can be avoided by proper site selection. Careful examination of sites during *initial* househunting searches can avoid costly water, wastewater, foundation and terrain stability problems later.

- Whether buying a vacant lot or existing structure, observe the property carefully and thoroughly. Look for: ground cracks • ground holes • disturbed earth • deposits of sediment or debris left by receding flood waters • signs of erosion • steep slopes, including on neighboring parcels • salt efflorescence on ground surface • surface depressions • wet ground • anomalous vegetation • cracked or disturbed foundations, walls, driveways, sidewalks • man-placed fill, engineered and non-engineered • water bodies or conveyances (canals, ditches) on or above the property • distribution of bedrock and/or boulders at ground surface.

  Interpretation of the significance of each of the above items must be done with caution; if any are present, professional advice should be sought.

  Be aware that operations such as landscaping and utility installation may alter the ground surface appearance to resemble or conceal a natural phenomenon.

  Modification of terrain in the vicinity of your parcel, either before you buy or after you build, particularly up-slope, may prove critical for you. Examples might include cutting into a slope, filling over a slope, drilling of an uncontrolled flowing well, diverting a spring, or installation of a deeply buried utility line.

  Ground surface observation normally is sufficient for the evaluation of a residential property; if there is doubt, one or more holes will need to be dug or drilled and soil samples taken to resolve difficult questions. *All* examinations for subsurface fluid waste disposal require percolation tests in the soil by Health Authorities.

  Ask questions of the realtor, homeowner, neighbors, but MOST IMPORTANT, conduct your own investigation, preferably with competent professional assistance (engineering geologist, geotechnical engineer).

- Consult State and Federal real estate and environmental documents for a broad statement of terrain conditions, but do not confine your examination of a particular parcel to the literature search.

WHEN YOU BUILD:

- Avoid constructing a home in the vicinity of moving earth, flood paths, fault traces or rock fall zones; do not build over underground openings or in depressions.

- Cost of construction, particularly in rural areas, can be reduced by knowing foundation conditions, depth to bedrock, depth to shallow groundwater, suitability of soils for wastewater disposal leach fields and groundwater depth and quality for primary or secondary water supply purposes.

- Adjust construction to accomodate these potential problems: moisture sensitive soils, high water table (shallow groundwater), low density soils, shallow bedrock or hardpan, severe earthquake ground-shaking zone, poor surface drainage, erosion-susceptible soil, steep or irregular topographic slope, boulders buried at shallow depth, springs or seeps on the property, variability of permeability of soils for fluid waste disposal.

- Maintenance problems can be reduced by prevention of erosion and soil movement under pavement, retaining walls and landscaping. Earth retention structures should all be properly engineered.

- Risk from earthquake to a single-family dwelling can be reduced by proper siting and construction.

Where you choose to build, even within a given parcel of land, can make a considerable difference.

FIGURE 15. -- Example of a general fact sheet widely distributed in Utah. It illustrates a common type of transfer technique identified as an educational service in list 4.

various community councils in Salt Lake County. The UGMS and the Utah County geologist conducted a class and field trip on geologic hazards for the 1988 annual education meeting of the Utah Chapter of the International Conference of Building Officials.

Field Trips

Field trips for both small and large groups have been conducted. A particularly comprehensive one-half day trip to selected geologic features and buildings in southern Davis and northern Salt Lake counties sponsored by UGMS and USGS was arranged and conducted by Keaton and Reavely (1986). Their well-illustrated text enhanced the opportunity for the nontechnical attendees to observe key geologic features and buildings in the metropolitan area.

Geologic features seen during the trip included surface evidence of movement along a fault plane, topographic scarps, and lateral spreads caused by earthquake-induced liquefaction. Vulnerable buildings visited included gravity-frame structures with masonry infill walls, potable water tanks straddling the Wasatch fault, sewage treatment plants subject to subsidence by tectonic deformation, and communications centers with little lateral force resistance. Seismic-resistant structures viewed included Salt Lake County Government Center buildings with concrete shear walls, braced and anchored brick-clad buildings, and the seismically-strengthened Veteran's Administration Hospital.

The three county geologists have conducted numerous field trips for their county commissioners, mayors, and other public officials to inform them of geologic hazards in their respective jurisdictions. The UGMS also conducts trips to trench sites for State and local government officials to inform them of research results and let them see the evidence first-hand.

News Media

The release of information and its subsequent publication and wide dissemination to television viewers, radio listeners, and newspaper readers is one of the most effective ways of delivering information about earthquake hazards to nontechnical users. A typical release by the USGS Public Affairs Office is shown in figure 16. Typical newspaper coverage is shown in figure 17.

FIGURES 16 AND 17 PAGES AA-94 and AA-95

According to Sprinkel (1988), UGMS, USGS, and CEM targeted the news media as an effective means to inform the public of the positive accomplishments of the earthquake program, and to raise public awareness of the potential threat earthquakes pose to Utahans. The news media are invited to all field trips, and nearly always attend. In addition, county geologists participate in local radio talk shows. The Utah Department of Natural Resources also performs much work to ensure good press coverage. Sprinkel observes that there is an eagerness by the Utah press community to cover most of the earthquake-related stories. The result is increased level of public understanding and awareness of Utah's susceptibility to earthquake hazards along the Wasatch Front.

Information Systems

At the inception of the regional earthquake hazards assessment program in Utah, Tarr and Mabey (1984, p. 148) specified the objective of the information system as follows:

- To make quality data readily available to meet the needs of researchers and policymakers.

United States
Department of the Interior
Geological Survey, Western Region
Menlo Park, California 94025

Public Affairs Office — Pat Jorgenson (415) 329-4000

For release: UPON RECEIPT (Mailed August 26, 1988)

EAST-CENTRAL UTAH AREA HAS UNEXPECTED EARTHQUAKES

A series of earthquakes that have been shaking east-central Utah and western Colorado for the past two weeks (since Aug. 14, 1988) occurred in a part of Utah where earthquakes have been rare in the past, according to a U.S. Geological Survey scientist.

"These quakes happened in a relatively inactive seismic area," said Ernest Anderson of the USGS Office of Engineering Geology and Tectonics in Golden, Colo. The tremors have been centered about 35 miles south of Price, Utah, in a sparsely populated area of Emery County.

Most of Utah's earthquakes have occurred along the Wasatch fault, a north-south fracture in the Earth's crust, generally paralleling the western base of the Wasatch Mountains just east of the Great Salt Lake. But Dr. Anderson said the Wasatch fault zone, which runs about 220 miles from Malad City, Idaho, south to Gunnison, Utah, about 120 miles south of Salt Lake City, would not have been a factor in the current series of earthquakes.

Carl Stover, a USGS geophysicist in Golden, Colo., who has compiled a series of seismicity maps for individual states, confirmed that the area of the August earthquakes has "no record of historic seismicity." The seismicity map he prepared of Utah shows only one other recorded earthquake in that area since 1850. It occurred Sept. 7, 1962, and had a magnitude of only 3.3.

The largest of the current earthquakes occurred Aug. 14 and was recorded at a preliminary magnitude of 5.6 on the Richter scale. The tremor, which occurred at 2:03 p.m. MDT, was preceded by a 3.5 magnitude earthquake at 12:59 p.m. and a 4.3 magnitude 4.3 magnitude tremor at 1:08 p.m. The area has continued to have aftershocks, with the largest (magonitude 3.5) occurring on the morning of Aug. 15.

Although the August earthquakes have caused no injuries and little damage, the 5.6 magnitude earthquake Aug. 14 was the fourth largest recorded earthquake in Utah's history. The only larger ones were a 6.1 magnitude earthquake in a remote area of the Utah-Idaho border in March 1975 and two earthquakes of magnitudes 6.0 and 6.6 in northwestern Utah in March 1934.

* * * USGS * * *

EARTH SCIENCE IN THE PUBLIC SERVICE

FIGURE 16. -- Typical press release by the USGS Public Affairs Office illustrating a common but effective transfer technique. It is identified as an educational service in list 4.

Salt Lake Tribune 2/18/87

Tests Warn Of S.L. Earthquake

By Joan O'Brien
Tribune Staff Writer

The trenches tell the story of the past, and sound the warning.

Trenching studies along the Salt Lake section of the Wasatch Fault show that a major earthquake occurs every 2,200 to 2,500 years — and the last one was 2,200 to 2,400 years ago.

"We are right in the window of vulnerability for the next earthquake," said Salt Lake County Geologist Craig V. Nelson.

The Wasatch Front is replete with geologic hazards, but residents can take precautions and mitigate the damage that would occur in a "characteristic" earthquake measuring 7.2 on the Richter Scale, Mr. Nelson said.

For the last year and a half Mr. Nelson has been translating hard geological data into a language city planners can understand. His maps detailing "red flag" zones will be available to developers and the public within a few months.

Mr. Nelson's federally funded position was created, in part, so the Salt Lake County Planning Commission could take geologic hazards into consideration in development proposals. The United States Geological Survey has also provided funding for similar positions in Weber and Davis counties and Utah and Juab counties.

The Wasatch Fault, stretching from Nephi to Brigham City, is actually a series of fault segments that could produce earthquakes independently of other segments, Mr. Nelson said.

Unlike California's San Andreas Fault, the Wasatch Fault does not creep. "Unfortunately, the Wasatch Fault does not creep and the strain is accumulating," Mr. Nelson said. "What we see in the trenches is that there are 6-foot breaks and then nothing, so it all builds up to a critical point."

When that critical point is reached, scientists expect a "characteristic" earthquake with a magnitude of over 7 on the Richter Scale.

County Geologist Advocates Long-Range Planning

Special to The Tribune

FARMINGTON — Mike Lowe, Davis County geologist, believes long-range planning is the key to protecting residents from geologic hazards.

Mr. Lowe, speaking to members of the Davis County Council of Governments, summerized his findings after one year as county geologist.

He said recent landslides, flooding, debris flows and the rising Great Salt Lake have created a high degree of public awareness concerning geologic hazards.

As a result of threats and damages by such hazards, Mr. Lowe was hired to collect and translate technical information for use by planners and local government officials in Davis and Weber counties.

Mr. Lowe said, during the Aug. 20 meeting, the county and many cities have adopted ordinances requiring geologic reports in potentially hazardous areas.

"By requiring these reports, hazards and mitigative measures can be identified and assessed," said Mr. Lowe.

"If development is allowed to proceed based on the report's recommendations, with zoning enforcers and building inspectors ensuring that those recommendations are followed, problems related to geologic hazards are less likely to arise," he added.

The geologist said he also has performed recent site evaluations focusing on new water tanks in North Salt Lake and Layton, three sites for a proposed new county jail and several landslide locations in the county.

In addition, the geologist said he did a number of site investigations of Bountiful and Farmington homes experiencing foundation cracks.

Salt Lake Tribune 8/24/86

Deseret News 9/9/86

Geologist gathering data for hazards ordinance

PROVO — Utah County doesn't have a geological hazards ordinance yet, but by the time Robert Robison finishes a three-year stint as a special consultant for the county, there will be more than enough information to write the ordinance.

Robison is one of three geologists assigned to the Wasatch Front by the federal government.

His work area includes Utah and Juab Counties and he is also available to work with cities in both those counties.

This week Robison told Utah County commissioners he is moving into his second year of work for the county. He said that during the past year he has established a library with 700 maps and articles pertaining to soils and geology in Utah County.

"The purpose of my assignment is to collect information, establish a library, index maps and act as a technical assistant to the county and cities," said Robison.

Jeff Mendenhall, Utah County planner, said Robison has provided much valuable information to the county.

"By the time he has finished gathering all the information, the county will be able to design the hazards ordinance and that will be a big help to us," Mendenhall said. "Most of the cities have one, but we haven't had the expertise to draw one up until now."

FIGURE 17. -- Typical local newspaper coverage of earthquake-hazard reduction activities. Permission to publish. These examples are valuable information transfer techniques shown in list 4.

- To create an information system that assures that new data will be available in the form most useful to meeting program objectives.
- To devise a system whereby potential users will have easy access to data in media, scales, and formats that will be most useful to them.

They suggested creating a "clearinghouse" with directories to its information. Much of what they envisioned is now reality (Sprinkel, 1988, p. 94).

During 1985-1988, UGMS compiled a comprehensive bibliography of geologic hazards in Utah. References were collected statewide from conventional sources of published information and some unconventional sources. All of the references were keyworded and entered into a computerized data base system for easy manipulation and retrieval. These sources were supplemented by many of the geotechnical engineering firms and government agencies in Utah that permit a review of their files for more site-specific information.

This compilation was initiated in October 1985 with the goal of <u>not only</u> compiling a computerized hazards bibliography but also producing generalized hazards maps for the State at a scale of 1:750,000. The hazards bibliography includes a comprehensive listing of all published and unpublished hazards information statewide. Information can be retrieved according to specific hazard, type of information, and geographic locality covered by each entry. When completed, the bibliography can be sorted geographically and printouts made available to various governmental entities (cities, counties, and multicounty agencies) so that they will be aware of what data are available for their jurisdictions.

In conjunction with the bibliography, UGMS maintains a file for each USGS 7½-minute quadrangle in the State which will include site-specific

hazards reports (where appropriate), inventory sheets of each report's contents, and an index map showing the location of the sites reported on. Mapping and bibliography compilation are proceeding concurrently and are scheduled for completion in 1989.

The second phase of the UGMS hazards compilation project is a cooperative effort with the USGS and five Wasatch Front counties. The three county geologists serving the five counties have collected all pertinent hazards information and developed a hazards library for each county. They use this information, supplemented with additional field studies as necessary, to compile hazards maps for each county. Files of site-specific hazards information are being maintained and index maps showing locations of hazards information are being compiled.

Texts are being prepared to accompany each map to explain the hazard -- likelihood, location, and severity. Discussions of possible engineering and site design techniques for mitigation are included, as well as guidelines for the types of information that should be included in site investigation reports. Figure 18 shows the status of these texts and maps as of December 1988.

FIGURE 18 NEXT PAGE

Public Inquiries

In addition to compiling and maintaining directories, the UGMS maintains a library, public inquiries section, and a sales office. According to Smith (1985b, p. 4), the library has several thousand items including materials on earthquake phenomena and hazards. The librarian has access to the computerized "Bibliography of Utah Geology" and can make

	Text	Weber	Davis	Salt Lake	Utah	Juab
1. Surface fault rupture (1:24,000)	F	F	F	F	D	D
2. Ground shaking (1:250,000)	D	-	-	-	-	-
3. Liquefaction potential (1:48,000)	F	Anderson and others (1982, 1986a, 1986b)				
4. Seismic slope stability (1:48,000)	F	Topham and others (1987)				
5. Tectonic subsidence (1:100,000)	F	Keaton (1987)				
6. Dam failure (variable scale$)	D	U.S. Bureau of Reclamation				
7. Landslide hazard (1:24,000)	F	D	D	D	D	D
8. Rock fall hazard (1:24,000)	F	D	D	D	D	D
9. Debris flow hazard (1:24,000)	F	F	F	D	D	D
10. Lake/stream flooding	F	NO MAP PLANNED				
11. Shallow ground water (1:48,000)	-	Anderson and others (1982, 1986a, 1986b)				
12. Problem soils (1:24,000)	-	-	-	-	-	-
13. Other (seiche, sensitive clay, hydrologic effects)	F	NO MAP PLANNED				

FIGURE 18. -- Status of geologic-hazard maps and texts being produced by county geologists as of June 1988 (rev. December 1988) from Christenson (1988, table 1, p. 7). Letter F indicates final completed, D indicates draft text or partial mapping completed, - indicates completion planned for subsequent years. References are given for maps completed by others; see Christenson (1988, p. 14).

searches by author, location, or type of study and is adding new titles to keep the list up-to-date.

The list of UGMS publications and maps is now on computer (PUBLIST). It is indexed by county and kind of study for easy location of specific publications. Its data processing section is preparing a new program to keep records of sales and inventories. All except the most recent UGMS publications are now available on microfiche so that no publication is ever completely "out-of-print."

The sales office fills mail orders for UGMS publications (over 70 percent of its business) as well as handling over-the-counter sales. Receipts for 1983-84 were $42,000; sales have been increasing annually. In addition, many materials are provided to the public at no charge. The UGMS staffs an Applied Geology Program to assist State and local units of government in assessing and reducing geologic hazards. The USGS operates ten public inquiries offices in the United States; one of them is in Salt Lake City.

Advisories

Specific advice on reducing earthquake hazards may be in oral or written form. Written information may consist of a general fact sheet that is widely distributed or a letter addressing a specific issue that is requested by a planner or decisionmaker. Figures 15 and 19 illustrate these two types.

FIGURE 19 NEXT PAGE

The UGMS and county geologists provide various advisory services. One example is the providing of explanations and advice along with hazard

United States Department of the Interior

GEOLOGICAL SURVEY

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EXPRESS MAIL

May 6, 1986

Mr. Jerold H. Barnes, AICP
Salt Lake County Planning Commission
2033 South State Street
Salt Lake City, Utah 84115

Dear Jerry:

In accord with your request yesterday, please find selected materials for use in developing a geologic-hazard-overlay amendment to the county zoning ordinance. These materials include examples of ordinances, discussions of need or use, and the content of geotechnical reports, all of which are paperclipped and highlighted for your convenience:

Ordinances

Potentially hazardous geologic conditions (Sonoma County, 1974)
Safety geologic (S-G) overlay (San Bernardino County, 1980)
Liquefaction investigation (City of San Diego, 1984)
G-H geologic hazard overlay district (Jefferson County, Colorado, 1983)
Geologic hazard maps (Santa Clara County, 1978)
Model geologic hazard area control (Colorado Geological Survey, 1974)
Resource management zoning district (San Mateo County, 1973)

Discussions

Site investigations in hazardous areas (Brown and Kockelman, 1983)
Engineering geology at the local government level (McCalpin, 1985)
Landslide hazard zones (Weber, 1980)
Role of geotechnical consultants and reviewers (Leighton, 1975)
Geologic review process (Hart and Williams, 1978)
Hazard avoidance and mitigation (Unknown)

Geotechnical Report Guidelines

Guidelines to geologic/seismic reports (CDMG, 1973)
General guidelines for geological reports (Ventura County, 1974)
Minimum standards for geotechnical reports (San Mateo County, 1977)

I deliberately selected a wide range of materials to provide you with the greatest flexibility, for example:

FIGURE 19. -- Example of a letter addressing a specific issue in Utah. It illustrates a type of transfer technique identified as an advisory service in list 4.

- The ordinances range from Sonoma County's one-page regulation requiring a site investigation and recommendations for preventive and corrective measures to San Mateo County's 24-page resource management zoning district that reduces dwelling unit density in soil- and scenic-resource areas as well as fault-rupture and landslide-hazard areas.

- The discussions include a case history on "challenging a geologic-hazard zone," use of a 1:12,000-scale hazard-overlay cadastral map, and land development goals from the viewpoints of the developer, the geologic consultant, and the public agency involved.

- The guidelines range from very general notes to four types of geologic reports requiring detailed data and descriptions, including county certification forms.

According to Jeff Keaton, the Utah Section of the Association of Engineering Geologists is preparing guidelines for engineering geologic reports, including surface-rupture, seismic-shaking, liquefaction, and slope-stability hazards. Genevieve Atwood advised me today that the UGMS is considering publishing these guidelines as UGMS notes.

As we discussed, it would be desirable to keep the geologic-hazard-overlay regulations succinct (as you did with the "hillside protection zone") and to adopt by reference both the official hazards maps and the required geotechnical reports. My experience indicates that such an approach makes it much easier for the public to understand; reduces direct pressure on the local government when references can be made to outside experts (State, Federal, university, consultants, and professional societies); and makes it easier to update them without amending the ordinance.

Caveat

The enclosed materials are in a raw form directly from my files and, of course, can not be endorsed or recommended by the U.S. Geological Survey. Although many of them have been in effect for several years without successful legal assault, others may have been revised, repealed, or not properly enforced. If a particular example seems promising for your needs, I would be pleased to make one or two inquiries concerning its status and provide you with the administrator's name and number for direct contact.

I hope these materials will be of some help to you, the Commission, and Salt Lake County. Please call me if you have any questions or if I can be of any further assistance.

Sincerely,

Bill

W.J. Kockelman

Enclosures

cc: G. Atwood
J. Keaton

FIGURE 19 (cont'd). -- Example of a letter addressing a specific issue in Utah. It illustrates a type of transfer technique identified as an advisory service in list 4.

maps and hazard reduction literature to prospective real-estate buyers, sellers, lenders, and developers. Building officials and planners, both city and county, frequently request advice on specific sites where geotechnical problems are encountered or suspected. The UGMS also advises the Utah State departments of Community and Economic Development and Facilities Construction and Management regarding use of earthquake-hazards information in State-funded projects.

The county geologists' advice has been sought by and given to the cities of Salt Lake, Ogden, South Weber, Mapleton, Centerville, Riverdale, and Washington Terrace and the counties of Salt Lake, Utah, and Weber on the content of ordinances regulating the use of hazardous lands.

Guidelines

The Utah Section of the Association of Engineering Geologists (1986, 1987) has been preparing guidelines concerning the preparation of engineering geologic reports and the evaluation of various geologic hazards including surface fault rupture, shaking, liquefaction potential, and landslide potential. Two of these have been published and distributed by the UGMS; one is shown in figure 20.

FIGURE 20 NEXT PAGE

Sometimes a scientist/author includes a transfer technique along with his or her translated material. A good example is a recommendation included in the earthquake-induced landslide potential report by Keaton and others (1987) that accompanies their seismic slope stability map. The recommendations in matrix format for critical facilities and other land uses are shown in figure 21.

UTAH GEOLOGICAL AND MINERAL SURVEY

GUIDELINES FOR EVALUATING SURFACE FAULT RUPTURE HAZARDS IN UTAH

by

The Utah Section of the
Association of Engineering Geologists

These guidelines have been compiled to assist geologists in the investigation of possible hazards due to surface fault rupture and to enable reviewers to evaluate the thoroughness of such investigations. The guidelines were developed by the Guidelines Committee of the Utah Section of the Association of Engineering Geologists, for the purpose of protecting the health, safety, and property of the people of Utah. Previously published guidelines for the State of California (California Division of Mines and Geology, 1975; Slosson, 1984) were used as models. The guidelines do not include systematic descriptions of all available techniques or topics, nor is it suggested that all techniques or topics be utilized on every project. Variations in site conditions and purposes of investigations may require more or permit less effort than is outlined here. All elements of these guidelines should be considered during the preparation and review of engineering geologic reports.

Future faulting generally is expected to recur along pre-existing faults (Bonilla, 1970, p. 68); the development of a new fault or reactivation of a pre-Quaternary fault is relatively uncommon and generally need not be a concern in site development for typical facilities. Generally, the more recent the faulting, the greater the probability of future faulting (Allen, 1975; Ziony and others, 1973). Regional and urban earthquake hazards and risk in Utah are reviewed by Hays and Gori (1984).

The evaluation of future fault rupture hazards involves careful application of skills and techniques not commonly used in other engineering geologic investigations (trenching, absolute dating). Many active faults are complex, consisting of multiple breaks which may have originated during different surface-faulting events. To accurately evaluate the potential hazards due to future surface fault rupture, the geologist must determine:

I. Fault Locations

This involves locating and accurately mapping all tectonic features at the site, at a scale large enough to be used for site planning (1 inch = 200 feet).

II. Nature of Deformation

Surface deformation over active faults may involve single large displacements, multiple small displacements, monoclinal flexure, backtilting, or a combination of all of these (see Bonilla, 1982). The way in which the surface deforms influences the type and degree of risk posed to various types of structures.

III. History of Fault Ruptures

The absolute age of past displacements should be obtained over as long a period of geologic time as possible. Two key measurements are: 1) the age of latest faulting, and 2) the average recurrence interval between surface-rupturing events.

Few structures intended for human occupancy are designed to withstand surface rupture of their foundations without serious damage. If such a structure is sited astride an active fault, the subsequent fault rupture hazard cannot be mitigated unless the structure is relocated. Therefore, the scope of the investigation depends on not only the complexity and economics of the project, but also on the level of risk acceptable for the proposed development. Because of variability in the risk and in the complexity of site geology, not all investigative techniques described here need to be or can be employed in evaluating a single site. The guidelines provide a checklist for preparing complete and well-documented reports.

Regardless of the size of the project (single-family residence vs high-rise building) the conclusions drawn from geologic data must be consistent and unbiased, and must not tie to the design life or perceived economics of the project. Recommendations must be clearly separated from conclusions, since recommendations are not solely dependent on geologic factors.

Suggested Outline for Reports Evaluating Surface Fault Rupture Hazard

The following subjects should be addressed in any geologic report on faults. Some of the investigative methods listed below should be extended well beyond the site being investigated. Not all of the methods identified will be useful at every site.

A. Purpose and Scope of Investigation

B. Geologic and Seismotectonic Setting

1. Regional Geology
2. Tectonic Setting
   a. Location and style of known active faults (see Anderson and Miller, 1979; Nakata and others, 1982).
   b. Major earthquakes in historic time (see Arabasz and others, 1979).

C. Site Description and Conditions-Include information on depth to ground water, geologic units, graded and filled areas, vegetation, existing structures, and other factors that may affect the choice of investigative methods and the interpretation of data.

D. Office Methods of Investigation

1. Review of published and unpublished literature, maps, or records concerning geologic units, faults, ground-water barriers, and other factors.
2. Stereoscopic interpretation of aerial photographs or other remotely sensed images to detect fault-related topography, soil and vegetation contrasts, and other lineaments of possible fault origin. Low-sun-angle photographs are particularly useful for fault scarp recognition (see Cluff and Slemmons, 1971).
3. Personal communication with those who have first-hand knowledge about geologic conditions or pertinent land-use history of the site.

E. Field Methods of Investigation

1. Surface
   a. Geologic mapping—distribution, depth, thickness and nature of geologic units, both surficial and bedrock.
   b. Location and relative ages of tectonic surface features, including fault scarps, sag ponds, aligned springs, offset bedding, disrupted drainage systems, offset ridges, faceted spurs; locations of zones of crushed rock (fault breccia). Relationships with dated alluvial terraces or shorelines (Currey, 1982) may yield indication of age. Surface topographic profiling of fault scarps may permit an age estimate if scarps result from a single rupture event (Nash, 1980; Hanks and others, 1984) or may show evidence of multiple events (Wallace, 1977).
   c. Locations and relative ages of other possibly earthquake-induced features caused by lateral spreading, liquefaction, or settlement. Locations of slope failures should be noted, although they may not be conclusively tied to earthquake causes.
2. Subsurface
   a. Trenching or other excavations across features of suspected tectonic origin. A detailed trench log should be prepared at a scale of 1:60 or larger showing geologic units, soil profiles, and all discontinuities (unconformities, fractures, shear zones, fault planes, sand or rubble-filled cracks, burrows). The position of all samples used for absolute dating must appear on the log. Systematic photographs should be taken to document the presence or absence of tectonic features. Because the location of trenches is critical in obtaining

UTAH GEOLOGICAL AND MINERAL SURVEY
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MISCELLANEOUS PUBLICATION

APRIL

FIGURE 20. -- Example of guidelines for evaluating a hazard and preparing reports in Utah. It is a type of transfer technique from list 4. When adopted by state or local governments as a requirement, it becomes a reduction technique identified in list 2.

tectonic or stratigraphic data, investigators are encouraged to discuss trench location, orientation, depth, and length with reviewers in advance of excavation. Multiple trenches, if needed, should be excavated concurrently, not sequentially. All critical excavation should be left open for at least 48 hours after logging is completed to allow access by reviewers. Fencing, posting, and shoring of all the trenches is strongly recommended (see Woods, 1976).

b. Absolute dating to determine timing of past surface rupture events. Methods commonly used for Quaternary deposits are reviewed by Colman and Pierce (1977, 1979) and McCalpin (1986). Samples should be collected which most tightly bracket the time of faulting; e.g., from the youngest parts of faulted units and from the oldest parts of unfaulted units.

c. Borings and test pits to collect data on geologic units, fault-plane geometry, and ground-water elevations. Data points must be sufficient in number and adequately spaced to permit valid correlations and interpretation.

3. Geophysical investigations. These are indirect methods that require knowledge of specific geologic conditions for reliable interpretation. Geophysical methods alone never prove the existence or absence of a fault, nor can they assess the recency of activity. Types of equipment and techniques used should be described. Methods commonly include seismic refraction, seismic reflection, electrical resistivity, gravity, magnetic intensity, and ground penetrating radar.

4. Other investigations; where special conditions or requirements for critical structures demand more intensive investigation.

a. Aerial reconnaissance overflights.

b. Geodetic and strain measurements.

c. Microseismicity monitoring.

F. Conclusions

1. Locations of mapped faults; style of associated displacement and age of past surface rupturing events.

2. Anticipated amount and pattern of earth displacements in the next probable surface-faulting event; delineation of areas of high risk.

3. Probability or relative potential for future surface displacements. The likelihood of future faulting may be estimated from the recurrence intervals between past events, plus the age of latest faulting, or from slip rates and amount of anticipated earthquake slip determined for the specific site or from an identified fault segment which includes the site (for Wasatch Fault segments, see Anderson, in press).

4. Comparison of conclusions developed from site data with previous interpretations on the same fault trace or segment.

5. Degree of confidence in and limitations of data and conclusions.

G. Recommendations

1. Recommended building restrictions or use limitations within any designated high-risk areas.

a. Setback distances from hazardous faults. Most Utah local governments currently have no laws dictating minimum setback. Therefore, justification must be clearly provided for recommended setback distances (see McCalpin, 1987).

b. Restrictions arising from causes other than discrete surface rupture (e.g., ground tilting, induced mass movements).

2. Risk evaluations relative to the proposed development. Any probabilistic estimates of fault rupture within the design life of the development should be supported with assumptions used and probable error ranges.

3. Need for additional studies.

H. References

1. Literature and records cited or reviewed.

2. Aerial photographs or images interpreted—list type, date, scale, source, and index numbers.

3. Other sources of information, including well records, personal communications, and other data sources.

I. Illustrations-These are essential in understanding the report and reducing the length of the text.

1. Location map—identify site locality, significant faults geographic features; 1:24,000 scale recommended.

2. General geologic map—shows geologic setting of site, geologic units, faults, other geologic structures, geomorphic features, lineaments, springs, epicenters of historic earthquakes of M≥4, 1:24,000 scale recommended.

3. Site map—combines a detailed, large-scale geologic map of the site with pertinent development-related data (site boundaries, existing and proposed structures, graded areas, streets, exploratory trenches, boring locations, geophysical traverses, and other data). Site geology must correlate with the regional geologic map but should provide refined data on surficial deposits. Recommended scale of 1 inch equals 200 feet or larger (1:2,400).

4. Geologic cross-sections, to extend to the depth of exploratory borings or foundation elements, whichever is greater; same horizontal scale as the site map.

5. Logs of exploratory trenches or borings. Trench logs in particular should show all relevant detail at a scale of 1:60 or larger within zones of suspected deformation; no vertical exaggeration.

6. Geophysical data and its geologic interpretation.

7. Photographs—of scarps, trenches, samples, or other features which enhance understanding of the pertinent site conditions.

J. Appendix-Supporting data not included above (e.g., water well data).

K. Signature of Investigating Geologist-The report must be signed by the engineering geologist who conducted the investigation. The State of Utah currently has no statutory definition of an engineering geologist; however, some local governments do define the minimum qualifications of geologists who can submit reports. Current registration as a geologist in another state may be used in support of demonstrating qualifications.

REFERENCES

Allen, C.R., 1975, Geologic criteria for evaluating seismicity: Geological Society of America Bulletin, v. 86, p. 1041-1057.

Anderson, L.W., and Miller, D.G., 1979, Quaternary fault map of Utah: Fugro Inc., Long Beach, CA, 35 p., scale 1:500,000.

Anderson, R.E., in press, Regional and local hazards mapping in the eastern Great Basin: National Earthquake Hazards Reduction Program, Summaries of Technical Reports, vol XXIII, U.S. Geological Survey Open-File Report.

Arabasz, W.J., Smith, R.B., and Richins, W.D. (eds.), 1979, Earthquake studies in Utah, 1850 to 1978: Special Publication, University of Utah Seismograph Stations, Salt Lake City, UT, 552 p.

Bonilla, M.G., 1970, Surface faulting and related effects, in Wiegel, R.L. (ed.), Earthquake Engineering: Prentice-Hall Inc., Englewood Cliffs, N.J., p. 47-74.

———1982, Evaluation of potential surface faulting and other tectonic deformation: U.S. Geological Survey, Open-File Report 82-0732, 91 p.

California Division of Mines and Geology, 1975, Guidelines for evaluating the hazard of surface fault rupture: CDMG Note 49, 4 p.

Cluff, L.S., and Slemmons, D.B., 1971, Wasatch Fault Zone—features defined by low-sun-angle photography, in Hilpert, L.S. (ed.), Environmental Geology of the Wasatch Front: Utah Geological Association Publication 1, p. H1-H29.

Colman, S.M., and Pierce, K.L., 1977, Summary table of Quaternary dating methods: U.S. Geological Survey Map MF-904.

———1979, Preliminary map showing Quaternary deposits and their dating potential in the conterminous United States: U.S. Geological Survey Miscellaneous Field Studies Map MF-1052, scale 1:7,500,000.

Currey, D.R., 1982, Lake Bonneville: selected features of relevance to neotectonic analysis: U.S. Geological Survey, Open-File Report 82-1070, 30 p., map 1:500,000.

Hanks, T.C., Buckham, R.C., Lajoie, K.R., and Wallace, R.E., 1984, Modification of wave-cut and faulting-controlled landforms: Journal of Geophysical Research, v. 89, no. B7, p. 5771-5790.

Hays, W.W., and Gori, P.L. (eds.), 1984, Proceedings of Conference XXVI, A Workshop on Evaluation of Regional and Urban Earthquake Hazards and Risk in Utah: U.S. Geological Survey, Open-File Report 84-763, 674 p.

McCalpin, James, 1986, Thermoluminescence dating in seismic hazard evaluations: an example from the Bonneville Basin, Utah in Wood, S.H. (ed.), Proceedings of the 22nd Symposium on Engineering Geology and Soils Engineering: Boise State University, Feb. 1986, p. 156-176

———, 1987, Recommended setbacks from active normal faults, in McCalpin, James (ed.), Proceedings of the 23rd Annual Symposium on Engineering Geology and Soils Engineering: Utah State University, April 6-8, 1987, p. 35-56.

Nakata, J.K., Wentworth, C.M., and Machette, M.N., 1982, Quaternary fault map of the Basin and Range and Rio Grande Rift Provinces, western United States: U.S. Geological Survey, Open-File Report 82-579, scale 1:2,500,000.

Nash, D.B., 1980, Morphologic dating of degraded normal fault scarps: Journal of Geology, v. 88, p. 353-360.

Schwartz, D.P. and Coppersmith, K.J., 1984, Fault behavior and characteristic earthquakes: examples from the Wasatch and San Andreas fault zones: Journal of Geophysical Research, v. 89, p. 5681-5698.

Slosson, J.E., 1984, Genesis and evolution of guidelines for geologic reports: Bulletin of the Association of Engineering Geologists, v. XXI, no. 3, p. 295-316.

Wallace, R.E., 1977, Profiles and ages of young fault scarps, north-central Nevada: Geological Society of America Bulletin, v. 88, p. 1267-1281.

Woods, M.C., 1976, Trench shoring: California Geology, v. 29, no. 1, p. 178-181.

Ziony, J.I., Wentworth, C.M., and Buchanan, J.M., 1973, Recency of faulting, a widely applicable criterion for assessing the activity of faults: Fifth World Conference on Earthquake Engineering, Rome, Italy, p. 1680-1682.

FIGURE 20 (cont'd). -- Example of guidelines for evaluating a hazard and preparing reports in Utah. It is a type of transfer technique from list 4. When adopted by state or local governments as a requirement, it becomes a reduction technique identified in list 2.

Guidebooks

Several guidebooks were specially prepared for reducing earthquake hazards in Utah. Four of these books are:

- Reducing losses from earthquakes through personal preparedness by Kockelman (1984).
- Suggested approach to geologic-hazard ordinances in Utah by Christenson (1987).
- Utah's geologic hazards -- a review for realtors by Christenson and Mabey (1987).
- Planning for natural hazards by the University of Utah Center for Public Affairs and Administration (1988).

The first guidebook introduces five phases of reduction -- pre-event mitigation techniques and preparedness measures, response during the earthquake, and post-event recovery operations and reconstruction activities. Several examples and citations are given for each. Because of the unique effort towards individual and community "self-reliance" in Utah, the guidebook emphasizes the relatively inexpensive actions that can be taken by responsible parents, neighborhoods, and employers. These include inspecting and strengthening the home, organizing the neighborhood, and securing contents and other nonstructural parts of buildings.

The second book encourages prudent land use in areas of geologic hazards, including earthquake hazards for the protection of the citizens of those cities and counties enacting ordinances. A concise discussion of hazards and availability of information is followed by a comprehensive survey of city and county geologic-hazard ordinances in Utah. An outline

FACILITY CLASS	EARTHQUAKE-INDUCED LANDSLIDE POTENTIAL ZONE				EXISTING LANDSLIDE	HIGH LIQUEFACTION POTENTIAL
	HIGH	MODERATE	LOW	VERY LOW		
CRITICAL Hospitals, Fire Stations Police Stations Other Emergency Facilities	YES	YES	YES	YES	YES	YES
LIFELINES Communications Transportation, Water Supply Electric Power, Natural Gas	YES	YES	YES	MAYBE	YES	YES
HIGH OCCUPANCY PUBLIC-OWNED Schools, State Capitol City Hall, Airports County Courts, Convention Centers	YES	YES	YES	MAYBE	YES	YES
HIGH OCCUPANCY PRIVATE-OWNED Office Buildings Apartments, Hotels Shopping Malls	YES	YES	MAYBE	NO	YES	YES
	Appropriate Disclosure Required					
INDUSTRIAL-SEVERE CONSEQUENCE Refineries, Sewage Plants Hazardous Waste, Explosives	YES	YES	MAYBE	NO	YES	YES
	Appropriate Disclosure Required					
INDUSTRIAL-MINOR CONSEQUENCE Trucking, Shipping Light Manufacturing	MAYBE	MAYBE	NO	NO	NO	MAYBE
	Appropriate Disclosure Required				Appropriate Disclosure Required	
RESIDENTIAL SUBDIVISION	MAYBE	MAYBE	NO	NO	NO	YES
	Appropriate Disclosure Required				Appropriate Disclosure Required	
RESIDENTIAL SINGLE LOT	NO	NO	NO	NO	MAYBE	MAYBE
	Appropriate Disclosure Required				Appropriate Disclosure Required	

FIGURE 21. -- Example of a matrix with recommendations for site-specific stability analysis for critical facilities and other land uses in several hazard zones by Keaton and others (1987, table 4, p. 76). It is a special type of transfer technique in list 4. It was designed by the scientists/authors for nontechnical users. When adopted by state and local governments as a requirement, it becomes a reduction technique identified in list 2.

of the steps to be included in a hazard reduction ordinance in jurisdictions having geologic-hazard maps and those without such maps is shown in figure 22. In addition, the Salt Lake County planning staff drafted a natural-hazards-reduction ordinance (Barnes, 1988b) which follows the guidebook recommendations. It contains a guide to natural hazards reports required for various types of facilities or developments and has been used as a model by other cities and counties (Barnes, 1988a).

FIGURE 22 NEXT PAGE

The third book was prepared to provide Utah's realtors with information that will enable them to place the State's geologic hazards in proper perspective and to communicate this risk to prospective home-buyers and business clients. The hazards considered include floods, slope failure, earthquakes, subsidence, and expanding soils. The authors emphasize the need for hazard assessment and then provide general information about the availability of hazard information, status of various hazard-mapping projects, ordinances dealing with hazard warnings or mitigation, and work accomplished by the UGMS Applied Geology Program. The report concludes that realtors "have a unique opportunity to inform the property owners of Utah and thus contribute to making Utah safer and more prosperous."

The fourth book offers a guide to the first steps that may be undertaken at the local level to understand potential hazards and plan for their reduction. It includes a discussion of local government responsibility and liability, an outline of the planning process, and State and county contacts for information and assistance.

A

1) Define boundaries of geologic hazards areas by establishing Geologic Hazards Zones (or equivalent) or officially adopting maps referenced to an ordinance.

2) Require geotechnical reports by qualified engineering geologists and engineers addressing hazards and, if necessary, recommending mitigation measures prior to development in geologic hazard areas.

3) Require review of geotechnical reports by county geologists or other qualified engineering geologists acting on behalf of local government.

4) Submit report and review comments to planning commission for action.

5) Amend geologic hazard area boundaries (zones or adopted maps) if proven necessary by site report.

B

1) Provide for review of all development proposals by county geologists or other qualified engineering geologists acting on behalf of local government to determine need for geotechnical reports.

2) Require geotechnical reports by qualified engineering geologists and engineers to address potential hazards indicated in review and, if necessary, to recommend mitigation measures. If initial reviews of development proposals are not performed, complete reports may be required for all sites.

3) Require review of geotechnical reports by county geologists or other qualified engineering geologists acting on behalf of local government.

4) Submit report and review comments to planning commission for action.

FIGURE 22. -- Suggested topical outline for geologic-hazards ordinances in areas with geologic-hazards maps (A), and without geologic-hazards maps (B) by Christenson (1987, table 1, p. 9). This is another type of transfer technique identifed as an advisory service in list 4.

Geographic Information Systems

For the purposes of this report, geographic information systems (GIS) are defined as the spatial representation of geologic, hydrologic, topographical, land use, land ownership, and other physical and socioeconomic information which can be readily combined, manipulated, analyzed, and displayed for various purposes by computer technology. The result is a quantifiable analysis of point, line, area, and volume data. The nature and capability of GIS provide an excellent basis for presenting and combining not only the various earthquake hazards, but critical facilities that might be affected. In addition, an easily used geo-reference map can be provided for the nontechnical user.

For example, Alexander and others (1987) in demonstrating the use of digital mapping technology, entered surface fault rupture, liquefaction potential, and landslide potential into a GIS for the Sugar House Quadrangle in east-central Salt Lake County. In addition to the hazard maps used in their atlas, other maps were used to illustrate the kinds of information needed to reduce earthquake hazards, namely: political jurisdictions, roads, selected lifelines, and land uses. They then combined hazards with specific land uses, for example; lifelines in potential surface fault rupture zones, schools and residential areas in high liquefaction potential zones, and schools and residential areas on lands with the lowest stability during earthquakes.

University of Utah Department of Geography professor Phillip Emmi has entered Salt Lake County's lifelines, other critical facilities, and building inventories, into a GIS to estimate earthquake loss probabilities. A CEM planner Wes Dewsnup entered all information for the Utah County Comprehensive Hazard Mitigation Project into the GIS operated

by the Utah State Office of Automated Geographic Referencing. Salt Lake County uses the AUTOCAD system and, according to C. V. Nelson (written commun., 1989), this will greatly increase the transfer of hazard information which has been referenced to land ownership records.

Review Services

The State and county geologists are sometimes asked to provide the type of review services in List 4. For example, the Salt Lake County geologist has assisted West Valley City by providing geologic hazard information to be incorporated into their computerized data bank for land-use planning; the UGMS and Utah County geologist provided hazard maps and interpretations for a Utah Division of Comprehensive Emergency Management and county project in the Provo-Orem area to aid emergency response personnel; and the Weber County geologist assisted the city of Washington Terrace in including geologic hazards into its 1987 master plan.

Comment

In all of the examples, delivery of translated information was provided; in many others, assistance and encouragement in its use for hazard reduction was provided or offered. The users ranged from practitioners and professional societies to interested citizens including children. Several of Utah's transfer techniques included suggested reduction techniques.

Special mention should be made of the unique efforts of the UGMS, USGS, university, and consulting researchers to release research findings early to practitioners and other users. This was accomplished through oral briefings, workshops, workshop proceedings (Hays and Gori, 1984, 1987; Gori and Hays, 1987, 1988), serial publications (Stringfellow, 1983 to present), newsletters (Hassibe, 1983-86; Jarva, 1987 to present), and

"official use only" materials.

The commitment of the U.S. Geological Survey to the transfer of research in Utah and the evaluation of its effectiveness may be seen in a recent award for a proposal by William Spangle and Associates, Inc. (1989). The summary of their approach follows:

> This project is designed to assist local officials in cities and counties of the Wasatch Front region of Utah apply the information provided by the USGS regional assessment of earthquake hazards. The direct experience of the consultants in research, planning practice and information transfer will be shared with Utah officials, especially city planners, on a regular basis during the year. This will be done by participating in up to four meetings throughout the year and being available as needed for direct consultation with local (and State) officials about options for earthquake-hazard reduction. A final report evaluating the effectiveness of the process and opportunities for transfer to other regions will also be prepared.

EVALUATION AND REVISION

The last component in Utah's comprehensive earthquake-hazard reduction program is evaulating the effectiveness of the reduction techniques and revising them if necessary. See figure 1. Evaluating and revising the entire program as well as the other components -- studies, translation, and transfer -- may also be undertaken.

The evaluation component was included as a task in the national earthquake-hazard reduction program by Wallace (1974) and as recommendations of the California Joint Committee on Seismic Safety (1974) advisory groups. Evaluation has been emphasized in a review of ten cities' efforts to manage floodplains (Burby and others, 1988, p. 9), in the comprehensive tasks of a national landslide-hazard reduction program (U.S. Geological Survey, 1982, p. 44), and in the recommendations of the NEHRP Expert Review Committee (1987, p. 81-85).

In Utah, evaluation is included in the abbreviated recommendations for earthquake-risk reduction by the Utah Seismic Safety Advisory Council (1981), as an active item from a governor's conference on geologic hazards (Utah Geological and Mineral Survey, 1983), and as a task in the Utah work plan.

Importance

The effectiveness of each hazard reduction technique varies with the time, place, and persons involved. Therefore, it is prudent to include a continuing systematic evaluation as part of any program for earthquake-hazard reduction. An inventory of uses made of the information, reports of interviews with the users, and an analysis of the results and responses will also result in identifying new users, innovative uses, as well as any problems concerning the research information, its translation, transfer,

and use. The evaluation will be helpful, even necessary, to those involved in funding, producing, translating, transferring, and using the research information as well as managing a comprehensive program.

Performing the studies and then translating and transferring the research information is expensive and difficult because of the limited number of scientists and geotechnicians -- National, state, local, university, corporate, and consulting -- particularly when aligned with the needs of communities throughout the United States. The adoption and enforcement of an appropriate hazard reduction technique is time-consuming, and requires many skills -- planning, engineering, legal, and political -- as well as strong and consistent public support.

Scarce financial and staff resources must be committed; necessarily persistent and difficult actions must be taken to enact a law, adopt a policy, or administer a reduction program over a long period of time. To discover later that the hazard reduction technique selected is ineffective, unenforced, or its cost is greatly disproportionate to its benefits is not only disheartening but may subject those involved to criticism and withdrawal of financial support!

Few systematic evaluations have been made of natural-hazards reduction techniques, including earthquake-hazards reduction techniques. To my knowledge, no rigorous studies of the benefits-to-costs have been conducted. However, a few intensive evaluations have been made for flood, landslide, and other reduction techniques and programs which may be applicable to earthquakes.

The following examples of various evaluations are presented for introductory purposes. Their findings and recommendations, although beyond the scope of this report, will be helpful to Utahans in their

selection of the most appropriate transfer and reduction techniques.

Evaluation of Reduction Techniques

Several reduction techniques (list 2) have been evaluated, problems identified, and improvements suggested; examples follow:

- Preparing and implementing local seismic safety elements by the California Seismic Safety Element Review Committee (1985).
- Lending, appraising, and insuring policies of the 12 largest home mortgage lenders in California by Marston (1984).
- Disclosing surface fault rupture hazards to real-estate buyers in Berkeley and Contra Costa County by Palm (1981).
- School earthquake safety and education project in Seattle and community outreach education centers at Memphis State University and Baptist College in Charleston, South Carolina, by Bolton and Olson (1987b).
- Strengthening, redeveloping, abandoning, or demolishing unreinforced masonry-bearing-wall buildings in the cities of Long Beach, Santa Ana, and Los Angeles by Alesch and Petak (1986).
- Strengthening masonry-bearing-wall buildings in the city of Los Angeles after the 1987 Whittier Narrows earthquake by Deppe (1988).
- Retrofitted highway bridges after the 1986 earthquake in Palm Springs by Mellon (1986).
- Mapping, investigating, and regulating surface-fault-rupture zones by Hart (1986).

Translation and Transfer Techniques

Several translation and transfer techniques (list 4) have been evaluated, problems identified, and recommendations made; some examples follow:

- Announcing earthquake prediction and forecast information by Turner and

others (1981).

- Disseminating earthquake education material to public and private schools by Bolton and Olson (1987a).
- Disseminating earthquake-hazards information to public officials and private sector representatives in Charleston, South Carolina, by Greene and Gori (1982).
- Using earth-science information in cities, counties, and selected regional agencies in the San Francisco Bay region by Kockelman (1975, 1976b, 1979), Kockelman and Brabb (1979), and Perkins (1986).
- Translating and transferring information in the U.S. Geological Survey by Bates (1979) and O'Kelley and others (1982).
- Conducting a workshop on preparing for and responding to a damaging earthquake in the eastern United States by Tubbesing (1982, p. 57-59).
- Adopting ordinances based on guidelines and model ordinances developed and transferred by the Southeastern Wisconsin Regional Planning Commission (1987, p. 24).

Evaluation of Programs

Several earthquake-hazard reduction programs have been evaluated, problems identified, and revisions suggested; examples follow:

- Community seismic safety programs before, during, and after the 1983 Coalinga, California, earthquake by Tierney (1985).
- Planning and implementing seismic-hazard mitigation in Alaska by Selkregg and others (1984).
- Use of earthquake-hazard information for enlightenment, decisionmaking, and practice in California, Washington, Utah, South Carolina, Massachusetts, Idaho, Puerto Rico, Kentucky, Alaska, Missouri, U.S. Virgin Islands, and the eastern, western, and central United States by Hays

(1988a).

- o National Earthquake Hazards Reduction Program in the United States by the NEHRP Expert Review Committee (1987).
- o Effectiveness of the geology and planning program in Portola Valley, California, by Mader and others (1988, p. 55-61).
- o San Francisco Bay Region Environmental and Resources Planning Study by Arthur D. Little, Inc. (1975) and Brown (1975).
- o Land use and reconstruction planning after the 1971 San Fernando, 1964 Alaska, and 1969 Santa Rosa earthquakes by Mader and others (1980).
- o Seismic safety policies of local governments by Wyner and Mann (1983).
- o Structure design and behavior investigation after over 200 earthquakes by members of the Earthquake Engineering Research Institute (Scholl, 1986).

Various Evaluations in Utah

Several reduction and transfer techniques and programs in Utah have been evaluated, problems identified, and revisions suggested; examples follow:

- o Awareness and reduction of earthquake hazards by Perkins and Moy (1988, p. 9-19).
- o Multi-hazard mitigation project for Ogden and Weber County by Olson and Olson (1985).
- o Hazardous building abatement and sensitive lands development ordinances for Provo by May and Bolton (1986).
- o County Hazards Geologist Program by Christenson (1988).
- o Earthquake knowledge, risk perception, and mitigation priorities in Salt Lake County by Madsen (1988).
- o Adequacy of engineering geologic reports by Nelson and others (1987).

o Perception of earthquake risk and support for regulations by Emmi (1987).

Reduction Techniques for Other Hazards

Several reduction techniques for other natural hazards have been evaluated, problems identified, and improvements suggested. Their evaluation methods, findings, and recommendations may be applicable to earthquake hazards; examples follow:

o Disclosing hurricane-flood-hazards information to prospective home buyers in Florida by Cross (1985).

o Providing state financial incentives for flood-hazard reduction to local governments by Burby and Cigler (1983).

o Subsidizing flood insurance for property owners and their lenders by Miller (1977), Burby and French (1981, p. 294), and Kusler (1982, p. 36, footnote 55).

o Notice, watch, and warning system for a potential 1978 Pillar Mountain landslide in Kodiak by Saarinen and McPherson (1981).

o Warnings for the 1980 Mount St. Helens volcano eruption by Saarinen and Sell (1985).

o Planning and engineering response and recovery to 1982 debris flows at Love Creek (Santa Cruz County) and Inverness (Marin County) by Blair and others (1985).

Evaluation Methods

There are numerous methods for evaluating the effectiveness of an earthquake-hazard reduction program and its components -- studies, translation, transfer, and reduction. The above examples of evaluation indicate that these methods vary widely because of the human and financial resources available, the region involved, and the evaluator's interest, experience, and commitment. A thorough discussion of these methods is

beyond the scope of this report, however, the following four will illustrate different levels of rigor:

1. Soliciting comments and suggestions from the producers, translators, transfer agents, and users of the research information.
2. Inventorying the documents where research information is cited and conducting systematic interviews with the users as to the types of information needed, used, problems with it, and improvements desired.
3. Comparing losses experienced in several areas having similar hazards and operating under the same type of reduction technique but where different levels of requirements, administration, or enforcement are in effect.
4. Collecting and comparing the benefits and costs -- public and private -- of several different reduction techniques before and after a damaging earthquake in a jurisdiction having a uniform geologic and tectonic environment.

The phrase "public and private costs" is used here to mean all direct and indirect costs and losses such as market value declines, road and utility repairs, emergency response activities, real-property damages, personal-property losses, deaths, injuries, tax revenue losses, industrial production losses, commerce interruption, and traffic delays. If it is demonstrated that the cost of a reduction technique is substantially less than the cost of anticipated damage we may conclude a favorable benefit-cost ratio for the use of the reduction technique.

The following will introduce the reader to several methods which address various topics and have different levels of rigor.

o Use of earth-science products by city, county, and selected multicounty organizations by Kockelman (1975, p. 20-26; 1976b, p. 16-20; 1979,

p. 27-31).

- Natural-hazard reduction plan appraisal and cost/benefit analysis by Lohman and others (1988, p. 183-201).
- Economics of landslide mitigation strategies by Bernknopf and others (1985).
- Methods of cost-benefit analysis for different building codes and for upgrading existing structures by Paté and Shah (1980).
- Testimony on the costs and housing impacts of unreinforced masonry building rehabilitation before a state agency (Boswell, 1987).
- Benefit-cost ratios for reconstructing over 1,350 state-owned buildings by H.J. Degenkolb Associates (1981).

Comment

These examples of evaluation vary as to topic, area affected, type of technique, evaluator, and comprehensiveness. What they all have in common is a critical look at the success or failure of a program or of the translation, transfer, or reduction techniques used.

Even if adequate earthquake-hazard research information is available, presented in a language understandable by nontechnical users, effectively transferred, and properly used as is being done in Utah, the lasting effectiveness of each earthquake-hazard reduction technique (list 2) depends upon many other factors, usually outside the control of the researcher, engineer, planner, or decisionmaker. For example:

- Continued awareness and interest by the public.
- Careful revision (if needed) of enabling legislation by the state legislature.
- Accurate site investigations by qualified geologists and geotechnical engineers.

- o Conscientious administration of regulations by plan-checkers, inspectors, and other building officials.
- o Sustained support of inspection and enforcement officials by political leaders and their constituents.
- o Consistent enforcement by government inspectors and attorneys.
- o Judicious adjustment of regulations by administrative appeal bodies.
- o Skillful advocacy by public regulators and plaintiffs, and proper interpretation by the courts.
- o Genuine concern for individual, family, and community safety by real-estate buyers, developers, insurers, and lenders.

A consultant and expert witness who is a former state geologist and former president of a state board of registration for geologists and geophysicists reports in Slosson and Havens (1985) on his experience during the past 25 years:

> ... many of the problems and losses related to damage from earthquakes ... are directly or indirectly attributable to government's (local, state, and/or federal) inability and/or failure to enforce existing policies, codes, or regulations.

The benefits of evaluation and revision cannot be restated often enough, namely: to avoid an unconscionable waste of taxpayers' money and an usually irreparable loss of program managers' credibility.

CONCLUSION

The reduction of casualties, damages, and interruptions in Utah require that appropriate earthquake research be conducted and used by planners, engineers, and decisionmakers. A major part of any effective earthquake-hazard reduction program must be dedicated to the translation of research information and its transfer to nontechnical users as is being done in Utah.

The selection of earthquake areas or processes for study and performing the necessary scientific and engineering studies are only the first steps in any earthquake-hazard reduction program. If the information prepared is inadequate, inappropriate, not translated, not transferred, or not used, earthquake losses will increase; public and private monies will be wasted; and demands will be made on Federal, state, and local government agencies for disaster relief and costly reconstruction.

Usually, public planners, engineers, and decisionmakers give most of their attention and resources to problems that are perceived to be serious or pressing. A 1977 study of 6 sites of varying political environments and attitudes toward seismic safety was conducted by Atkisson and Petak (1981, p. I39). They found at that time that the "seriousness attributed to earthquakes ... was consistently low in all sites." See figure 23. With the exception of floods (10th in Salt Lake City) and earthquakes (10th in Los Angeles), natural hazards at all sites were considered least serious -- 13 to 18 on the list of serious problems.

FIGURE 23 NEXT PAGE

Problem Seriousness Scores in the Six Sites

	CA		LA		MA		BOSTON		UTAH		SLC	
	$\bar{X}$	RANK	$\bar{X}$	RANK	$\bar{X}$	RANK	$\bar{X}$	RANK	$\bar{X}$	RANK	$\bar{X}$	RANK
INFLATION	7.6	1	6.6	4	7.5	4	7.1	5	7.2	1	7.5	1
POLLUTION	7.2	2	7.5	1	6.0	8	4.4	13	5.7	3	6.7	2
UNEMPLOY.	7.0	3	7.0	3	8.6	1	7.6	2	4.2	8	4.5	9
CRIME	6.9	4	5.9	8	7.3	5	7.3	4	5.5	4	5.6	3
WELFARE	6.9	5	7.1	2	8.2	2	7.4	3	5.9	2	5.0	6
EDUCATION	6.2	6	6.3	5	5.4	11	7.0	6	4.1	9	4.3	11
DRUGS	6.0	7	6.0	7	6.1	7	6.6	8	5.1	5	4.9	7
TRAFFIC	5.7	8	6.2	6	5.1	12	6.5	9	3.8	10	4.7	8
HOUSING	5.5	9	5.7	9	6.4	6	6.4	10	4.8	7	5.5	4
FIRES	5.3	10	4.2	14	6.0	9	5.9	11	3.4	12	3.7	12
TOO LITTLE GROWTH	5.0	11	5.0	12	7.8	3	7.7	1	3.7	11	3.3	14
RACE	4.7	12	4.4	13	5.4	10	6.9	7	2.6	16	3.4	13
QUAKES	4.6	13	5.5	10	1.2	18	1.3	18	3.2	15	1.2	16
PORNOGRAPHY	4.1	14	5.3	11	4.0	14	5.4	12	5.0	6	5.1	5
FLOODS	3.3	15	2.8	15	4.5	13	2.2	15	3.3	13	4.5	10
TOO MUCH GROWTH	2.5	16	1.6	16	1.3	17	1.3	16	3.3	14	3.0	15
HURRICANES	1.3	17	1.0	17	3.1	15	2.3	14	1.0	17	1.2	17
TORNADOES	1.1	18	1.0	18	1.5	16	1.3	17	1.0	18	1.0	18
$\bar{X}$ =	5.05		4.95		5.30		5.26		4.04		4.17	

FIGURE 23. -- Rankings by key public and private decisionmakers as to the relative seriousness of 18 state and local issues for 3 states and 3 cities from Atkisson and Petak (1981, table I9, p. I40).

Recently, Perkins and Moy (1988, rpt. 3, table 4, p. 15) asked 15 city managers and county administrators in Utah to indicate what earthquake-hazard reduction techniques had been adopted in the past five years. According to Perkins (verbal commun., 1989), 13 responded: all 13 had adopted at least one technique; nine had adopted a technique primarily for reasons of earthquake safety, and four of these had adopted four or more techniques. Obviously, Utahans are not only more aware of the earthquake hazard but are continuing to take appropriate actions.

The effective use of research information in Utah depends upon: (1) the users' interest, capabilities, and experience in hazard-related activities; (2) enabling legislation authorizing State and local hazard-reduction activities; (3) adequate detailed information in a readily usable and understandable form; and (4) the use of effective transfer techniques. These four elements exist in Utah. All that remains is for Utahans to continue to adopt appropriate reduction techniques and enforce them over many years.

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REFERENCES CITED

Advisory Committee on the International Decade for Natural Hazard Reduction, 1987, Confronting natural disasters -- An international decade for nattural hazard reduction: Washington, D.C., National Academy Press, 60 p.

Agnew, D.C., Allen, C.R., Cluff, L.S., Dieterich, J.H., Ellsworth, W.L., Keeney, R.L., Lindh, A.G., Nishenko, S.P., Schwartz, D.P., Sieh, K.E., Thatcher, W.R., and Wesson, R.L., 1988, Probabilities of large earthquakes occurring in California on the San Andreas fault: U.S. Geological Survey Open-File Report 88-398, 62 p.

Alesch, D.J., and Petak, W.J., 1986, The politics and economics of earthquake hazard mitigation -- Unreinforced masonry buildings in southern California: Boulder, University of Colorado, Institute of Behavioral Science, Program on Environment and Behavior, Monograph 4, 276 p.

Alexander, R.H., 1983, Land resource information needs of county government -- A case study in Larimer County, Colorado: U.S. Geological Survey Open-File Report 83-103, 80 p.

Alexander, R.H., Crane, M.P., Di Nardo, T.P., Firestone, L.M., Jessen, Eldon, Mladinich, C.S., and Rich, C.L., 1987, Sugar House Quadrangle Atlas -- Applying digital cartographic and geographic information systems technology and products to the national earthquake hazards reduction program, in Hays, W.W., and Gori, P.L., eds., A Workshop on "Earthquake Hazards Along the Wasatch Front, Utah," Proceedings of Conference XXXVIII, May 16, 1986, Salt Lake City: U.S. Geological Survey Open-File Report 87-154, p. 100-146.

Algermissen, S.T., Perkins, D.M., Thenhaus, P.C., Hanson, S.L., and Bender, B.L., 1982, Probabilistic estimates of maximum acceleration and

velocity in rock in the contiguous United States: U.S. Geological Survey Open-File Report 82-1033, 99 p.

Algermissen, S.T., and Steinbrugge, K.V., 1984, Seismic hazard and risk assessment -- Some case studies: Proceedings of the first meeting of the International Working Group on Natural Disasters and Insurance: Geneva, United Nations Disaster Relief Organization, The Geneva Papers on Risk and Insurance, v. 9, no. 30, p. 8-26.

Amimoto, Perry Y., 1980, Advisory services: Sacramento, California Division of Mines and Geology, California Geology, May 1980, p. 99-100.

Anderson, L.R., Keaton, J.R., and Bischoff, J.E., 1986, Liquefaction potential map for Utah County, Utah: Logan, Utah University Department of Civil and Environmental Engineering; Salt Lake City, Dames and Moore, 46 p., 16 pl.

Applied Technology Council, 1978, Tentative provisions for the development of seismic regulations for buildings -- A cooperative effort with the design professions, building code interests, and the research community: Washington, D.C., U.S. Government Printing Office, Publication ATC 3-06, 505 p., 2 pl.

Arthur D. Little, Inc., 1975, An evaluation of the San Francisco Bay region environment and resources planning study -- Report to the U.S. Department of Housing and Urban Development Office of Policy Development and Research: San Francisco, Calif., Arthur D. Little, Inc., 93 p.

Atkisson, A.A., and Petak, W.J., 1981, Seismic safety policies and practices in U.S. metropolitan areas -- A three city case study: Redondo Beach, Calif., J.H. Wiggins Co., Technical Report 80-1373-2, Contract EMW-C-0043, 289 p.

Atwater, B.F., 1988, Probable local precedent for earthquakes of magnitude 8

or 9 in the Pacific Northwest, in Hays, W.W., ed., Workshop on "Evaluation of earthquake hazards and risk in Puget Sound and Portland areas" -- Proceedings of Conference XLII, 1988: U.S. Geological Survey Open-File Report 88-541, p. 62-68.

Atwood, Genevieve, 1983, UGMS responds to disasters: Salt Lake City, Utah Geological and Mineral Survey, Survey Notes, v. 17, no. 2, p. 2.

Atwood, Genevieve, and Mabey, D.R., 1987, Reducing earthquake risk in Utah -- Past trends and future opportunities, in Gori, P.L., and Hays, W.W., eds., Assessment of Regional Earthquake Hazards and Risk Along the Wasatch Front, Utah, vol. II: U.S. Geological Survey Open-File Report 87-585, p. S1-S38.

Bakun, W.H., Bredehoeft, J.D., Burford, R.O., Ellsworth, W.L., Johnston, M.J.S, Jones, L.M., Lindh, A.G., Mortensen, C.E., Roeloffs, E.A., Schulz, Sandra, Segall, Paul, and Thatcher, W.R., 1986, Parkfield earthquake scenarios and response plans: U.S. Geological Survey Open-File Report 86-365, 46 p.

Barnes, J.H., 1988a, Utilization of hazard maps in Salt Lake County, in Hays, W.W., ed., A review of earthquake research applications in The National Earthquake Hazards Reduction Program, 1977-1987, Proceedings of Conference XLI, 1987: U.S. Geological Survey Open-File Report 88-13A, p. 362-376.

-----1988b, Natural hazards ordinance: Salt Lake City, Salt Lake County Public Works Planning Division, Draft no. 4, chapt. 19.75, 16 p., 8 maps.

Bates, T.F., 1979, Transferring earth science information to decisionmakers -- Problems and opportunities as experienced by the U.S. Geological Survey: U.S. Geological Survey Circular 813, 30 p.

Bernknopf, R.L., Brookshire, D.S., Campbell, R.H., Shapiro, C.D., and Fleming, R.W., 1985, The economics of landslide mitigation strategies in Cincinnati, Ohio -- A methodology for benefit-cost analysis, in Campbell, R.H., ed, Feasibility of a nationwide program for the identification and delineation of hazards from mud flows and other landslides: U.S. Geological Survey Open-File Report 85-276, p. D1-D16.

Blair, M.L., and Spangle, W.E., 1979, Seismic safety and land-use planning -- Selected examples from the San Francisco Bay region, California: U.S. Geological Survey Professional Paper 941B, 82 p.

Blair, M.L., Vlasic, T.C., Cotton, W.R., and Fowler, William, 1985, When the ground fails -- Planning and engineering response to debris flows: Boulder, University of Colorado, Institute of Behavioral Science, Program on Environment and Behavior, Monograph 40, 117 p.

Blair-Tyler, M.L., and Gregory, P.A., 1988, Putting seismic safety policies to work: Portola Valley, Calif., William Spangle and Associates, Inc., 40 p.

Bolton, P.A., Heikkala, S.G., Greene, M.M., and May, P.J, 1986, Land use planning for earthquake hazard mitigation -- A handbook for planners: Boulder, University of Colorado, Institute of Behavioral Science, Natural Hazards Research and Applications Information Center, Special Publ. 14, 123 p.

Bolton, P.A., and Olson, Jon, 1987a, An assessment of dissemination activities of the California earthquake education project: Seattle, Battelle Human Affairs Research Centers, Contract SSC-6009, 43 p.

-----1987b, Final report on the evaluation of three earthquake education projects: Seattle, Battelle Human Affairs Research Centers, BHARC 800-88-027, 153 p.

Borcherdt, R.D., ed., 1975, Studies for seismic zonation of the San Francisco Bay region -- Basis for reduction of earthquake hazards, San Francisco Bay region, California: U.S. Geological Survey Professional Paper 941A, 102 p.

Borcherdt, R.D., Gibbs, J.F., and Lajoie, K.R., 1975, Maps showing maximum earthquake intensity predicted in the southern San Francisco Bay region, California, for large earthquakes on the San Andreas and Hayward faults: U.S. Geological Survey Miscellaneous Field Studies Map MF-709, sheet 2, scale 1:125,000.

Boswell, Brenda, ed., 1987, Costs and housing impacts of unreinforced masonry building rehabilitation: Sacramento, California Seismic Safety Commission, 90 p.

Brabb, E.E., 1987, Analyzing and portraying geologic and cartographic information for land-use planning, emergency response, and decisionmaking in San Mateo County, California, in GIS '87-- San Francisco " ... into the hands of the decisionmaker," Second Annual International Conference, Exhibits and Workshops on Geographic Information Systems, October 26-30, 1987: Falls Church, Virginia, American Society for Photogrammetry and Remote Sensing and the American Congress on Surveying and Mapping, p. 362-374.

Brown, R.D., Jr., 1975, Project management -- San Francisco Bay region environment and resources planning study (unpubl. report): Menlo Park, Calif., U.S. Geological Survey, 41 p.

Brown, R.D., Jr., and Kockelman, W.J., 1983, Geologic principles for prudent land use -- A decisionmaker's guide for the San Francisco Bay region: U.S. Geological Survey Professional Paper 946, 97 p.

Brown, R.D., Jr., and Wolfe, E.W., 1972, Map showing recently active breaks

along the San Andreas fault between Point Delgada and Bolinas Bay, California: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-692, scale 1:24,000.

Burby, R.J., Bollens, S.A., Holloway, J.M., Kaiser, E.J., Mullan, David, Sheaffer, J.R., 1988, Cities under water -- A comparative evaluation of ten cities' efforts to manage floodplain land use: Boulder, University of Colorado, Program on Environment and Behavior, Monograph 47, 250 p.

Burby, R.J., and Cigler, B.A., 1983, Flood hazard management -- Effectiveness of state assistance programs for flood hazard mitigation: Chapel Hill, University of North Carolina, Center for Urban and Regional Studies, 29 p.

Burby, R.J., and French, S.P., 1981, Coping with floods -- The land use management paradox: Journal of the American Planning Association, v. 47, no. 3, p. 289-300.

Burningham, G.L., 1983 (rev.), I can make (a) the difference -- Emergency preparedness: Salt Lake City, Utah State Office of Education, 83 p.

California Joint Committee on Seismic Safety, 1974, Meeting the earthquake challenge -- Final report to the legislature: Sacramento, California Division of Mines and Geology Special Publ. 45, 223 p.

California Seismic Safety Commission, 1986, California at risk -- Reducing earthquake hazards, 1987 to 1992: Sacramento, California Seismic Safety Commission, 92 p.

-----1987, Appendix to the guidebook to identify and mitigate seismic hazards in buildings: Sacramento, California Seismic Safety Commission, Report SSC 87-03, 96 p.

California Seismic Safety Element Review Committee (Mader, G.G., chm.), 1985, A review of the seismic safety element requirement in California -- A report to the California Seismic Safety Commission: Sacramento,

California Seismic Safety Commission Report SSC 85-05, 26 p.

Case, W.F., 1987, Rockfall hazard susceptibility due to earthquakes, central Wasatch Front, Utah, in Gori, P.L., and Hays, W.W., eds., Assessment of Regional Earthquake Hazards and Risk Along the Wasatch Front, Utah, vol. II: U.S. Geological Survey Open-File Report 87-585, p. V1-V36.

Central United States Earthquake Consortium, 1987, Map users guide: Memphis, Tenn., Central United States Earthquake Consortium, 4 p.

Christenson, G.E., 1987, Suggested approach to geologic hazards ordinances in Utah: Salt Lake City, Utah Geological and Mineral Survey Circular 79, 16 p.

-----1988, Final technical report -- Wasatch Front county hazards geologist program: Salt Lake City, Utah Geological and Mineral Survey, USGS Grant 14-08-0001-G991, 14 p.

Christenson, G.E., Barnes, J.H., Moore, Joseph, Nelson, C.V., Robison, R.M., Lowe, Mike, and Kockelman, W.J., 1987, Collecting, compiling, translating, and disseminating earthquake-hazards information for urban and regional planning and development in the Wasatch Front area, Utah, in Hays, W.W., and Gori, P.L., eds., A Workshop on "Earthquake Hazards Along the Wasatch Front, Utah," Proceedings of Conference XXXVIII, Salt Lake City, May 14-18, 1986: U.S. Geological Survey Open-File Report 87-154, p. 80-86.

Christenson, G.E., and Mabey, D.R., 1987, Utah's geologic hazards -- A review for realtors: Salt Lake City, Utah Geological and Mineral Survey Open-File Report 109, 5 p.

Council of State Governments, 1976, Natural resource data needs recommendations: Lexington, Ky., The Council of State Governments, 25 p.

Crone, A.J., 1984, The Borah Peak, Idaho, earthquake -- An analog of future

Wasatch Front earthquakes?: Salt Lake City, Utah Geological and Mineral Survey, Wasatch Front Forum, v. I, no. 3, p. 3.

Cross, J.A., 1985, Flood hazard information disclosure by realtors: Boulder, University of Colorado, Institute of Behavior Sciences, Natural Hazard Research, Working Paper 52, 44 p.

Davis, J.F., Bennett, J.H., Borchardt, G.A., Kahle, J.E., Rice, S.J., and Silva, M.A., 1982, Earthquake planning scenario for a magnitude 8.3 earthquake on the San Andreas fault in southern California: California Division of Mines and Geology Special Publ. 60, 128 p.

Degenkolb, H.J., Associates, 1981, Seismic hazard survey -- State of California buildings: Sacramento, California Seismic Safety Commission Report SSC-604, 83 p.

Deppe, Karl, 1988, The Whittier Narrows, California, earthquake of October 1, 1987 -- Evaluation of strengthened and unstrengthened unreinforced masonry in Los Angeles City: El Cerrito, Earthquake Engineering Research Institute, Earthquake Spectra, v. 4, no. 1, p. 157-180.

Dewsnup, Wes, 1987, The Utah County comprehensive hazard mitigation project: Salt Lake City, Utah Geological and Mineral Survey, Wasatch Front Forum, v. 3, no. 3-4, p. 8-9.

Drabek, T.E., 1986, Human system responses to disaster -- An inventory of sociological findings: New York, Springer-Verlag, 509 p.

Emmi, P.C., 1987, Utahans nervous about earthquake risk -- Survey shows support for regulations: Salt Lake City, Utah Geological and Mineral Survey, Wasatch Front Forum, v. 3, no. 3-4, p. 4-5.

Evernden, J.F., Kohler, W.M., and Clow, G.D., 1981, Seismic intensities of earthquakes of conterminous United States -- Their prediction and interpretation: U.S. Geological Survey Professional Paper 1223, 56 p.

Evernden, J.F., and Thomson, J.M., 1988, Predictive model for important ground motion parameters associated with large and great earthquakes: U.S. Geological Survey Bulletin 1838, 27 p.

Federal Emergency Management Agency, 1985-1988, (various titles relating to seismic safety): Washington, D.C., Federal Emergency Management Agency, hazards reduction series nos. 1-39.

Frank, Lorayne, 1987, Energy systems and disruption: Salt Lake City, Utah Geological and Mineral Survey, Wasatch Front Forum, v. 3, no. 3-4, p. 9-10.

Gori, P.L., and Hays, W.W., eds., 1987, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Open-File Report 87-585, 2 vols.

-----1988, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Open-File Report 88-680, v. III, 160 p.

Greene, M.R., and Gori, P.L., 1982, Earthquake hazards information dissemination -- A study of Charleston, South Carolina: U.S. Geological Survey Open-File Report 82-233, 57 p.

Greensfelder, R.W., 1972, Maximum credible bedrock acceleration from earthquakes in California: Sacramento, California Division of Mines and Geology Map Sheet 23, scale 1:2,000,000 (Revised August 1974, modified by California State Department of Transportation Office of Structures, October 1974).

Hanks, T.C., 1985, The national earthquake hazards reduction program -- Scientific status: U.S. Geological Survey Bulletin 1659, 40 p.

Hansen, D.C., and Morgan, R.L., 1982, Rules and regulations governing dam safety in Utah: Salt Lake City, Utah Department of Natural Resources

and Energy, Division of Water Rights, 17 p.

Hart, E.W., 1986, Zoning for surface faulting hazards in southern California, in Brown, W.M., III, Kockelman, W.J., and Ziony, J.I, Workshop on Future Directions in Evaluating Earthquake Hazards of southern California, Proceedings of Conference XXXII, Nov. 12-13, 1985, Los Angeles: U.S. Geological Survey Open-File Report 86-401, p. 74-83.

-----1988, Fault-rupture hazard zones in California: Sacramento, California Division of Mines and Geology Special Publ. 42, 24 p.

Harty, K.M., and Christenson, G.E., 1988, Flood hazard from lakes and failure of dams in Utah: Salt Lake City, Utah Geological and Mineral Survey Map 111, 8 p., scale 1:750,000.

Hassibe, W.R., ed., 1983-1986, Wasatch Front Forum (quarterly): Salt Lake City, Utah Geological and Mineral Survey.

Hays, W.W., 1980, Procedures for estimating earthquake ground motions: U.S. Geological Survey Professional Paper 1114, 77 p.

-----1981, Facing geologic and hydrologic hazards -- Earth-science considerations: U.S. Geological Survey Professional Paper 1240B, 109 p.

-----1984, Regional earthquake hazards assessment program: Salt Lake City, Utah Geological and Mineral Survey, Wasatch Front Forum, v. 1, no. 3, p. 2.

-----1987, Making the implementation process of the National Earthquake Hazards Reduction Program work in Utah, in Gori, P.L., and Hays, W.W., eds., Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Open-File Report 87-585, p. R1-R44.

-----, ed., 1988a, A review of earthquake research applications in the National Earthquake Hazards Reduction Program, 1977-1987 -- Proceedings of

Conference XLI: U.S. Geological Survey Open-File Report 88-13-A, 597 p.

-----1988b, The knowledge utilization process, in Williams, M.E., and Hays, W.W., eds., Proceedings of the Executive Briefing on Strategic Planning to Reduce Economic Impacts of Earthquake Hazards Throughout the World, Washington, D.C., March 8-9, 1988: U.S. Geological Survey Open-File Report 88-361, p. 99-103.

Hays, W.W., Algermissen, S.T., Miller, R.D., and King, K.W., 1978, Preliminary ground response maps for the Salt Lake City, Utah, area: Proceedings of the Second International Conference on microzonation for safer construction -- Research and application, San Francisco, Nov. 26-Dec. 1, 1978, v. 1, p. 497-507.

Hays, W.W., and Gori, P.L., eds., 1984, A workshop on "Evaluation of Regional and Urban Earthquake Hazards and Risk in Utah," Proceedings of Conference XXVI, Salt Lake City, Aug. 14-16, 1984: U.S. Geological Survey Open-File Report 84-763, 687 p.

-----1986, A workshop on "Evaluation of regional and urban earthquake hazards and risk in Alaska," Proceedings of Conference XXXI, Anchorage, Alaska, Sept. 5-7, 1985: U.S. Geological Survey Open-File Report 86-79, 450 p.

-----1987, A Workshop on "Earthquake Hazards Along the Wasatch Front, Utah," Proceedings of Conference XXXVIII, May 14-18, 1986, Salt Lake City: U.S. Geological Survey Open-File Report 87-154, 164 p.

Headquarters Structural Engineering Staff, 1987 (rev.), Structural Directives (including seismic safety): Salt Lake City, Church of Jesus Christ and Latter-day Saints, 9 p.

Information Systems Council's Task Force on Long-Range Goals for USGS's Information Dissemination, 1987, Review of current and developing U.S. Geological Survey earth-science information dissemination activities

(summary version): Reston, Va., U.S. Geological Survey, update of May 1985 report, 6 p.

International Conference of Building Officials, 1988, Uniform Building Code: Whittier, Calif., International Conference of Building Officials, 926 p.

Jacknow, Joel, 1985, Technology transfer -- An entrepreneurial approach to Federal research: Government Executive, v. 17, no. 4, p. 18-19.

Jaffe, Martin, Butler, JoAnne, and Thurow, Charles, 1981, Reducing earthquake risks -- A planner's guide: Chicago, American Planning Association Advisory Services Report 364, 82 p.

Jarva, J.L., ed., 1987 to present, Wasatch Front Forum (quarterly): Salt Lake City, Utah Geological and Mineral Survey.

Jochim, C.L., Rogers, W.P., Truby, J.O., Wold, R.L., Jr., Weber, George, and Brown, S.P., 1988, Colorado landslide hazard mitigation plan: Denver, Colorado Geological Survey Bulletin 48, 149 p.

Kaliser, B.N, 1984a, Earthquake hazard situation in Utah (rev.): Salt Lake City, Utah Geological and Mineral Survey, 1 p.

-----1984b, Earthquake safety in Utah (rev.): Salt Lake City, Utah Geological and Mineral Survey, 1 p.

-----1984c, Earthquake faulting in Utah (rev.): Salt Lake City, Utah Geological and Mineral Survey, 1 p.

Keaton, J.R., 1986, Earthquake-induced soil liquefaction: Salt Lake City, Utah Geological and Mineral Survey, Wasatch Front Forum, v. 2, no. 3, p. 2-4.

-----1987, Potential consequences of earthquake-induced regional tectonic deformation along the Wasatch Front, north-central Utah: Logan, Utah State University Department of Civil and Environmental Engineering, 23 p., 6 pl.; text also in McCalpin James, compiler and ed., Proceedings

of the 23rd Symposium on Engineering Geology and Soils Engineering: Boise, Idaho Department of Transportion, p. 19-34

Keaton, J.R., Anderson, L.R., Topham, Dale, and Rathbun, D.J., 1987, Earthquake-induced landslide potential in and development of a seismic slope stability map of the urban corridor of Davis and Salt Lake counties, Utah: Logan, Utah State University Department of Civil and Environmental Engineering, 47 p. 4 pl.; text also in McCalpin, James, compiler and ed., Proceedings of the 23rd Symposium on Engineering Geology and Soils Engineering: Boise, Idaho Department of Transportion, p. 57-80.

Keaton, J.R., and Reaveley, L.D., 1986, Field guide to selected geologic features and buildings in southern Davis and northern Salt Lake counties, Utah, July 18, 1986: Salt Lake City, Utah Geological and Mineral Survey, 22 p.

Keefer, D.K., 1984, Landslides caused by earthquakes: Geological Society of America Bulletin, v. 95, p. 406-421.

Kerch, Steve, 1988, In quakes, many homes shake, rattle -- not roll: Chicago, Ill., Chicago Tribune, Home Guide section, February 27, 1988, 2 p.

Kockelman, W.J., 1970, Overall program design for the State Planning Office: Santa Fe, New Mexico State Planning Office, 124 p., 16 app.

-----1975, Use of U.S. Geological Survey earth-science products by city planning agencies in the San Francisco Bay region, California: U.S. Geological Survey Open-File Report 75-276, 110 p.

-----1976a, Educational, advisory, and review services: Menlo Park, Calif., U.S. Geological Survey administrative report, 25 p.

-----1976b, Use of U.S. Geological Survey earth-science products by county planning agencies in the San Francisco Bay region, California: U.S. Geological Survey Open-File Report 76-547, 185 p.

-----1979, Use of U.S. Geological Survey earth-science products by selected regional agencies in the San Francisco Bay region, California: U.S. Geological Survey Open-File Report 79-221, 173 p.

-----1984, Reducing losses from earthquakes through personal preparedness: U.S. Geological Survey Open-File Report 84-765, 13 p.

-----1985, Using earth-science information for earthquake-hazard reduction, in Ziony, J.I., editor, Evaluating earthquake hazards in the Los Angeles region -- An earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. 443-469.

-----1986, Some techniques for reducing landslide hazards: College Station, Tex., Association of Engineering Geologists Bulletin, v. 23, no. 1, p. 29-52.

Kockelman, W.J., and Brabb, E.E., 1979, Examples of seismic zonation in the San Francisco Bay region, in Brabb, E.E., ed., Progress on seismic zonation in the San Francisco Bay region: U.S. Geological Survey Circular 807, p. 73-84.

Kusler, J.A., 1982, Regulation of flood hazard areas to reduce flood losses: Washington, D.C, U.S. Government Printing Office, U.S. Water Resources Council, v. 3, 357 p.

Lane Publishing Co., 1982, Getting ready for a big quake: Menlo Park, Calif., Lane Publishing Company, Sunset Magazine, p. 104-111.

Lohman, Ernst, Vrolijks, Luc, and Roos, Jaap, 1988, Disaster Mitigation -- A manual for planners, policymakers, and communities, final draft: Geneva, United Nations Office of the Disaster Relief Coordinator, 489 p.

Los Angeles City Council, 1981, Ordinance no. 154,807 relating to earthquake hazard reduction in existing buildings: Los Angeles Municipal Code, chapt. IX, art. 1, div. 68, sec. 91.6801 and following.

Lowe, Mike, and Eagan, Keith, 1987, Geology and geologic hazards of the Brigham City area, Box Elder County, Utah, with recommendations for land-use planning (unpubl. report): Farmington, Utah, 49 p.

Mabey, D.R., 1985, Earthquake hazards in Utah: Salt Lake City, Utah Geological and Mineral Survey, Survey Notes, v. 18, no. 4, p. 3-4 and 6-11.

Machette, M.N., Personius, S.F., and Nelson, A.R., 1987 (rev. 1988), Quaternary geology along the Wasatch fault zone -- Segmentation, recent investigations, and preliminary conclusions, in Gori, P.L., and Hays, W.W., eds., Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Open-File Report 87-585, v. 1, p. A1-A72.

Machette, M.N., Personius, S.F., and Nelson, A.R., Schwartz, D.P., and Lund, W.R., 1989, Segmentation models and Holocene movement history of the Wasatch fault zone, Utah, in Schwartz, D.P., and Sibson, R.H., eds., Workshop on "Fault segmentation and controls of rupture initiation and termination": Proceedings of Conference XLV, U.S. Geological Survey Open-File Report 89- _____, p. 229-245.

Mader, G.G., and Blair-Tyler, M.L., 1988, California at risk -- Steps to earthquake safety for local government: Sacramento, California Seismic Safety Commission Report SSC-88-01, 55 p.

Mader, G.G., Spangle, W.E., Blair, M.L., Meehan, R.L., Bilodeau, S.W., Degenkolb, H.J., Duggar, G.S., and Williams, Norman, Jr., 1980, Land use planning after earthquakes: Portola Valley, Calif., William Spangle and Associates Inc., 158 p.

Mader, G.G., Vlasic, T.C., and Gregory, P.A., 1988, Geology and planning -- The Portola Valley experience: Portola Valley, Calif., William Spangle and Assoc., Inc., 67 p., 2 app.

Madsen, G.E., 1988, Earthquake knowledge, perceptions of risk, and mitigation priorities of planners and building officials in Salt Lake County: Salt Lake City, Utah Geological and Mineral Survey, Wasatch Front Forum, v. 5, no. 1, p. 5-6.

Mancarti, G.D., 1981, New concepts in earthquake retrofitting of highway bridges -- Paper presented at Northwest Bridge Engineers Conference, Boise, Idaho, 1981: Sacramento, California Department of Transportation, 22 p.

Manson, C.J., 1988, Seismic hazards of western Washington and selected adjacent areas -- Bibliography and index, 1855-June 1988: Olympia, Washington Division of Geology and Earth Resources, Open-File Report 88-4, 1,039 p.

Mapleton City Council, 1985, Ordinance no. 85-2 creating a critical environment zone: Zoning Ordinance section 7-6-12, Mapleton, Utah, Mapleton City Council, 12 p.

Marston, S.A., 1984, A political economy approach to hazards -- A case study of California lenders and the earthquake threat: Boulder, University of Colorado Institute of Behavioral Science, Natural Hazards Research Working Paper 49, 31 p.

May, Fred, 1988, Governor's conference on comprehensive hazards reduction: Salt Lake City, Utah Geological and Mineral Survey, Wasatch Front Forum, v. 4, no. 3-4, p. 15-16.

May, P.J., and Bolton, P.A., 1986, Reassessing earthquake hazard reduction measures: American Planning Association Journal, v. 52, no. 4, p. 443-451.

McCalpin, James, 1985, Engineering geology at the local government level -- Planning, review, and enforcement: Association of Engineering Geolo-

gists Bulletin, v. 22, no. 3, p. 315-327.

-----1987, Recommended setbacks from active normal faults, in McCalpin, James, ed., Proceedings of the 23rd Symposium on Engineering Geology and Soils Engineering: Logan, Utah State University, p. 35-56.

McCann, M.W. Jr., and Boissonnade, A.C., 1985, An assessment of earthquake and dam failure consequences in the Ogden/Pineview, Utah, area: Salt Lake City, Utah Division of Comprehensive Emergency Management; Mountain View, Calif., Jack R. Benjamin and Associates, Inc., JBA 210-030, 110 p.

McKelvey, V.E., 1972, Concluding remarks at the American Association of Petroleum Geologists meeting, Denver, Colorado, April 17, 1972.

Mellon, Steve, 1986, Highway bridge damage -- Palm Springs earthquake July 8, 1986 -- Seismic report, post-earthquake investigation team (intra-agency document): Sacramento, California Department of Transportation, Office of Structures Design, 40 p.

Miller, H.C., 1977, Coastal flood hazards and the national flood insurance program: Washington, D.C., Federal Emergency Management Agency FIA-9, March 1981, 50 p.

Mintier, J.L., 1987 (rev.), State of California general plan guidelines: Sacramento, California, Governor's Office of Planning and Research, 368 p.

Morton, D.R., ed., 1986, A selected annotated bibliography of recent (1985-1986) hazards publications: Boulder, University of Colorado Natural Hazards Research and Applications Information Center, 146 p.

National Research Council, 1986, Active tectonics -- Studies in geophysics: Washington, D.C, National Academy Press, 266 p.

National Science Foundation, 1980, A report on flood hazard mitigation: National Science Foundation, Washington, D.C., 253 p.

NEHRP Expert Review Committee, 1987, The National Earthquake Hazards Reduction Program -- Commentary and recommendations of the expert review committee: Washington, D.C., Federal Emergency Management Agency, 85 p.

Nelson, C.V., 1987, Surface fault rupture and liquefaction hazard areas map, Salt Lake County: Salt Lake City, Salt Lake County Planning Division, scale approximately 1:36,000.

-----1988, Geoseismic evaluation, Granite Fire Station, Salt Lake County, Utah: Salt Lake City, Utah Geological and Mineral Survey Report of Investigations 218, p. 99-128.

Nelson, C.V., Christenson, G.E., Lowe, Mike, and Robison, R.M., 1987, The review process and adequacy of engineering geologic reports, Wasatch Front, Utah, in McCalpin, James, ed., Proceedings of the 23rd Annual Symposium on Engineering Geology and Soils Engineering -- Utah State University, April 6-8, 1987: Logan, Utah State University, p. 83-85.

Nichols, D.R., 1982, Application of earth sciences to land-use problems in the United States with emphasis on the role of the U.S. Geological Survey, in Resources for the Twenty-first century -- Proceedings of the International Centennial Symposium of the U.S. Geological Survey: U.S. Geological Survey Professional Paper 1193, p. 283-291.

Noson, L.L., Qamar, Anthony, and Thorsen, G.W., 1988, Washington State earthquake hazards: Olympia, Washington Division of Geology and Earth Resources Information Circular 85, 77 p.

Ogden City Council, 1983, Ordinance no. 8-83 creating seismic requirements for buildings: Ogden, Utah, Municipal Code sec. 16.04.090, p. 1-4.

-----1985, Ordinance no. 27-85 creating a sensitive area overlay zone: Ogden, Utah, Municipal Code chapt. 27, sec. 19-27-1 and following.

O'Kelley, J.T., Jr., Fleisig, Susan, Shapiro, Carl, Kugel, T.L., DuBose,

Lorraine, Gordon, Leonard, and Pittman, Russell, 1982, Program evaluation of USGS information translation and transference activities (unpubl. report): Reston, Va., U.S. Geological Survey, 90 p.

Olson, R.S., and Olson, R.A., 1985, The Utah multi-hazard mitigation project -- An evaluation (unpubl. report): Sacramento, VSP Associates, Inc., 44 p.

Orem City Council, 1986, Ordinance no. 579 relating to seismic areas: Orem, Utah, City Code, chapt. 23, Subdivision Ordinance sec. 23-7-3, p. 31.

Palm, Risa, 1981, Real estate agents and special studies zones disclosure -- The response of California home buyers to earthquake hazards information: Boulder, University of Colorado Institute of Behavioral Science Program on Technology, Environment, and Man, Monograph 32, 147 p.

Paté, M.E., and Shah, H.C., 1980, Public policy issues -- Earthquake engineering: Seismological Society of America Bulletin, v. 70, no. 5, p. 1955-1968.

Perkins, J.B., 1986, Results of a survey of local governments -- Use of earthquake information: Oakland, Calif., Association of Bay Area Governments, 14 p.

-----1987, On shaky ground: Oakland, Calif., Association of Bay Area Governments, 32 p.

Perkins, J.B., and Moy, Kenneth, 1988, Liability of local governments for earthquake hazards and losses -- Background research reports: Oakland, Calif., Association of Bay Area Governments, 3 rpts., 295 p.

Personius, S.F., 1988, Preliminary surficial geologic map of the Brigham City segment and adjacent parts of the Weber and Collinston segments, Wasatch fault zone, Box Elder and Weber counties, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-2042, scale 1:50,000.

Petak, W.J., 1984, Geologic hazard reduction -- The professional's responsi-

bility: College Station, Tex., Association of Engineering Geologists Bulletin, v. 21, no. 4, p. 449-458.

Peters, T.J., and Waterman, R.H., Jr., 1982, In search of excellence -- Lessons from America's best-run companies: New York, Harper and Row, 360 p.

Peterson, D.W., 1986, Volcanoes -- Tectonic setting and impact on society, in Active Tectonics -- Studies in Geophysics: Washington, D.C., National Academy Press, p. 231-246.

Power, M.S., Chang, C.-Y., Idriss, I.M., and Kennedy, R.P., 1986, Engineering characterization of ground motion -- Task II, Summary Report: Washington, D.C., U.S. Nuclear Regulatory Commission, NUREG/CR-3805, v. 5, 131 p., 1 app.

Provo Municipal Council, 1985, Sensitive lands development ordinance: Provo, Utah, Provo Municipal Council, City Ordinances, chapt. 15.08, p. 287-293.

Reilly, W.K., 1987, Foreword in Davies, J.C., Covello, V.T., and Allen, F.W., eds., Risk communication: Washington, D.C., The Conservation Foundation, 143 p.

Richter, C.F., 1958, Elementary seismology: San Francisco and London, W.H. Freeman and Company, 768 p.

Robison, R.M., 1988a, Text to accompany surface fault rupture hazard maps for Utah and Juab counties, Utah: Provo, Utah County Planning Department, 19 p.

-----1988b, Text to accompany tectonic subsidence hazard maps for Utah and Juab counties, Utah: Provo, Utah County Planning Department, 19 p.

Rogers, A.M., 1986, Living with the earthquake risk: Salt Lake City, Utah Geological and Mineral Survey, Wasatch Front Forum, v. 3, no. 2, p. 2-4.

Rogers, A.M., Smith, Robert, and Ward, D.B., 1986, The ground shaking hazard and various aspects of loss estimation in the Wasatch Front area of

Utah: Salt Lake City, Utah Geological and Mineral Survey, Wasatch Front Forum, v. 2, no. 4, p. 4.

Rogers, A.M., Tinsley, J.C., and Borcherdt, R.D., 1985, Predicting relative ground response in Ziony, J.I., ed., Evaluating earthquake hazards in the Los Angeles region -- An earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. 221-247.

Saarinen, T.F., and McPherson, H.J., 1981, Notices, watches and warnings -- An appraisal of the U.S.G.S's warning system with a case study from Kodiak, Alaska: Boulder, University of Colorado Institute of Behavioral Science, Natural Hazard Research Working Paper 42, 88 p.

Saarinen, T.F., and Sell, J.L., 1985, Warning and response to the Mount St. Helens eruption: Albany, State University of New York Press, 240 p.

Salt Lake City Council, 1981, Site development regulations: Salt Lake City, Utah, Salt Lake City Council, Revised Ordinances, title 47, chapt. 1-7, 138 p.

Salt Lake County Commission, 1985, Salt Lake County master plan program -- Emigration Canyon master plan: Salt Lake City, Utah, Salt Lake County Commission, 19 p.

San Francisco Bay Area Regional Earthquake Preparedness Project, 1988, Hazardous buildings -- Case studies: Oakland, Calif., Bay Area Regional Earthquake Preparedness Project, 4 studies, glossary.

Santa Barbara County Planning Department, 1979, Seismic safety and safety element: Santa Barbara, Calif., County Planning Department, 207 p.

Sarna-Wojcicki, A.M., Williams, K.M., and Yerkes, R.F., 1976, Geology of the Ventura fault, Ventura County, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-781, scale 1:6,000.

Scholl, R.E., mgr., 1986, Reducing earthquake hazards -- Lessons learned

from earthquakes: El Cerrito, Calif., Earthquake Engineering Research Institute, 208 p.

Schwartz, D.P., 1988, Geologic characterization of seismic sources -- Moving into the 1990s (reprint): Park City, Utah, Earthquake Engineering and Soil Dynamics II Proceedings, GT Division/ASCE, 42 p.

Selkregg, L.L., Ender, R.L., Johnson, S.F., Kim, J.C.K., Gorski, S.E., Preuss, Jane, and Kelso, Duncan, 1984, Earthquake hazard mitigation -- Planning and policy implementation -- The Alaska case: National Science Foundation Grant CEE 8112632.

Slosson, J.E., and Havens, G.W., 1985, Government appears to be failing in enforcement (unpubl. paper): Van Nuys, Calif., Slosson and Associates, 5 p.

Slovic, Paul, 1986, Informing and educating the public about risk: Journal of the Society for Risk Analysis, New York, Plenum Publishing Corp., v. 6, no. 4, p. 403-415.

Smith, M.R., 1985a, Information program at the UGMS: Salt Lake City, Utah Geological and Mineral Survey, Survey Notes, v. 19, no. 4, p. 3-5.

-----1985b, Utah Geological and Mineral Survey annual report, 1983-84: Salt Lake City, Utah Geological and Mineral Survey Circular 78, 10 p.

Smith, R.B., Arabasz, W.J., Pechmann, J.C., and Richins, W.D., 1985, Integrated studies of earthquake source zone characteristics, hazards, and prediction in the Wasatch Front urban corridor and adjacent intermountain seismic belt: Salt Lake City, Utah Geological and Mineral Survey, Wasatch Front Forum, v. 2, no. 2, p. 3-6.

Sorenson, J.H., and Mileti, Dennis, 1987, Public warning needs, in Gori, P.L., and Hays, W.W., eds., A workshop on "The U.S. Geological Survey's Role in Hazards Warnings," Feb. 2-3, 1987, Proceedings of Conference

XL, Denver, Colorado: U.S. Geological Survey Open-File Report 87-269, p. 9-75.

Southeastern Wisconsin Regional Planning Commission, 1968, Project completion report, urban planning grant project no. Wis. P-53 -- Educational, advisory, and review service programs: Waukesha, Wisc., Southeastern Wisconsin Regional Planning Commission, 32 p.

-----1987, Twenty-five years of regional planning in southeastern Wisconsin -- 1960-1985: Waukesha, Wisc., Southeastern Wisconsin Regional Planning Commission, 49 p.

Spall, Henry, ed., 1975 to present, Earthquakes and Volcanoes (bimonthly) (formerly Earthquake Information Bulletin); Reston, Va., U.S. Geological Survey.

-----1985, Earthquake potential of the Wasatch Fault in Utah: U.S. Geological Survey Earthquake Information Bulletin, v. 17, no. 6, p. 218-225.

Spanish Fork City Council, 1980 (rev.), Subdivisions -- Hillside site development: Spanish Fork, Utah, title 16, sec. 12, 2 p.

Sprinkel, D.A., 1988, A review of the regional earthquake hazards assessment program for the Wasatch Front area, Utah -- Will Utah meet the challenge?, in Hays, W.W., ed., A review of earthquake research applications in The National Earthquake Hazards Reduction Program, 1977-1987 -- Proceedings of Conference XLI, 1987: U.S. Geological Survey Open-File Report 88-13-A, p. 88-99.

Steinbrugge, K.V., 1982, Earthquakes, volcanoes, and tsunamis -- An anatomy of hazards: New York, Skandia America Group, 392 p.

Steinbrugge, K.V., Bennett, J.H., Lagorio, H.J., Davis, J.F., Borchardt, Glenn, and Toppozada, T.R., 1987, Earthquake planning scenario for a magnitude 7.5 earthquake on the Hayward fault in the San Francisco Bay

area: California Division of Mines and Geology Special Publ. 78, 229 p., 4 app., 23 map sheets.

Stringfellow, J.R., ed., 1983 to present, Survey Notes (quarterly): Salt Lake City, Utah Geological and Mineral Survey.

Szanton, Peter, 1981, Not well advised: New York, Russell Sage Foundation and The Ford Foundation, 173 p.

Tarr, A.C., 1984, Progress reports: Salt Lake City, Utah Geological and Mineral Survey, Wasatch Front Forum, v. 1, no. 3, p. 5-6.

Tarr, A.C., and Mabey, D.R., 1984, Wasatch Front hazards information system, in Hays, W.W., and Gori, P.L., eds., Workshop on "Evaluation of Regional and Urban Earthquake Hazards and Risk in Utah," August 14-16, 1984, Salt Lake City, Proceedings of Conference XXVI: U.S. Geological Survey Open-File Report 84-763, p. 148-150.

Taylor, A.J., 1979, Directions for social research in disaster prevention, mitigation and relief, in Disasters, The International Journal of Disaster Studies and Practice: Oxford, Pergamon Press, v. 3, no. 3, p. 275-281.

Taylor, C.E., and Ward, D.B., 1979, Seismic risk assessment of Utah primary and secondary schools and recommendations for risk reduction: Salt Lake City, Utah Seismic Safety Advisory Council, Contract 79-5037, 91 p.

Thorsen, G.W., 1981, The circuit rider geologist: Final report, U.S. Geological Survey Agreement 7020-086-79, Project 9-7020-26001, 29 p.

Tierney, K.J., 1985, Report on the Coalinga earthquake of May 2, 1983: Sacramento, California Seismic Safety Commission Report SSC-85-01, 90 p.

Tingey, James, 1986, Utah earthquake preparedness project: Salt Lake City, Utah Geological and Mineral Survey, Wasatch Front Forum, v. 3, no. 1, p. 2-4.

-----1988, Research applications and the Utah earthquake preparedness program, in Hays, W.W., ed., A Review of Earthquake Research Applications in the National Earthquake Hazards Reduction Program, 1977-1987 -- Proceedings of Conference XLI: U.S. Geological Survey Open-File Report 88-13-A, p. 100-105.

-----1989, Utah's earthquake hazard -- Awareness and preparedness: Salt Lake City, Utah Division of Comprehensive Emergency Management, 15 p.

Tingey, J.L., and Findlay, R.F, 1987, Emergency management in Utah for earthquakes, in Gori, P.L., and Hays, W.W., eds., Assessment of Regional Earthquake Hazards and Risk Along the Wasatch Front Utah, v. 2: U.S. Geological Survey Open-File Report 87-585, p. T1-T19.

Tingey, James, and May, Fred, 1988, CEM alert report summary of August 14, 1988 -- Earthquake in Emery County: Salt Lake City, Utah Geological and Mineral Survey, Survey Notes, v. 22, no. 1-2, p. 20-21.

Tinsley, J.C., Youd, T.L., Perkins, D.M., and Chen, A.T.F., 1985, Evaluating liquefaction potential, in Ziony, J.I., ed., Evaluating earthquake hazards in the Los Angeles region -- An earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. 263-315.

Tubbesing, Susan, 1982, Highlights of the workshop on preparing for and responding to a damaging earthquake in the eastern United States, in Hays, W.W., ed., A workshop on "Preparing for and Responding to a Damaging Earthquake in the Eastern United States," Conference XV, Proceedings: U.S. Geological Survey Open-File Report 82-220, p. 37-54.

Turner, R.H., Nigg, J.M., Paz, D.H., and Young, B.S., 1981, Community response to earthquake threat in southern California: Los Angeles, University of Southern California Institute for Social Science Research, 10 pts.

United Nations Educational, Scientific, and Cultural Organization, 1976, Intergovernmental conference on the assessment and mitigation of earthquake risk (final report): Paris, United Nations Educational, Scientific, and Cultural Organization, 50 p.

U.S. Geological Survey, 1982, Goals and tasks of the landslide part of a ground-failure hazards reduction program: U.S. Geological Survey Circular 880, 48 p.

U.S. Office of Science and Technology Policy, 1978, Earthquake hazards reduction -- Issues for an implementation plan: Washington, D.C., Executive Office of the President, Office of Science and Technology Policy, Working Group on Earthquake Hazards Reduction, 231 p.

University of Utah Center for Public Affairs and Administration, 1988, Planning for natural hazards -- A technical manual for Utah communities: Salt Lake City, University of Utah, 36 p.

Utah Geological and Mineral Survey, 1983, Governor's conference on geologic hazards: Salt Lake City, Utah Geological and Mineral Survey Circular 74, 99 p.

Utah Multi Hazards Mitigation Project Administrative Review Committee, 1985, Ogden City and Weber County multi hazards mitigation plan: Ogden, Utah, Utah Multi Hazards Project Administrative Review Committee, 32 p.

NOTE TO TEXT EDITOR: "Multi hazards" are used above without hyphens.

Utah Museum of Natural History, 1985, Utah geologic hazards: Salt Lake City, Utah Museum of Natural History, 4 p.

Utah Section of the Association of Engineering Geologists, 1986, Guidelines for preparing engineering geologic reports in Utah: Salt Lake City, Utah Geological and Mineral Survey Miscellaneous Publ. M, 2 p.

-----1987, Guidelines for evaluating surface fault rupture hazards in Utah: Salt Lake City, Utah Geological and Mineral Survey Miscellaneous Publ. N, 2 p.

Utah Seismic Safety Advisory Council, 1981, A brief summary of earthquake safety in Utah and abbreviated recommendations for risk reduction: Salt Lake City, State of Utah Seismic Safety Advisory Council, 13 p.

Wallace, R.E., 1974, Goals, strategy, and tasks of the earthquake hazard reduction program: U.S. Geological Survey Circular 701, 27 p.

Washington Terrace City Council, 1988, Ordinance no. 16-88 providing for a development overlay zone: Washington Terrace, Utah, revised ordinances, chapt. 28, secs. 28-15-1 and following.

Wenk, Edward, Jr., 1979, Scientists, Engineers, and Citizens excerpt from Margins for Survival, New York, Pergamon Press, p. 144-147: Science, v. 206, no. 4420 (editorial).

Wesson, R.L., Helley, E.J., Lajoie, K.R., and Wentworth, C.M., 1975, Faults and future earthquakes, in Borcherdt, R.D., ed., Studies for seismic zonation of the San Francisco Bay region: U.S. Geological Survey Professional Paper 941A, p. 5-30.

White, G.F., Baker, E.J., Baumann, D.D., Chow, W.T., Downing, T.E., Lord, W.B., Marts, M.E., Mitchell, J.K., Platt, R.H., Sorenson, J.H., Tubbesing, S.K., and Waterstone, Marvin, 1976, Natural hazard management in coastal areas: Washington, D.C., U.S. Office of Coastal Zone Management, 294 p.

White, G.F., and Haas, J.E., 1975, Assessment of research on natural hazards: Cambridge, Mass., MIT Press, 487 p.

Wieczorek, G.F., Wilson, R.C., and Harp, E.L., 1985, Map showing slope stability during earthquakes in San Mateo County, California: U.S. Geolo-

gical Survey Miscellaneous Investigations Series Map I-1257-E, scale 1:62,500.

William Spangle and Associates, 1989, Proposal for rendering assistance in implementing seismic safety programs in the Wasatch region, Utah: Portola Valley, Calif., U.S. Geological Survey Grant 14-08-0001-G1681.

Wyner, A.J., and Mann, D.E., 1983, Seismic safety policy in California -- Local governments and earthquakes: Santa Barbara, University of California, Department of Political Science, National Science Foundation Grant ENV77-03688, 350 p.

Yanev, Peter, 1974, Peace of mind in earthquake country: San Francisco, Chronicle Books, 304 p.

Yin, R.K., and Andranovich, G.D., 1987, Getting research used in the natural hazards field -- The role of professional associations: Washington, D.C., Cosmos Corporation, 205 p.

Yin, R.K., and Moore, G.B., 1985, The utilization of research -- Lessons from the natural hazards field: Washington, D.C., Cosmos Corporation, 101 p.

Youd, T.L., and Hoose, S.N., 1978, Historic ground failures in northern California triggered by earthquakes: U.S. Geological Survey Professional Paper 993, 177 p., 5 pl.

Youngs, R.R., Swan, F.H., Power, M.S., Schwartz, D.P., and Green, R.K., 1987, Probabilistic analysis of earthquake ground shaking hazard along the Wasatch Front, Utah, in Gori, P.L., and Hays, W.W., Assessment of Regional Earthquake Hazards and Risk Along the Wasatch Front, Utah, v. II: U.S. Geological Survey Open-File Report 87-585, p. M1-M110.

Ziony, J.I., ed., 1985, Evaluating earthquake hazards in the Los Angeles region -- An earth-science perspective: U.S. Geological Survey Professional Paper 1360, 505 p.

Ziony, J.I., and Yerkes, R.F., 1985, Evaluating earthquake and surface-faulting potential, in Ziony, J.I., ed., Evaluating earthquake hazards in the Los Angeles region -- An earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. 43-91.

Interactive Workshops: Essential Elements of the Earthquake Hazards Research And Reduction Program in the Wasatch Front, Utah

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INTRODUCTION

Communication and collaboration between researchers and users of research are essential in a complex, multi-disciplinary, multi-year program. The program of earthquake hazards research and reduction focused in the Wasatch Front, Utah, was such a program. In the early planning phase of the program, it was evident immediately that if hazards reduction was to be successful, researchers from the U.S. Geological Survey (USGS), the Utah Geological and Mineral Survey (UGMS), the University of Utah, and researchers from other State and academic institutions in other parts of the country, as well as public officials from the State and local governments, Federal agencies, and private organizations and citizens, would need to play active roles in the five-year research and implementation program. Coordination of USGS efforts would be a complex undertaking in and of itself with researchers from Menlo Park, California; Golden, Colorado, Reston, Virginia, and Salt Lake City, Utah, representing many different parts and tasks of the agency.

At the onset of the program in 1983, representatives of the major institutions

in the program: USGS, UGMS, Utah Federal Emergency Management Agency (FEMA), Utah Comprehensive Emergency Management (CEM), and University of Utah endorsed a strategy of convening annual, interactive workshops to review progress of the program and to recommend further research and implementation activities. Proceedings of annual workshops were chosen as vehicles to communicate findings of researchers and experiences of public officials and professionals to others who were unable to attend.

The annual workshop was not a new experience for USGS or FEMA. Since 1980 the USGS and FEMA had convened earthquake-related workshops responding in part to an Office of Science and Technology Report which stated, "It is crucial, then, that Federal agencies that produce hazards information collaborate with program and local officials as they develop policies and procedures. Furthermore, research shows that, whenever possible, interaction among Federal, State, and local officials should take place on a face-to-face basis." (Office of Science and Technology Policy, p. 182). Prior success with the process of convening interactive workshops and the shortage of travel funds for non-Utah based participants in the program mandated the use of large, annual workshops to communicate findings and experiences, recommend future research and implementation activities, galvanize support for earthquake related policy, and energize the participants and communities in the program.

This paper evaluates the effectiveness and importance of the workshop process in the overall program by providing an assessment of the role and value of the interactive workshops in the five-year program of hazards research and hazards reduction in the Wasatch Front area. The assessment will be valuable to: 1)

USGS in its long term planning of future multidisciplinary focused research and implementation programs, 2) participants in the ongoing Utah program, and 3) other institutions which will be undertaking long term, complex programs which involve information transfer. The paper is not an evaluation of the focused research and implementation program in the Wasatch Front area. This evaluation will be best undertaken at a later date, upon completion of the program and after sufficient time has elapsed to allow for implementation of earthquake hazards information and research into public and private policy.

The paper shows that interactive workshops during the Utah program provided the forum and stimulus necessary to foster collaboration between participants in the program, energized the participants in the program, and reduced the time necessary to implement a complex interdisciplinary program of earthquake hazards reduction. The paper describes the Utah Regional Earthquake Hazards Assessment program. Literature regarding the effectiveness of workshops in facilitating collaboration between users of research and researchers is reviewed and the workshop process and the results of interviews and surveys of participants in the program are described in context. In the final section of the paper, conclusions are drawn from interviews and surveys and observations about the usefulness and importance of interactive workshops to the focused earthquake hazards research and reduction program in the Wasatch Front, Utah, are made.

UTAH REGIONAL EARTHQUAKE HAZARDS ASSESSMENT PROGRAM

More than 80 percent of Utah's 2 million people are located along the Wasatch Front. A large earthquake centered near Salt Lake City has the potential to

cause extensive damage to buildings, lifelines, and public facilities. The October 28, 1983, Borah Peak, Idaho, magnitude (m_s 7.3.) earthquake demonstrated the fact that large earthquakes occur in the Intermountain Seismic Belt where the Wasatch Front is situated.

In 1983, USGS targeted the Wasatch Front for a five-year program of focused earthquake hazards research and hazard reduction called the Utah Regional Earthquake Hazards Assessment program. The goals of the program were to: 1) accelerate the development of a knowledge base on seismic sources, size, frequency of occurrence, and the physical effects of earthquakes in a 10 county area along the Wasatch Front, including Salt Lake, Davis, Juab, Weber, Wasatch, Summit, Morgan, Cache, Utah, and Box Elder counties and 2) foster implementation of earthquake hazards mitigation measures (Hays and Gori 1984, p. 17-22). The goals were to be tackled simultaneously by subdividing the effort into five components:

1) Development of information systems for use in earthquake hazards evaluations, risk assessment, and implementation of loss reduction measures.

2) Synthesis of new and existing geological and geophysical data needed for the evaluation of earthquake hazards.

3) Development of ground motion models and maps of ground-shaking hazard.

4) Development of loss estimation models for loss and casualty estimates for urban areas.

5) Implementation of measures to mitigate the earthquake hazards.

To carry out these objectives successfully, the program of focused earthquake hazards research and hazards reduction required the participation of a diverse set of institutions. The major institutions which particpated in the program were:

U.S. Geological Survey
  Geologic Division
  Mapping Division

Federal Emergency Management Agency
  National Headquarters
  Region VIII

Utah Geological and Mineral Survey

Utah Division of Comprehensive Emergency Management

University of Utah

Utah State University

Numerous other organizations and individuals participated in the program from its inception in 1983, including but not limited to: county and city planners; State, county and local government officials; engineers; consulting

geologists, and representatives from USGS Division of Water Resources, U.S. Bureau of Reclamation, U.S. Corps of Engineers, local utilities, private colleges and universities, and the media.

The major participants agreed on six strategies to meet their twin goals of increasing the level of understanding of the seismic hazards in the Wasatch Front and implementing earthquakes hazards mitigation measures.

The six strategies were as follows:

1) USGS and UGMS would foster strong partnerships with the universities, private sector, units of local government, and other State and Federal agencies.

2) Results of past research studies would be used to the fullest extent possible.

3) Ten counties along the Wasatch Front would be studied. Although Salt Lake, Davis, Utah, and Weber Counties would receive the primary attention because of their population density, potential risk, and the availability of information from prior and ongoing research studies, Cache, Box Elder, Summit, Wasatch, and Juab Counties would also be studied.

4) Each year, a workshop would be held in Salt Lake City to review the year's progress and recommend future research.

5) Proceedings of the workshops, which would include papers documenting

results from all research projects in the Wasatch Front, would be published as USGS Open-File Reports. A USGS professional paper, including the major research findings, would be published at the conclusion of the program.

6) Knowledge gained from earthquakes such as the Borah Peak, Idaho, earthquake of October 1983 would be used to improve the methodology that is currently used in the evaluation of earthquake hazards and the assessment of risk in the Wasatch Front area. Earthquakes in other parts of the world that share a similar tectonic setting with the Wasatch Front would be investigated to provide insight into the characteristics of groundshaking and the physical effects that might occur in a major earthquake (Hays and Gori, 1984, p. 21-22).

Especially significant is the fact that the planners of the Regional Earthquake Hazards Assessment Program decided early in the process to convene annual workshops in Salt Lake City to review what was accomplished each year and to plan future activities. In fact, three of the six strategies depended on workshops. Strategy #1, formation of partnerships, relied on the workshop process because only through an interactive process could strong partnerships be initiated and maintained. Workshops provided that arena and, as will be discussed below, helped form bonds between participants. Strategy #4 called for annual workshops to be convened, and strategy #5 suggested that proceedings from the annual workshops be used to disseminate research results and results from hazard mitigation activities. Therefore, workshops were designated from the beginning of the program to fulfill important functions.

The Regional Earthquake Hazards Assessment Program constituted a major effort of the Office of Earthquakes, Volcanoes, and Engineering of USGS and of UGMS and resulted in programmatic changes. A large number of scientists from the USGS Branch of Geologic Risk Assessment and scientists from other Branches conducted research on the Wasatch Front area during the program. UGMS, with funds from USGS and the State, substantially increased its efforts of earthquake hazards assessment, mapping, and information dissemination during the program. Similarly FEMA and CEM increased attention and funding for earthquake hazards. During the program, the Office of Earthquakes, Volcanoes, and Engineering funded universities and private firms through its external research program to conduct research in the Wasatch Front area in tandem with its internal research program. FEMA funded State and local organizations to implement loss reduction activities in the area. As an indication of how many individuals were intimately involved in the program, 60 individuals contributed one or more articles to the USGS Professional Paper on Assessing Regional Earthquake Hazards and Risk along the Wasatch Front Utah.

A major scientific contribution of the Regional Earthquake Hazards Assessment Program was a refinement of the explantion for seismicity along the Wasatch Front to include a greater understanding of the Wasatch fault and its 12 segments which had been identified. Scientists also identified the "characteristic" earthquake for the region to be similar to the 1983 Borah Peak, Idaho, magnitude (M_S 7.3,) earthquake and concurred that moderate, but potentially damaging earthquakes, without surface rupture (M 5.5 to 6.5), might occur anywhere within the Wasatch Front on known or unknown faults. Researchers had stressed the possibility for a large earthquake centered near Salt Lake City causing numerous injuries, loss of life, and extensive damage

to buildings, lifelines, and public facilties as a result of: 1) Peak ground acceleration expected to be 0.2 - 0.4g, 2) Surface fault rupture, 3) Tectonic deformation, 4) Landslides including rockfalls and rockslides, and 5) Liquefaction. At the close of the five-year program of focused research, the participants drafted a consensus document which specified the extent of the earthquake hazards and types of mitigation measures which were appropriate to minimize damage and losses from future earthquakes. Federal, State and local government, as well as private institutions and individuals, had begun to act on the information provided from the program. By 1989, the program moved into a second phase which emphasized implementation of loss reduction measures at the State, local, and individual level, although the participants recognized the need to continue assessing and mapping the earthquake hazards.

THE ROLE OF INTERACTIVE WORKSHOPS

The USGS, in its planning for the Regional Earthquake Hazard Assessment Program, followed the well documented assumption that interaction between researchers and users of research increases the probability that research will be relevant to the user's needs and, therefore, will be more readily used (Nigg, 1987; Yin and Moore, 1985; Yin and Gwaltney, 1985; Glaser 1983). Researchers agree that knowledge is likely to be utilized where interpersonal communication networks have been established and maintained. The network of researchers and users must be supported during the life of the research, even as knowledge production is occurring and after it has been completed, to assist in its utilization (Yin and Gwaltney, 1985; Yin and Moore, 1985; and Yin and Andranovich, 1987).

The focus of utilization is people, not maps and reports. When researchers interact with users there is two-way communication. Preliminary information is transmitted to potential users, who in turn communicate their needs and explain how to modify the research to meet those needs. Individuals develop working relationships with each other. Not only do users become acquainted with the authors of reports, they also become acquainted with other research which may also be useful. The researchers, in turn, benefit from refined problem identification, and by participation in a network of other scientists and users, help create an audience and a market for their information and products.

Knowledge utilization is enhanced through the networking process which can sometimes be defined as collaboration. There are numerous arenas where collaboration can take place. Interactive workshops, advisory committees, interdisciplinary research projects, information centers, and professional societies are some of the arenas. USGS chose interactive workshops as one of the arenas to foster collaboration between researchers and users of research because during interactive workshops, individuals from many different disciplines meet each other, learn to appreciate each other's needs, and learn about concurrent research and implementation of research, and finally, form ongoing networks to enhance the utilization of research.

Because of the importance of maximizing resources allocated to research and because of society's need for new and better ways to solve problems, social science research has focused for the last two and one-half decades on how new information is incorporated into policy. During that time, researchers and practitioners have reached a similar conclusion, that personal interaction

between investigators doing the research and potential users of the research is essential to knowledge utilization.

Three of several theories (Glaser et. al. 1983) which explain how research is utilized are as follows:

1) Knowledge-driven theory: Utilization of research is characterized by a sequence of activities where research discovery moves through various phases. This theory is also called the "research development and diffusion theory."

2) Problem solving theory: Utilization of research occurs when users identify a need or problem and research is initiated in response to that need.

3) Social interaction theory: Utilization of research occurs as a result of interaction between knowlege producers and knowledge users prior to, during, and following the research.

Yin and Moore (1985) scrutinized the natural hazards field to ascertain which of the above theories or combination of theories best explained why and how research gets used in the natural hazards field. They based their findings on case studies of natural hazards projects which experts rated as exemplary.

In cases where knowledge from the research projects were utilized, the investigators found strong support for the social interaction theory as evidenced by the following conditions:

1) Research producers and research users belonged to overlapping networks.

2) During early stages of research project, communications and interactions resulted in modification of research design as a result of information obtained from users.

3) During the course of the project, communication occurred before, during and after completion of the project.

4) Results were disseminated through some medium, catering to users, not other researchers. (Yin and Moore 1985)

Yin and Moore's work reinforces the importance of maintaining persistent interaction (two-way communication) between investigators doing the research and potential users of the research so that their concept of a "market share of ideas" can develop where the researchers and users of research exchange ideas, information, and experiences.

Yin and Moore's research is based in part on the theories and research findings presented by Glaser et. al. The role of interpersonal interaction is explored in this encyclopedia of research on applications of knowledge for planned change. Glaser and others document the importance of informal contact. Glaser's research concluded that the most effective way to increase information is through personal interaction; and that a well-informed colleague serves to channel information to co-workers. (Glaser et. al., 1983,

302). For example "as much as 85% of useful scientific information is exchanged informally before the usual bibliographical sources are consulted to ascertain whether published information is available" (Glaser et. al., 1983, 304). In fact, the studies showed that researchers depend heavily on informal networks and interaction with applied scientists who are in touch with colleagues from different disciplines. To increase information exchange, one researcher recommended that isolated scientists be brought into closer contact with scientists who are the foci of information networks (Glaser et.al., 1983, 303).

Glaser and others (1983) document the effectiveness of workshops and seminars which include users and producers of research to increase utilization of knowledge. Workshops and seminars contribute to utilization by providing an arena for practitioners to acknowledge the implications of research findings and researchers to obtain feedback from those who would use their findings. The authors also document the effectiveness of conferences and workshops to link research to practice through the personal bonds which are formed at these meetings.

The authors found evidence that utilization of new information is further enhanced when the conference or workshop provides a publication of the conference proceedings and the conference is one of a series of annual meetings on the same topic (Glaser et. al., 1983, 306).. In addition, when attendees participate in the formation of action plans to implement research results, utilization of research tends to occur at a quicker pace (Glaser et.al., 1983, 306).

Participants at a U.S. Department of Energy sponsored Technology Transfer Workshop entitled, "A Synthesis of Technology Transfer Methodologies," in 1984, documented similar experiences and prescribed similar actions to increase the use of scientific information. The participants of this workshop, who were interested in the transfer of technical information not related to natural hazards, found that the transfer process is a human activity conducted by "enthusiastic people!" (Traeger, 1984, 181).

Robbins (1984,) suggested five principles necessary for successful technology transfer. They are:

1) Access to information is necessary but not sufficient.

2) Information must be translated.

3) Personal contact is the most important channel through which technical information is obtained.

4) Solutions must be adapted to user's problems.

5) Products must meet the needs of users, not producers (Robbins, 1984, 72-74).

Others at the workshop emphasized the interpersonal aspect of technology transfer. "Information dissemination is a human function. While it is essential to incorporate a large resource base, including printed reports, library services, data bases, technical experts, consultants, as well as

private, public, and governmental agencies, our experience has demonstrated that the amount of technology actually transferred is directly proportionate to the amount of face-to-face activity." (Marlow, 1984, 143). Participants recommended many different ways to increase face-to-face activities, including professional society meetings, conferences, and workshops.

In fact, Traeger, a workshop participant, related that when individuals at Sandia National Laboratories were asked to identify the catalyst which initiated transfer of technology from 1981 to 1983, meetings and workshops were among the most important. (Traeger, 1984, 176).

Greene and Gori (1982) also documented the fact that hazard information was obtained by Charleston decisionmakers through personal contacts and that workshops were effective catalysts for stimulating action (Greene and Gori, 1982, 27-28). In presentations at three workshops on "A Review of Earthquake Research Applications in the National Earthquakes Hazards Reduction Program," (Hays 1987) workshops were cited as important areas for the exchange of new information on need for and measures to reduce earthquakes vulnerability. Whitehead (1987) from Kentucky; Molinelli (1987) from Puerto Rico; Olson (1987), Bagwell (1987), and Lindbergh (1987) from South Carolina; and Johnston-Fischer (1987) from the U.S. Virgin Islands referenced one or more interactive workshops conducted by the USGS as important factors in increasing their and others' concern and knowledge about earthquake hazards reduction in their region.

INTERACTIVE WORKSHOPS IN UTAH

Methodology of the Study

In order to gage the effectiveness of workshops in Utah, the opinions and experiences of participants in the program were sought and analyzed in two different ways. First, the opinions and experiences of the leaders of the program were recorded during two lengthy round table conversations in Salt Lake City during an annual workshop Second, the author completed a systematic survey of researchers, public officials, and private individuals partcipating in the program. Responses from recorded conversations and written questionnaires form the basis of the findings.

The Workshop Process

Each workshop followed essentially the same model. A steering committee was established to formulate the basic working concepts and procedures for the meeting. The steering committee, made up of representatives from the sponsoring groups, then formulated an agenda, a list of speakers, and a list of invitees. The agenda, speakers, and participants were chosen to represent many disciplines, as well as the local experience. The workshop was organized to exchange information and to develop recommendations or "action plans" which could be implemented once the workshop is adjourned. Proceedings from each workshop, made up of the talks given at the workshop and the recommendations of the participants, were published as open-file-reports by the USGS and disseminated to the participants of the workshop and the public.

Following this model, seven workshops were convened in Utah from 1984 to 1989. Four of the workshops were objects of this study:

August 14-16, 1984: Workshop on "Evaluation of Earthquake Hazards and Risk in Utah."

July 10-11, 1985: Workshop on "Earthquake and Landslide Hazards in the Wasatch Front Region of Utah," (hosted by Utah Geological and Mineral Survey).

July 30-September 1, 1985: Workshop on "Earthquake and Landslide Hazards in the Wasatch Front Region of Utah," (hosted by Utah Division of Comprehensive Emergency Management).

July 14-18, 1986: Workshop on "Earthquake Hazards Along the Wasatch Front, Utah."

(The 1985 workshops were organized by the State agencies and dealt with topics pertinent to the host agency. Individuals participating in the Utah program were invited to one meeting or the other.)

The workshops in Utah were designed as important yearly events--milestones in the program. Participation was open and well publicized. Lists of invitees and speakers, as well as the workshop agenda, were formulated by the steering committee which was made up of representatives from the participating organizations. Workshop agendas were intended to involve all the diverse interests in Utah in a way that would allow the exchange of new information that had been gathered through research and experience during the year. The other general objectives of the workshops were to:

1) Set goals for research and implementation through consensus.

2) Energize participants, both in research and implementation communities.

3) Recruit allies and formulate advocates for earthquake hazard reduction.

Typically, workshops had a mix of formal presentations, small discussion groups and informal gatherings. A quarterly newsletter, "The Wasatch Front," edited and published by UGMS, communicated with participants in the program during the year and offered the participants an informal method of disseminating new findings and experiences. Proceedings of the workshops, which included a summary of the workshop, papers presented, small discussion group reports, and list of participants were published six months to a year following each workshop.

Results from Recorded Conversations

Leaders in the program were invited to share their thoughts regarding the role of the workshops at two luncheons held in the summer of 1986 during the annual workshop. The first group consisted of scientists; the second group consisted of public officials and others who were not scientists. The leaders were divided into two groups, to make the conversations manageable by giving each individual a chance to respond and focus on the conversation.

The following individuals took part in the conversations which lasted

approximately 1-1/2 hours each:

Group I:

David Schwartz, USGS, Menlo Park, CA (formerly Woodward Clyde Consultants)
Robert Smith, University of Utah, Dean, Department of Geology and Geophysics and formerly Director, University of Utah Seismograph Stations
Al Rogers, USGS, Branch Chief, Golden, Colorado
Jeff Keaton, Dames & Moore, Salt Lake City, UT
Walter Hays, USGS, Office of Earthquakes, Volcanoes, & Engineering, Reston, VA
Don Mabey, Deputy Director, UGMS, Salt Lake City, UT
Wendy Hassibe, USGS, Director, Public Information Office and Editor of Wasatch Front Forum, Salt Lake City, UT

Group II:

Loren Anderson, College of Engineering, Utah State University, Logan, UT
Ralph Finlay,[1] CEM, Salt Lake City, Utah
Lawrence Reaveley, Reaveley Engineers and Associates, Inc. Salt Lake City, UT
Walter Hays, USGS, Office of Earthquakes, Volcanoes, & Engineering, Reston, VA
Genevieve Atwood, State Geologist and Director, UGMS, Salt Lake City, UT
Jim Tingey, CEM, Salt Lake City, UT
Lorayne Tempest Frank, Director, CEM, Salt Lake City, UT
Gary Johnson, FEMA, Washington, D.C.
Delbert Ward, Structural Facilities Inc., Salt Lake City, UT

[1]Deceased

The conversations were conducted during lunch. A small microphone was set up in the center of the table and people responded to general questions or topics which the author outlined. The topics centered on the workshop's role in introducing new sources of information, research findings, and methodologies. Individuals spoke without much prompting or interference from the author except when it was necessary to move on to the next topic.

Each group of leaders was asked to reflect on what happened at the workshops, what people they met, what they learned, and what they did differently following the workshop that they could attribute to what they learned at the workshop. The two groups had similar views of the workshops, and therefore, their opinions will be reported together.

The leaders all remarked that the workshops gave them an opportunity to meet and communicate with new people. The workshops let individuals identify who had the information that they needed. Researchers met individuals conducting similar research. They also met individuals whose work they knew but with whom they had never had a chance to talk. Researchers met the public officials and design professionals who depended on their work. Everyone met individuals from different parts of the country whom they might otherwise never have had the opportunity to meet. One Federal official stated that he met individuals from Utah whom he would call on to teach courses in other regions; he also stated that he would use demonstrations that he saw in the workshops at future training courses.

Both the researchers and practicioners agreed that the workshops were excellent forums to communicate with individuals "inside" and "outside" their

fields. For some researchers, it was the first opportunity in their careers to hear from the users of scientific information. This opportunity resulted, in some cases, in redirection of the research into new areas. A university scientist stated that at the workshops he learned about scientific areas which were not being addressed and problems which needed to be solved. He, therefore, embarked on a new area of research in order to do something "brand new."

The workshop was seen as a mechanism to place individuals and their work into the larger program. Each year the number of individuals at the workshop increased and the areas of expertise and interest expanded. The locals saw their relation to Federal and State representatives and vice versa. The contacts formulated in the workshop increased the likelihood that individuals would be called on during the year for assistance. A university scientist stated that he could not overestimate the importance of making contacts with people with common objectives. Contacts formed at the workshops made it easier to approach individuals at a later date for information or to get problems solved.

For the participants, especially the local scientists and design professionals, the workshops brought them "up-to-date" in a hurry. The Director of UGMS stated that the workshops gave her and her staff an opportunity to be up-to-date on scientific research. A geotechnical engineer stated that the workshop gave him an opportunity to have one-on-one discussions with scientists he may not have ever met. The workshops allowed the local scientists at UGMS to learn what USGS scientists were discovering and what university and individual researchers funded by USGS were learning.

The researchers valued the time constraint that the workshops placed on them, forcing them to put their findings down on paper for everyone to review. At the same time, the workshops gave the scientists a regional forum in which to relate their findings and an immediate method of disseminating their results. A university scientist remarked that the workshops may have lowered the cost of the program by getting "more bang for the buck" in that the workshops inspired other research which the university undertook on their own. An architect stated that the workshop brought the participants new information in a meaningful way because it showed them how to use the new information. A university scientist remarked that as a result of the workshop, he changed the earthquake engineering course that he teaches. An emergency manager stated that not only did the workshops keep him "current" but they made his job easier, especially in his contacts with the news media.

The conversations reinforced the theories previously discussed. The leaders emphasized the importance of the workshops to introduce the participants and their research, experiences, and responsibilities to each other. A representative from UGMS stated that the workshops were a bonding experience, and a university scientist stated that the workshops served as a forum where you could present your work, get recognition, and where you were able to interact with people who would use your information. A practicing architect identified the important aspect of the workshop as the "driving mechanism for coordination of random research." Finally, representatives from the State government stated that the intangible benefit of the workshops was the commitment they instilled in the participants to the goals of the program.

The scientists valued the workshops because they gave them a sense of involvement in reducing hazards. They were cajoled into putting their results into a form that would be usable to planners. A scientist from the Federal government stated that scientists were forced to talk to planners in a language that they were not accustomed to using. A university professor related his experience of sitting down with an engineer and showing him how to use the data in his model. The proceedings of the workshops were also seen as important topical references of what was being done in Utah and by whom.

Conversations with the leaders in the program showed that they valued the workshops not only as arenas to meet new people and learn new ideas, but as an essential ingredient in the overall program, coordinating and focusing the research, expanding the uses of the research, focusing the participants on the goals of the program, and lastly, tying the program and its diverse participants together.

Results From Questionnaire

Participants were asked to assist in evaluating the role of the workshops by completing a questionnaire mailed to them late in 1986. The mailing list for the Wasatch Front Forum Newsletter was used because it included all the past workshops' participants and others interested in earthquake hazards in the Wasatch Front. (Individuals who had attended the recorded conversations were not mailed a questionnaire.) Of the 250 questionnaires mailed, 91 responses were received (79 from individuals who had attended one or more workshops and 13 from individuals who had not attended the workshops). The response rate was approximately 37 percent. The responses to the questionnaire were used to

corroborate opinions that the leaders had expressed in the recorded conversations. Only the responses from those who attended the workshops were used for this study. Some respondents chose not to answer all questions. The respondents were not asked to identify themselves. See appendix A for a copy of the questionnaire.

Respondents represented all sectors of the Utah earthquake hazards community in terms of affiliation and profession. Most respondents worked for a county, city, or State governmental agency; however, many of the respondents worked for the Federal government, a university, or the private sector. The following is a breakdown of how the respondents characterized their workplace:

City or County	24
State	20
Federal Government	17
University	9
Private	9

Respondents represented many different disciplines involved in the program. The majority of respondents were scientists and engineers; however, there was a good response from land-use planners and emergency service professionsals. Respondents described their agency or office as follows:

Scientific	25
Planning	21
Emergency Services	14
Geotechnical Engineering	8

Structural Engineering	3
Building Department	1
Architectural	1
Other	6

Most of the respondents had attended two or three workshops, although many had attended only one, and a smaller number had attended all four. The responses were as follows:

Attended 1 workshop	24
Attended 2 workshops	27
Attended 3 workshops	19
Attended 4 workshops	9

Participants in the workshops were asked a number of questions concerning who they met at the workshops, what they learned at the workshops, and what use they made of their new contacts and information. In addition, they were asked a series of questions to document what other needs and functions the workshops fulfilled.

Most respondents met new people within their field at the workshops. Forty-one respondents met between one and five new individuals. Fifteen met between six and ten, and nine met more than ten. Only 14 individuals responded that they met no one new in their own field at the workshops. The new people were from:

Salt Lake City	42

Other parts of Utah	30
Washington, D.C.	27
Other parts of country	28

Denver and California were mentioned frequently under "other parts of country." The concentration of responses in Utah and Salt Lake City (72) points out that attendees of the workshops (the majority of whom were from Utah and Salt Lake City) met other individuals in their field of interest who were from the Wasatch Front study area. In fact, when asked if they had called on these new contacts after the workshops, 48 individuals responded that they had contacted between 1 and 10 or more individuals for information. The responses were as follows:

Contacted none	31
Contacted 1 - 5	40
Contacted 5 - 10	6
Contacted 10 or more	2

The respondents were also asked how many new people they met at the workshops from other fields. The majority of individuals met more new people outside their fields than within their fields. Only four individuals stated that they met no one new outside their discipline. Twenty respondents met over 10 new individuals; 21 met between 6 and 10 new individuals; and 34 met between 1 and 5 new individuals outside their field. Respondents were asked to identify the fields new individuals represented. They were asked to select one or more of the following disciplines:

Scientific

Geotechnical Engineering

Structural Engineering

Architectural

Planning

Emergency Services

Building Department

Other

The respondents selected between 0 and 8 areas from which they met new individuals. Thirty four met individuals in 2 or 3 other disciplines; 31 met individuals in 4 or 6 other disciplines; and 5 met individuals in 7 or 8 new fields. The actual responses are as follows:

0 new disciplines	4
1 new discipline	5
2 new disciplines	16
3 new disciplines	18
4 new disciplines	15
5 new disciplines	11
6 new disciplines	5
7 new disciplines	3
8 new disciplines	2

A major conclusion of the questionnaire is that a large number of participants at the workshops met individuals outside their immediate profession or discipline. Respondents were then asked to rank new sources of information

who they encountered at the workshop. The responses were grouped into very useful, useful, and not useful. To be counted as very useful, an answer would need to use an adjective such as extremely, very useful, etc., and or, in some cases, explain how they used the information. To be characterized as useful, the respondent would need to use adjectives such as helpful, useful, etc. Those respondents who did not answer the question or who used "not" in front of the adjective were characterized as not useful. Thirty-eight respondents characterized the usefulness of their new sources of information as very useful; seventeen found the new individuals who they met at the workshop to be useful sources of information; and twenty-four respondents did not find new individuals to be good sources of information, or they did not seek information from the new individuals they met at the workshops.

Some explanations of how the new information sources were used are as follows. A Utah State scientist stated that it was "extremely useful to meet and ask questions of authors of reports he had previously read." An official from a Utah State emergency services department stated, "Even though we receive the printed material in our office, the people making the presentations added to my understanding of the earthquake threat." A geotechnical engineer with the State wrote, "the contacts have been useful in exchanging information and acquiring technical assistance." Another individual with the State emergency services department commented, "I refer questions to contacts that I have made or back up my reply with a reference to such a contact. Also, I ask people whom I met at the workshops to speak at local workshops." A local land-use planner said that he has a "better idea of what agencies I can contact for assistance or technical expertise." And lastly, a journalist answered that the workshops provided "new sources for

news stories and personal contacts with people who had previously been only names."

Many of the Federal scientists at the workshop also found that new contacts became useful. For example, a Federal scientist stated, "The workshops were most helpful in knowing who's doing what in Utah. Being located out of Salt Lake City is a hindrance, so this aspect of workshops is very beneficial." Another Federal scientist found the workshops to be useful for "renewing contacts with colleagues in order to remain current on the directions and results of their research."

Participants who responded to the questionnaire agreed with the leaders about meeting new people at the workshops. Approximately two-thirds of the participants responding to the questionnaire characterized the new contacts they met at the workshop as useful, and many of these contacts were from different fields.

Participants were also questioned about new information they might have learned at the workshop. Specifically, they were asked to describe what new information they learned about earthquake hazards in Utah. The author asked participants to identify new information they had acquired about segmentation of the Wasatch fault system, recurrence intervals, maximum size of the expected earthquakes, the characteristic earthquake, and some of the other earthquake hazards such as liquefaction, landslides, etc., that was presented and debated at the workshop. Sixty-three individuals were capable of describing, in their own words, much of the new information that they learned. Forty-five individuals were able to identify and describe one or

more of the above topics. Eighteen only identified one, and 16 were either unable or did not attempt to answer the question. With 80 percent of those responding to the questionnaire capable of stating what they learned, the workshop participants, like the leaders in the program, clearly came away with new knowledge about the earthquake hazards of the Wasatch Front.

It is important for new information to be applied if it is to be of value. Therefore, participants were asked how they used the new information. The respondents were asked if they used the information in their research, job, or private life. Of the 62 individuals (which represents approximately 80 percent) who stated that they had an opportunity to apply the new information, 50 used the information in their job, 30 in their research, and 18 in their private life.

Nearly two-thirds of the respondents found the information that they learned at the workshops to be useful. Forty-one of those who responded characterized the information as very useful, 12 as somewhat useful, and 26 as not useful or no response. The following comments exemplfy how the new information was used. A building department official stated that he used the new information in "siting new State buildings and preparing environmental assessments." A State land-use planner said that the new information was used in "promoting a comprehensive earthquake hazard mitigation program." A State emergency services official used the information to "better inform the public and private industry of the possibility of damage to their particular facilities and how they might mitigate such damage." A Federal scientist used the information in a risk-based evaluation of dams. Another Federal scientist stated, "The awareness of other researchers' work has contributed to applying

new ideas to my area of study." A university scientist bought earthquake insurance after attending one of the workshops; and a county land-use-planner used the information to design a sensitive-land ordinance for geologic hazards and to designate which areas would require regulation.

Finally, the repondents were asked what other needs and functions the workshops fulfilled. They were asked to respond to a list of statements by ranking their answers from 1 to 5 with 1 representing low agreement and 5 representing high agreement with the statement.

By selecting "5," "4," or "3," more that eighty percent of the repondents registered their beliefs that the workshops:

Enhanced appreciation of other disciplines.

Provided focus for news media.

Enhanced public awareness of earthquake hazards.

Provided a forum for recognition of individual research.

Set an agenda for research.

Provided a timely document for research and or implementation (the proceedings).

Renewed commitment to solving problems or implementing policy.

The majority of respondents did not believe that the workshops "provided a deadline for adoption of mitigation." Nor did a majority believe that the workshops "provided a deadline for completion of research"; however, most respondents (27 and 32 respectively) answered "3" to these questions. The actual responses to all the statements are as follows.

Workshops also may have fulfilled other needs and functions for you, your community, or State. Please rate how well the workshops may have contributed to the following:

	Low 1	2	3	4	High 5
1) Enhanced appreciation of other disciplines.....	0	6	20	37	15
2) Provided focus for news media.....	1	14	18	29	15
3) Enhanced public awareness of earthquake hazards.	3	9	23	27	17
4) Provided forum for recognition of individual research.....	0	10	19	33	16
5) Set agenda for research.....	1	9	28	25	8
6) Set agenda for action.....	2	10	29	26	7
7) Provided deadline for completion of research....	6	16	32	12	5
8) Provided deadline for adoption or implementation of policy.....	9	22	27	7	3
9) Provided a timely document for research and or implementation (the proceedings).....	0	8	20	34	11
10) Renewed committment to solving problems or implementing policy.....	2	4	20	33	15

The respondents were also asked to list other contributions that the workshops may have made which were not previously addressed. Most respondents chose not to answer the question; however, of the the eleven who answered, nine identified contributions to understanding and two identified contributions to research.

The following are some of the Federal scientists' comments.

> I gained appreciation of the need for clearer communication of scientific results in terms that users can understand and apply.

> I understand better than before the importance of subtleties of implementing scientific information.

> From a scientific point of view, the information was very useful to me. Focused scientific sessions which bring together people who are working on the same problem or related problems are much more effective means of communication than ordinary scientific meetings.

A university, geotechnical engineer and a private structural engineer stated:

> The workshops provided opportunity to determine what was needed by non-technical people regarding geotechnical issues.

> Without the workshops, the Utah community would be years behind in seismic awareness and planning issues.

Possibly, one of the best explanations of the role of the workshops was expressed by a State planner.

> Workshops provide one of the few forums where individuals from many disciplines can exchange information and ideas directed towards a specific goal. Through concerned experts, earthquake problems and solutions have been better defined. For myself, the contacts with these experts instills confidence and reassurance that I can influence earthquake hazard mitigation.

CONCLUSION

The survey of participants was conducted to gauge whether leaders' opinions were shared by the participants. The response to the survey represented the diverse nature of the participation in the program. The respondents' answers to the questionnaire were indeed similar to those expressed by the leaders. According to the participants' responses, the workshops served as arenas where individuals met others who were working on earthquake hazard reduction in the Wasatch Front. The individuals expanded their circle of colleagues to include individuals from other disciplines, other agencies, and other regions of the country. The new sources of information were contacted for many different reasons, and most of the respondents judged them useful.

Similar to the leaders, the participants learned new information about earthquake hazards in the Wasatch Front at the workshops, information which they used in their research, their jobs, and in their private lives. The

respondents' explanation of how they used the information replicated many of the statements made by the leaders of the program, as did their responses to the list of specific functions that the workshops fulfilled. Like the leaders, the participants believed that the workshops fulfilled a role of broadening their appreciation and understanding of the many different disciplines and individuals involved in the program. The respondents agreed also that the workshops provided a forum for recognition of indiviual researchers, as well as a method for disseminating timely information in the form of workshop proceedings. Many individuals also saw the workshops as tools for influencing the research agenda. In terms of increasing awareness and commitment to solving problems and implementing policy, most participants gave high marks to the workshops, as did the program leaders.

The representatives of institutions involved in planning earthquake hazards research and reduction program were correct to give the annual workshops a prominent role in the program. The interviews and questionnaires verified the effectiveness of interaction between researchers and users of research and the use of workshops to encourage implementation. The workshop process set up a "marketplace" of ideas that did not begin or end with the workshop itself, but was carried on throughout the 5-year program. What individuals gained at the workshops and how contacts and information were later applied in research and implementation activities leads to the conclusion that the workshop process was an invaluable element in the 5-year program. Any plans for future, complex, multi-disciplinary programs would do well to follow the example of this program and incorporate the use of frequent interactive workshops into its design.

The use of workshops was valuable to the earthquake hazards research and reduction program. Although not fully evaluated in this paper, the workshop process also may have facilitated the incorporation of hazards information into public and private practice. This assessment can only take place after sufficient time has elapsed to allow for implementation of public and private policy. The evaluation of the influence of the earthquake hazards research and reduction program focused in the Wasatch Front will be an important future research topic.

Selected References

Bagwell, J. B., 1988, Application of the National Earthquake Hazards Reduction Program through an Earthquake Education Center at Charleston, South Carolina, in Hays, W. W., ed., 1988, A Review of Earthquake Research Applications in the National Earthquake Hazards Reduction Program: 1977-1987: U.S. Geological Survey Open-File Report 88-13A, p. 106-114.

Glaser, E. M., Abelson, H. H., and Garrison, K. N., 1983, Putting Knowledge to Use, Facilitating the Diffusion of Knowledge and Implementation of Planned Change: Jossey-Bass, 636 p.

Greene, M. R. and Gori, P. L., 1982, Earthquake Hazards Information Dissemination: A Study of Charleston, South Carolina: U.S. Geological Survey Open-File Report 82-233, 57 p.

Hays, W. W., ed., 1988, A Review of Earthquake Research Applications in the National Earthquake Hazards Reduction Program: 1977-1987: U.S. Geological Survey Open-File Report 88-13A, 583 p.

Hays, W. W. and Gori, P. L., 1984, Regional and urban earthquake hazards, evaluation, Wasatch front, Utah, Draft Work Plan: FY 84-85," in Hays, W. W. and Gori, P. L., eds., 1984, Proceedings of Conference XXVI, a workshop on "Evaluation of regional and urban earthquake hazards and risk in Utah:" U.S. Geological Survey Open-File Report 84-763, p. 17-21.

Johnston-Fischer, P., 1988, Earthquake Vulnerability and Risk Assessment in

the U.S. Virgin Islands, in Hays, W. W., ed., 1988, A Review of Earthquake Research Applications in the National Earthquake Hazards Reduction Program: 1977-1987: U.S. Geological Survey Open-File Report 88-13A, p. 309-314.

Lindbergh, C., 1988, Southeastern United States, in Hays, W. W., ed., 1988, A Review of Earthquake Research Applications in the National Earthquake Hazards Reduction Program: 1977-1987: U.S. Geological Survey Open-File Report 88-13A, p. 118-129.

Marlow, H. ,L, 1984, Another Perspective on Technology Transfer - the PENNTAP Experience, in Meridian Corporation, 1984, Proceedings: A Synthesis of Technology Transfer Methodologies: U.S. Department of Energy Technology Transfer Workshop: U.S. Department of Commerce, p. 135-160.

Meridian Corporation, 1984, Proceedings: A Synthesis of Technology Transfer Methodologies: U.S. Department of Energy Technology Transfer Workshop: U.S. Department of Commerce, 432 p.

Molinelli-Freytes, J., 1988, The Earthquake Vulnerability Study for the Metropolitan area of San Juan: Research Applications, in Hays, W. W., ed., 1988, A Review of Earthquake Research Applications in the National Earthquake Hazards Reduction Program: 1977-1987: U.S. Geological Survey Open-File Report 88-13A, p. 304-308.

Nigg, J. M., 1988, Framework for Understanding Knowledge Dissemination and Utilization: Applications for the National Earthquake Hazards Reduction

Program, in Hays, W. W., ed., 1988, A Review of Earthquake Research Applications in the National Earthquake Hazards Reduction Program: 1977-1987: U.S. Geological Survey Open-File Report 88-13A, p. 13-33.

Office of Science and Technology Policy, Executive Office of the President, 1978, Earthquake Hazards Reduction: Issues for an Implementation Plan, 229 p.

Olson, N. K., 1987, Applications: Seismic Safety Organizations -- South Carolina Seismic Safety Consortium in Hays, W. W., ed., 1988, A Review of Earthquake Research Applications in the National Earthquake Hazards Reduction Program: 1977-1987: U.S. Geological Survey Open-File Report 88-13A, p. 259-271.

Robbins, M. D., 1984, Technology Transfer-An Overview, in Meridian Corporation, 1984, Proceedings: A Synthesis of Technology Transfer Methodologies: U.S. Department of Energy Technology Transfer Workshop: U.S. Department of Commerce, p. 65-76.

Trager, R. L., Technology Transfer Revisited, in Meridian Corporation, 1984, Proceedings: A Synthesis of Technology Transfer Methodologies: U.S. Department of Energy Technology Transfer Workshop: U.S. Department of Commerce, p. 173-200.

Whitehead, C., 1988, Earthquake Hazards Research Applications in Kentucky, in Hays, W. W., ed., 1988, A Review of Earthquake Research Applications in the National Earthquake Hazards Reduction Program: 1977-1987: U.S.

Geological Survey Open-File Report 88-13A, p. 315-319.

Yin, R. K. and Andranovich, G. O., 1987, Getting Research Used in the Natural Hazards Field: The Role of Professional Associations: Cosmos Corporation, p. 1-172.

Yin, R. K., Gwaltney, M. K., 1981, Knowledge Utilization as a Networking Process, in Knowledge: Creation, Diffusion, Utilization, Vol. 2, No. 4: Sage Publications, Inc., p. 555-580.

Yin, R. K. and Moore, G. B., 1985, The Utilization of Research: Lessons from the Natural Hazards Field: Cosmos Corporation, 101 p.

PUBLIC PERCEPTIONS OF THE IMPLEMENTATION OF EARTHQUAKE MITIGATION POLICIES ALONG THE WASATCH FRONT IN UTAH

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ABSTRACT

The earthquake hazard potential along the Wasatch Front in Utah has been well defined by a number of scientific and engineering studies. Translated earthquake hazard maps have also been developed to identify areas that are particularly vulnerable to various causes of damage such as ground shaking, surface rupturing, liquefaction, etc. The implementation of earthquake hazard reduction plans are now underway in various communities in Utah. The results of our study presented in this paper indicate that technical public officials (planners and building officials) have an understanding of the earthquake hazards in Utah and know what can be done to mitigate the hazard. Although the survey shows that the general public has a slightly lower concern about the potential for economic losses, they recognize the potential problems and they can support a number of earthquake mitigation measures. The study suggests that many community groups along the Wasatch Front including volunteer groups and business groups and elected and appointed officials are ready for action-oriented educational programs. These programs could lead to a significant reduction in the risks associated with earthquake hazards.

INTRODUCTION

The effect of earthquakes can cause loss of life and costly property damage; therefore, in areas of high seismic activity, earthquake hazard mitigation must be an important consideration for intelligent land use planning and for the establishment and implementation of local ordinances and

building codes. Damage during earthquakes can result from surface faulting, ground shaking, ground failure, generation of large waves (tsunamies and seiches) in bodies of water, and tectonic deformation. All of these causes of damage need to be considered in reducing the potential for loss of life and economic losses during earthquakes.

The occurrence of earthquakes along the Wasatch Front in Utah has been documented since the arrival of the early pioneers in about 1850 (Arabasz and others, 1979), and recent scientific work has documented the seriousness of the earthquake hazard problem (see Gori and Hays, 1987). In addition to earthquakes, a number of other geologic hazards exist along the Wasatch Front that should be considered in land use planning. For example, during approximately three months in the Spring of 1983, the State of Utah, with a population in excess of 1.6 million people, sustained direct damages from landslides, debris and mud flows, and flooding in excess of $400 million. These disastrous events were so extensive that 22 of the 29 counties in the state were declared natural disaster areas (Anderson and others, 1984). U.S. Geological Survey-sponsored workshops on earthquake hazards in Utah from 1985 to the present have broadened earthquake hazard awareness beyond the scientific community. These well-organized workshops have summarized the research efforts of seismologists, geologists, and engineers and have heightened the awareness of planners and the staff of local government agencies. However, much work must be done to bring the urgency of the earthquake hazard problem to the general public in a way that they will understand the work of scientists, engineers, and planners and then embrace the implementation of ordinances, building codes, and other actions aimed at mitigating earthquakes and other natural hazards.

Kockelman (1989:2) has identified five components that are needed in the development of any earthquake hazard reduction program:

1. Conducting scientific and engineering studies of the physical processes of earthquake phenomena that may be hazardous--source, location, size, likelihood of

occurrence, severity, triggering mechanism, path, ground response, structure response, and equipment response.

2. Translating the results of such studies into reports and onto maps at an appropriate scale so that the nature and extent of the hazards and their effects are understood by nontechnical users.

3. Transferring this translated information to those who will or are required to use it, and assisting them in its use through educational, advisory, and review services.

4. Selecting and using appropriate hazard reduction techniques such as legislation, regulations, design criteria, education, incentives, public plans, and corporate policies.

5. Evaluating the effectiveness of the hazard reduction techniques after they have been in use for a period of time and revising them if necessary. Evaluation and revision of the entire program as well as the other components--studies, translation, and transfer--may also be undertaken.

Research activities sponsored by the U.S. Geological Survey's Earthquake Hazard Reduction Program during the past several years have produced a number of translated research that identifies the seriousness of earthquakes hazards along the Wasatch Front. Maps specifically for Salt Lake County have been completed that identify the potential for fault rupture, ground shaking, ground failure (by liquefaction and earthquake-induced landslides) and tectonic deformation. Thus components 1 and 2 above have already received a great deal of attention. A current project by Madsen and others (1988) is directed toward meeting objectives 3 and 4 as described above by Kockelman.

Before implementation activities can be successful, the public must have an awareness and an understanding of the hazards, and engineers, planners, and public policy officials must be aware of the level of hazard reduction activities that the public will accept. The public must understand that many things can be done to significantly reduce earthquake hazards at little additional costs to them, provided that the problems are identified and mitigated early.

The current project (Madsen and others, 1988) is aimed at implementing an earthquake hazard reduction plan for Salt Lake County, the most populous county in the State of Utah. The

overall project is directed toward earthquake preparedness rather than programs dealing with emergency response and recovery during or after earthquakes. The major objective of the implementation project is to develop a program of earthquake hazard preparedness in Salt Lake County involving public officials, community groups, and the general public. The program is designed to create heightened awareness of earthquake problems, create a public acceptance of earthquake hazard reduction programs, and to develop and implement an earthquake hazard reduction plan for the county. The first step in the project was to assess the earthquake hazard awareness and understanding of public officials (that are working in a technical capacity) and the general public, and to determine types of mitigation measures that they will support.

This paper presents the results of a survey of technical public officials (planners and building officials) and the general public. It assesses concerns of these two groups regarding the potential for widespread and damaging earthquakes in the Salt Lake County area of Utah, and assesses support they give to various mitigation strategies.

METHODOLOGY

Salt Lake County contains twelve municipalities, ten of which have at least one planning or building official. Unincorporated areas are served by personnel of Salt Lake County government. Two surveys were conducted to determine levels of awareness of earthquake problems and support for various mitigation strategies. Twenty-eight officials were identified for inclusion in the first survey. In the largest governmental units, the highest level administrative personnel were identified. Each individual was interviewed in person during May and June of 1988. The completion rate was 100 percent. The public survey was composed of 409 male and female adults who resided in Salt Lake County. They were randomly drawn from Salt Lake County telephone listings and interviewed over the phone during September of the same year. This represents a 70

percent completion rate from the sampling frame. The interviews were conducted by the Survey Research Center at the University of Utah. Among the findings are those which pertain to the assessment of three factors: earthquake hazard knowledge, perceptions of earthquake risks, and priorities for earthquake risk reduction.

RESULTS AND ANALYSIS OF RESULTS

The planners and building officials were asked to rank seven causes of damage from potential earthquakes in Salt Lake County (Salt Lake Valley). They were asked to assign the number one to the item with the highest potential for damage and the number seven to the item with the lowest potential, with corresponding numbers assigned to items between the extremes. The results are presented in Table 1. They indicate a high correspondence between the local officials and the scientific community (see Christenson, 1987). For example, the problem of ground shaking is considered to be the greatest potential hazard based upon scientific investigations. The general public were not asked to make this ranking because of its highly technical content.

Next, how do local planners and building officials (technical officials) and the public perceive earthquake risks? Both samples were asked to indicate how likely it is that there will be an earthquake causing widespread and severe damage in the Salt Lake Valley during three time periods: within the next 100 years, the next 50 years, and the next 10 years. The response alternatives were very high, high, moderate, low, and very low. The point value five was assigned to the alternative very high, high = 4, moderate = 3, low = 2, and very low = 1. The results are presented in Table 2.

The responses from our surveys indicate a great deal of concern about the likelihood of a future damaging earthquake affecting the Salt Lake Valley. In the 100 year period the technical

Table 1. Rankings of potential damage from earthquake hazards in the Salt Lake Valley by local government planners and building officials.

Causes of Damage	$\bar{x}$ of Ranks*	S.D. of Ranks
Ground Shaking	1.52	.75
Ground Failure Induced by Liquification	2.26	1.13
Fault Rupture	3.63	1.55
Landslides and Rockfalls	4.04	1.29
Tectonic Deformation	4.82	1.39
Dam Failure	5.22	.94
Water Waves	6.52	1.37

*Number 1 = highest potential for damage, number 7 = lowest potential for damage.

Table 2. Perceptions of the likelihood of a future damaging earthquake in the Salt Lake Valley: Comparing local technical officials (planners and building officials) and public residents.

Earthquake Risk Time Period	Technical Officials*			Public Residents*				Public Residents by Gender*						
								Men			Women			
	N	$\bar{X}$	S.D.	N	$\bar{X}$	S.D.	S.E.	N	$\bar{X}$	S.D.	N	$\bar{X}$	S.D.	t-Ratio
Likelihood of earthquake causing widespread and severe damage in the Salt Lake Valley within the next 100 years?	28	4.64	.62	394	3.97	1.02	.05	179	3.98	1.05	212	3.94	1.00	.38
Likelihood of earthquake causing widespread and severe damage in the Salt Lake Valley within the next 50 years?	28	4.18	.77	385	3.56	1.08	.06	172	3.48	1.07	210	3.65	1.06	1.55
Likelihood of earthquake causing widespread and severe damage in the Salt Lake Valley within the next 10 years?	28	3.14	.71	385	2.80	1.10	.06	171	2.68	1.03	211	2.91	1.15	2.05

*The response alternative very high was assigned a point value of 5, high = 4, moderate = 3, low = 2, and very low = 1. No probability statistics were calculated for the technical officials. They were a population, not a sample drawn from a population as was the case for the public respondents. Gender was not determined for three public residents.

officials' mean ($\bar{x}$) of 4.64 approaches the highest ranking of "very high" whereas the public sample mean of 3.97 is associated with the ranking of "high." For each time period, the mean of the technical officials is higher than that of the public. However, even the public's rating for the ten year time period ($\bar{x}$=2.80) approaches the ranking of "moderate" likelihood. There is also greater variability among the public than for the technical officials as indicated by the standard deviations (SDs). The technical officials comprised a population, but since the public sample was randomly drawn from a larger population, a standard error was calculated for each public sample mean. For example, the 95 percent confidence interval for the 100 year period is $\bar{x}$ = 3.97 plus or minus .1, which is a small range of variability from sample to sample drawn from the same population. Data from the public sample which compares men and women are also presented in Table 2. A t-test between means yields a statistically significant difference at the .05 level for the ten-year period only. Thus, in general, men and women appear to have similar views about the likelihood of future damaging earthquakes in the Salt Lake Valley.

Respondents to the public survey were also asked questions directed toward concerns about damages to their residences and personal safety if a serious earthquake were to occur in the Salt Lake Valley. The questions were taken from a survey by Rossi and others (1982:318), and the present wording was modified from theirs in order to refer to earthquakes instead of a more general reference to natural disasters. Data pertaining to these questions are presented in Table 3. Each respondent was asked whether he/she was very concerned, somewhat concerned, or not at all concerned that (1) the building in which one lives would suffer serious damage, (2) the contents of the residence would be seriously damaged, and (3) the respondent or someone in the family would be seriously injured.

The results indicate approximately 85 to 90 percent of the respondents were either somewhat or very concerned about their residence, its contents, and the likelihood of personal injury. The category most often identified for both building damage and contents damage was "somewhat

Table 3. Concern of Public Residents About a Future Serious Earthquake Occurring in the Salt Lake Valley.

Area of Concern	Concern Levels of Public Residents							Concern Levels of Public Residents by Gender												Chi Square p
								Men							Women					
	Not at all N	%	Somewhat N	%	Very N	%	Total N	Not at all N	%	Somewhat N	%	Very N	%	Total N	Not at all N	%	Somewhat N	%	Very N	%	Total N	
The building in which you live would suffer serious damage	42	10.3	202	49.8	162	39.9	406	27	14.6	92	49.7	66	35.7	185	15	6.9	108	49.5	95	43.6	218	.026
The contents of your residence (furniture, carpets, appliances) would be seriously damaged	62	15.3	221	54.6	122	30.1	405	41	22.1	100	54.1	44	23.8	185	21	9.7	118	54.4	78	35.9	217	.0006
That you or someone in your family would be seriously injured	44	10.8	134	33.0	228	56.2	406	27	14.5	66	35.5	93	50.0	186	17	7.8	66	30.4	134	61.8	217	.025

*Gender was not determined for three public residents.

concerned," with 49.8 and 54.6 percent respectively. The mode for the personal injury question was "very concerned," with 56.2 percent of the total. These findings are consistent with Rossi and others' (1982:114-115) findings. In their survey of California residents, it was found that people were more concerned about personal injuries with respect to natural disasters than concerns for building or contents damage.

Gender was also found to be an important variable with respect to feelings of concern. We used a chi-square test to compare the responses of men and women. It yielded statistically significant differences for all three questions, with women indicating higher overall levels of concern. The percentages of men and women identifying themselves as "somewhat concerned" are very similar for the three questions. However, the percentages of women in the "not at all concerned" category were consistently about half the percentages for the men, and the responses of women were about 8 to 12 percentage points above the men in the "very concerned" category.

Higher levels of earthquake concern among women than men are supported by other related studies. In a review of the literature concerning responses to public disaster warnings, Sorenson and Mileti (1987) documented that women are more likely than men to hear warnings, to believe such warnings, and to engage in protective warning responses. The findings of Turner and others (1986) also found gender differences in levels of fear and concern about an earth uplift in the Palmdale, California area. This uplift was identified as a possible precursor to an earthquake. Women reported higher levels of fear and concern than men, and taking warnings seriously was also related to fear and concern.

It is important to know if local technical officials are knowledgeable about earthquake hazards and consider a serious earthquake to be likely. It is also important to determine whether the public perceive similar risks and are concerned about them. However, are these attributes of knowledge and concern related to support for policies to decrease earthquake risks in the Salt Lake Valley? To

identify mitigation policies, the technical officials were also asked open-ended questions followed by fixed-alternative questions regarding actions they felt should be taken to reduce the risks from earthquakes in the Salt Lake Valley. Several fixed-alternative items were derived from Kockelman (1986). Items receiving the highest overall ranks using both methods were identified. These same items were then presented to the public sample for their evaluations. The data comparing the two groups are presented in Table 4. The response alternatives to the policy items were: very high importance, high importance, moderate importance, low importance, and not at all important. The response alternative very high was assigned a point value of 5, high = 4, moderate = 3, low = 2, and not at all important = 1.

The averages of the technical officials for ten of the eleven policy items were higher than those of the public sample. However, with the exception of "requiring disclosure of earthquake hazards to real estate buyers," which the public rated 3.61, no item fell below a mean of 4.0 (corresponding to high importance) among the public resident sample. In general, the standard deviations indicated greater variability among the public respondents than for the technical officials. The standard errors (SEs) for each public sample mean when multiplied by 1.96 produce 95 percent confidence intervals of slightly less than one-tenth to slightly more than one-tenth of a point.

Gender comparisons are also identified in Table 4. The data reveal that the averages on all 11 policy items are higher for women than men. These mean differences are statistically significant at the .05 level or greater (t-ratios of 1.96 or larger) for all policy items except, "promoting land use planning which considers earthquake hazard areas." Not only are women more concerned than men about future earthquakes, they are also more supportive of mitigation policies to reduce earthquake risks. We now turn to the problem of converting concerns and support of policy into action-oriented programs of policy implementation.

Table 4. Policies do reduce earthquake risks in the Salt Lake Valley: Comparing local technical officials (planners and building officials) and public residents.

	Technical Officials[a]			Public Residents[a]				Public Residents by Gender[a]						
								Men			Women			
	N	$\bar{X}$	S.D.	N	$\bar{X}$	S.D.	S.E.	N	$\bar{X}$	S.D.	N	$\bar{X}$	S.D.	t ratio
Controlling the location and specific design requirements of new schools, police facilities, and fire stations	28	4.68[b]	.54[b]	407	4.45	.82	.04	186	4.35	.88	218	4.54	.76	2.28
Strengthening existing hospitals, schools, police facilities, and fire stations	28	4.58[b]	.67[b]	406	4.15	.95	.05	185	3.92	1.02	218	4.34	.85	4.46
Informing and educating the public about earthquake hazards and earthquake preparedness	28	4.75	.44	408	4.29	.86	.04	186	4.12	.93	219	4.43	.77	3.67
Providing public officials with earthquake hazard information	28	4.64	.56	405	4.22	.91	.05	186	4.10	.93	216	4.32	.89	2.50
Providing public officials with professional technical assistance	...[c]	...	...	406	4.13	.94	.05	185	3.99	.94	218	4.25	.94	2.76
Promoting land use planning which considers earthquake hazard areas	28	4.54	.74	402	4.11	.99	.05	185	4.03	1.03	214	4.20	.91	1.75
Adhering to existing earthquake-related building codes, zoning ordinances, and building inspections	28	4.58	.88	400	4.31	.87	.04	183	4.19	.92	214	4.43	.75	2.79

Table 4. (continued)

	Technical Officials[a]			Public Residents[a]				Public Residents by Gender[a]						
								Men			Women			
	N	$\bar{X}$	S.D.	N	$\bar{X}$	S.D.	S.E.	N	$\bar{X}$	S.D.	N	$\bar{X}$	S.D.	t ratio
Establishing more stringent earthquake-related building codes, zoning ordinances, and building inspections	28	3.86[d]	1.08	395	4.06	.97	.05	180	3.89	1.01	212	4.22	.87	3.45
Adopting uniform earthquake-related building codes, zoning ordinances, and building inspections	...[c]	...	...	401	4.02	1.03	.05	183	3.91	1.00	215	4.13	.98	2.14
Requiring disclosure of the earthquake hazard(s) to real estate buyers	28	4.32	1.02	397	3.61	1.15	.06	179	3.37	1.21	215	3.84	1.04	4.10
Encouraging public agency programs which improve emergency responses	28	4.21	.79	405	4.03	1.08	.05	185	3.94	1.15	217	4.14	.96	1.97

[a]The response alternatives for the items (except the two indicated) were: very high importance was assigned a point value of 5, high importance = 4, moderate importance = 3, low importance = 2, and not at all important = 1. No statistical tests were calculated for the technical officials. They were a population, not a sample drawn from a population as was the case for the public respondents. Gender was not determined for three public residents.

[b]These first two policy items were originally presented to the technical officials as eight separate items. Each type of facility was presented separately. The means and standard deviations for the technical officials in the table are the averages of the four means and S.D.s for each item. The actual figures for contorlling the location of new hospitals were $\bar{x}$ = 4.96, S.D. .19; schools 4.82 and .39; police facilities 4.39 and .79; and fire stations 4.54 and .79. Corresponding figures for strengthening hospitals were $\bar{x}$ = 4.82, S.D. = .39; schools 4.75 and .52; police facilities 4.29 and .90; and fire stations 4.46 and .88.

[c]Two items were identified by the technical officials in open-ended questions which solicited policy items without the prompting one gets from fixed-alternative items. These two items were not ranked in the same way as the fixed-alternative. They were included because they were identified more often than others as being important policies.

[d]This item fell below all others ranked by the technical officials. It was used in the public survey because the mean of the planners was 4.29 while the building officials was 3.18. This difference between the two subgroups was greater than for any of the original 49 policy items which were ranked.

APPLICATION OF RESEARCH FINDINGS TO IMPLEMENTATION OF EARTHQUAKE HAZARD REDUCTION ON THE WASATCH FRONT

Kockelman (1989) in his analysis of the success of the Wasatch Front earthquake hazard reduction program identifies the importance of targeting specific audiences with specific messages tailored to their needs. Sorenson and Mileti (1987) provide a theoretical model that puts this observation in context: individuals must hear a message, understand it, believe it, and personalize it before they will take action.

How do these observations apply to the Wasatch Front? First, the Salt Lake County survey results indicate a high degree of opinion congruence between technical officials and the general public. Now we need to make the elected and appointed officials who enact public policy know that there is broad-based support for hazard mitigation. The importance of public support in the mitigation process has been identified by Selkregg and others (1984:167) who have stated:

> This relationship between public awareness, support, and implementation is an important one. It suggests that the political and technical leaders are less likely to achieve policy goals related to risk reduction in the absence of public support.

Concerning the importance of educational programs, Selkregg and others (1984:166) have further suggested:

> Scientists and planners need to build communication skills to inform the public and the policy makers of their findings. Consideration of seismic risk in land use planning, building structures, site planning, critical facilities, and other areas will gain greater prominence only if scientists and researchers promote understanding of their work, learn how to communicate and evaluate their needs and the needs of planners and policy makers, and design their products and recommendations to be of optimum use. This broadening scientific responsibility would enhance public understanding and support of research needed to assist policy makers in setting guidelines for public safety. Elected officials, planners, professionals, and scientists need to assume the role of public education.

The results of the Salt Lake County surveys suggest that educational programs concerning earthquake hazards and earthquake preparedness can be directed toward receptive audiences. These data indicate that many community groups along the Wasatch Front including volunteer groups and business groups and elected and appointed officials are ready for action-oriented educational programs. These programs could significantly lead to a reduction in the risks associated with earthquake hazards.

The gender differences identified among the public sample suggest that women in the general public are likely to be a readily identifiable group of individuals who believe in the earthquake hazards and are likely to take action. This raises the possibility that NEHRP could target this group and tailor information in such a way that it will be most readily understood and personalized by them. To our knowledge, this "targeting" has not been done on the basis of gender.

One implication of this study is the need to better understand this observation of a gender difference among the general public. An application of this study's results might be to develop information specifically targeted for the perceived needs of some of the more visible women's groups in Utah. These include local chapters of the League of Women Voters, Parent Teacher Associations, and the Church of Jesus Christ of Latter-day Saints (LDS) Relief Society. Each of these group's differing missions contains elements that could be related to NEHRP. For instance, the League of Women Voters has supported land use planning along the Wasatch Front that incorporates geologic hazards including earthquakes. Local PTA organizations have advocated earthquake hazard preparedness in the schools. The LDS Relief Society plays a key role in the preparation of food supplies in case of emergency. Can earthquake information be "translated" in terms specifically designed for these groups as well as others? Can it be personalized for various memberships in such a way that it leads to a personal commitment to personal preparedness? Can an education program be developed so that it not only leads to personal preparedness but also to active support for changes in public policy? We feel these challenges are worth pursuing.

Utah needs to prepare for a major damaging earthquake along the Wasatch Front. The scientific evidence for the hazard is overwhelming even though it has not been experienced in historic time. The challenge in Utah is to take policy actions before the devastating earthquake. The results of this research strongly suggest a window of opportunity which should not be missed.

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REFERENCES

Anderson, L. R., Keaton, J. R., Saarinen, T. F., and Wells, W. G., 1984. The Utah Landslides, Debris Flows, and Flood of May and June, 1983. Washington, D.C., National Academy Press.

Arabasz, W. J., Smith, R. B., and Richins, W. D., (eds), 1979. "Earthquake Studies in Utah, 1850--1978." Salt Lake City, University of Utah Seisimograph Station, Special Publication.

Christenson, G. E., 1987. Suggested Approach to Geologic Hazards Ordinances in Utah. Utah Geological and Mineral Survey, Circular 79.

Gori, P. L., and Hayes, W. W. (eds.), 1987. Assessment of Regional Earthquake Hazards and Risk Along the Wasatch Front, Utah. (2 Vols). U.S. Geological Open-File Report 87-585.

Kockelman, W. J., 1986. "Some Techniques for Reducing Landslide Hazards," Bulletin of the Association of Engineering Geologists, Vol. 23, No. 1, pp. 29-52.

_____, (1989). "Reducing Earthquake Practitioners Hazards in Utah: The Crucial Connection between Researchers and Practitioners," USGS Open-File Report.

Madsen, G., Barnes, J., and Anderson, L. R., 1988. The Implementation of an Earthquake Hazard Mitigation Program in Salt Lake County, Utah. Funded by U.S. Geological Survey, Grant No.: 14-08-0001-G1531.

Selkregg, L. L., Preuss, Ender, R. L., Johnson, S. F., Kim, J. C. K., Gorski, S. E., and Kelso, D., 1984. Earthquake Hazard Mitigation: Planning and Policy Implementation. The Alaska Case, Anchorage, University of Alaska and Seattle, Urban Regional Research.

Sorenson, J. H., Mileti, D., 1987, "Public Warning Needs," in Gori, P. L. and Hays, W. W. (eds.), Proceedings of Conference XL: A Workshop on the U.S. Geological Survey's Role in Hazards Warnings, Open-File Report 87-269, Reston, VA, U.S. Dept. of Interior, Geological Survey, pp. 9-75.

Turner, R. H., Nigg, J. M. and Heller Paz, D., 1986. Waiting for Disaster: Earthquake Watch in California. Berkeley, University of California Press.

A DATA BASE DESIGNED FOR URBAN SEISMIC HAZARDS STUDIES

by

Arthur C. Tarr

ABSTRACT

A computerized data base has been designed for use in urban seismic hazards studies conducted by the U. S. Geological Survey. The design includes file structures for 16 linked data sets which contain geological, geophysical, and seismological data used in preparing relative ground response maps of large urban areas. The data base is organized along relational data base principles. A prototype urban hazards data base has been created for evaluation in two urban areas currently under investigation: Wasatch Front, Utah and Puget Sound, Washington. The initial implementation of the urban hazards data base (UHDB) was accomplished on a microcomputer using dBASE III Plus software and transferred to minicomputers and a workstation.

INTRODUCTION

For more than a decade, the USGS has been studying seismic hazards in earthquake-prone urban areas of the U.S. Part of the process of seismic risk assessment is the evaluation of site response of soils and underlying geological units (relative to nearby bedrock) to earthquake motions. **Site response** (also called relative ground response) is a complex function of many geological and geophysical variables (Rogers and others, 1985). Spatial variations of intensity in a localized area are due principally to site response.

Determining which combination of geological and geophysical factors is most significant in affecting site response is the subject of ongoing research. Once those significant factors are determined, one exceedingly important task is organizing a (frequently) large body of data so that site response may be correlated with geotechnical variables and with Modified Mercalli (M.M.) intensities, when they are available. This report describes a computerized data base designed for use in urban seismic hazards assessment.

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SUMMARY OF METHODS

Previous theoretical and empirical studies have indicated that seismic site response may be influenced by the thickness and degree of consolidation of sediments at the site, by the seismic shear velocity and mean void ratio of the sediment layers, and by degree of saturation and depth to water table. Figure 1 schematically illustrates these general characteristics. In general, greater thicknesses of soft, low-velocity sediments beneath a site yield higher overall levels of relative ground response (site 1 in Figure 1) relative to a bedrock reference site (Borcherdt, 1975; Ohta and others, 1978; Kagami and others, 1982; Rogers and others, 1985; Kagami and others, 1986). In addition, narrow bandwidth amplification is frequently observed

at sites where thin layers of low-velocity sediments overlay hard rock (site 2 in Figure 1); the amplification is due to resonance in the thin low-velocity layers (Rogers and others, 1985).

Site effects, due to whatever causes, are commonly invoked to explain substantial variations, within rather localized areas, of observed earthquake intensity patterns and instrumentally-recorded ground motions. For example, severe but localized damage to medium-rise structures in Mexico City has been explained by resonance amplification (due to deposits of young, soft, lakebed sediments) of seismic ground vibrations from the September 19, 1985 Mexico earthquake (Cluff, 1985).

Relative ground response can be determined without relying on strong earthquake ground motions. Studies conducted in the San Francisco Bay, California region (Borcherdt and others, 1975), in the Los Angeles, California area (Rogers and others, 1985), and in the Wasatch Front region of Utah (Hays and King, 1982) have relied on nuclear explosions as seismic sources. Similar studies using microtremors (small-amplitude vibrations) as seismic sources have been conducted in Japan and the San Fernando Valley of southern California (Ohta and others, 1978; Kagami and others, 1982; Kagami and others, 1986). Relative ground response values determined from small ground motions have been shown to be comparable to response values determined from recordings of strong ground motions (Rogers and others, 1985).

The results of the Los Angeles study are illustrative. Fourier spectra of seismograms recorded at sites in the Los Angeles urban area were compared with spectra recorded at a

single reference site (Rogers and others, 1985). The recordings were of nuclear explosions at the Nevada Test Site (NTS). Seismic stations were widely distributed across the Los Angeles area and installed on diverse geologic materials; the reference site was located on hard rock.

Spectral ratios were computed for each seismic event by dividing smoothed Fourier spectra of the various site records by the smoothed Fourier spectrum of the reference site record. Mean spectral ratios for each recording site and seismic event were computed for three period bands: **short-period** (0.2-0.5 s; 5-2 Hz), **intermediate-period** (0.5-3.3 s; 2-0.3 Hz), and **long-period** (3.3-10 s; 0.3-0.1 Hz). Geological and geotechnical data were gathered from logs of nearby water wells and from boreholes drilled for soil-engineering studies. The geographical variation in relative ground response was evaluated in terms of the underlying geotechnical conditions at each recording site by means of cluster and discriminant analyses.

In the Los Angeles area, Rogers and others (1985) found that ground motions were enhanced at sites underlaid by Holocene and Pleistocene sediments, with the overall response generally increasing with the thickness of Quaternary deposits and depth to bedrock. The chief factors controlling short-period relative ground response in the Los Angeles study were mean void ratio in near-surface layers, thickness of unconsolidated (principally Holocene) sediment, and depth to bedrock. Intermediate and long-period response were controlled principally by depth to bedrock and by thickness of Quaternary alluvium.

Similar studies have been completed by the USGS in Utah along the Wasatch Front urban corridor (Hays and King, 1982) and are now in progress in the Puget Sound area of Washington. Preliminary results in Utah indicate correlations of relative ground response with geotechnical parameters similar to the Los Angeles study. Over fifty boreholes were drilled and logged for the Wasatch Front study (J. Tinsley, written communication).

Once the critical geotechnical factors affecting site response have been identified, a theoretical ground response model is constructed and maps displaying the model are produced. The theoretical ground response model is employed in the construction of probabilistic acceleration maps which are necessary for a variety of applications, such as loss estimation.

DATA BASE MANAGEMENT SYSTEM

Producing a site response map of a large urban area at risk from strong ground shaking requires many relative ground response values to establish response zones on the map. These values are derived from a clustering analysis of measured ground response utilizing variables which have been demonstrated as being significant factors in affecting ground response. Measured values of these significant factors can be quite numerous. Therefore, it should be clear that a large urban seismic hazards study involves an extensive data collection, data organization, and data analysis effort; this effort is facilitated by a utilitarian data base design and computerized data base management system (DBMS).

BENEFITS AND COSTS OF A DATA BASE MANAGEMENT SYSTEM

The benefits derived from organization of a voluminous amount of data with a good DBMS are:

Orderliness. A good data base design assures that logically associated data will be related by the DBMS.

Efficiency. Data entry, editing, and retrieval operations are fast, compared with manual record keeping systems, in a good DBMS.

Flexibility. A good DBMS allows restructuring of data file design as necessary (without additional or redundant data entry) and permits establishing complex relationships between data contained within several or many files.

Security. Once data have been entered into a data base, edited, and proofed, they are part of a permanent record, and are less susceptible to accidental loss or alteration.

Transportability. Data that are organized with a good DBMS on one computer system can be easily moved to another computer system.

The costs associated with the organization of large data sets in a DBMS are:

Software cost. DBMS software is sometimes expensive to purchase, depending on the host computer used and the application.

Hardware cost. Hardware cost is minimal if an existing computer is used, more expensive (sometimes prohibitively so) if a new computer system is to be dedicated to the DBMS software.

Labor cost. Manual data entry is labor-intensive (and hence costly) for large data sets. Data base maintenance (updating, verification, backup, archiving) is usually less labor-intensive following initial data entry. In-house programming costs are largely up-front and may be high (one of the tradeoffs if DBMS software is written in-house).

A manual records system is entirely adequate for small numbers of observations of only a few geotechnical factors; one can keep the data close to hand and in mind and the cost of organizing the data is insignificant. However, a manual records system becomes more unwieldy as the number of response observations and geotechnical factors increases. Further, as the geotechnical analysis becomes more complex, relating data items from numerous sources (data sheets, tables, notebooks, etc.) and graphing data become tedious and the opportunities for error increase. Computerization of the data is inevitable if applications software is used to analyze the data. If several data formats are required for different applications software packages, incompatibilities may arise and duplicate keyboarding may be required.

In summary, a good DBMS and standard data structures can minimize problems when data sets are large, when several applications software packages are used to analyze the data, and when analytical techniques become complex.

DESIGN OBJECTIVES

The preceding discussion has indicated the complex relationship of geological, physical, and geotechnical factors in

determining a theoretical relative ground response model. Relative ground response maps derived from the model are the principal end products of seismic hazards research. The maps traditionally have been constructed by overlaying transparent sheets on which the various data sets have been plotted and by manually drafting the final map. Recently, Geographic Information System (GIS) technology has been employed to construct the maps by extracting the ground response data and associated geotechnical data from a data base and by electronically combining these data layers. Thus, three major considerations influence data base design: how the data are acquired, how the data are analyzed, and how the data are to be used.

DATA BASE DESIGN CONSIDERATIONS

Three sets of data base terminology are often used interchangeably, to describe similar entities and similar characteristics of the data base (Martin, 1977). The sets of terms differ because of differences in viewpoint of the data user, the data manager, and the applications programmer toward the form of the data and toward the organization of data:

(1) **The form of the data is tangible and physical for the user.** The data user (and frequently the data gatherer) probably uses a manual system for recording and organizing the data: notebook pages or sheets of paper upon which are written specific data values, often in tabular form; graphs upon which data values are plotted; and index cards, such as bibliographic citations, which can be sorted.

(2) **The form of the data is symbolic for the data manager.** The data manager views the data as organized into generalized lists or tables of data items, and very seldom thinks in terms of the actual values the data items may assume.

(3) **The applications programmer visualizes the data both symbolically and physically.** To the programmer, the symbolic lists and tables of the data manager become arrays of variables (containing data values) which will be manipulated within a program and which will be physically stored in computer memory or in a disk file.

Figure 2 compares the three sets of terms as they apply to a data **table**, a **relation**, and a data **file**. In the following discussion, square brackets ([ ]) enclose alternate terms, to help the reader as the perspective shifts among the three viewpoints.

The provisional design for the urban hazards data base is **relational** in organization, consisting of several large tables [relations, arrays, files] of data. The data are arranged in the table in **rows** and **columns**, each row representing a unique entity such as a seismic station, a borehole site, or a rock unit. Each column [**attribute**] represents one property or characteristic of the entities listed in the table; latitude and borehole depth are examples of attributes. Each row of attribute values is called a **tuple** or **record** and the part of a record containing an attribute value is called a **field**. The entire collection of records is called a **data set**, **data file**, or **flat-file**. A group of related

data sets or data files is called a **data base** in all three terminologies.

EXAMPLE OF RELATIONAL ORGANIZATION

Suppose that we have completed an experiment at six locations where seismic instruments have recorded seismograms of seismic events; seismic response ratios will be computed from the seismograms. Further, suppose that at two of the sites (Figure 3) boreholes were drilled for determination of vertical profiles of seismic velocity and geological properties. Say that we desire a list that will comprehensively and completely summarize in one place the properties of the six response sites. In a manual records system, we would probably construct a table and list each of the site locations on a separate line, identifying each site by a number, a code, an address, or a comment. Each line would contain other information such as coordinates, elevation, site geology, and, if a borehole had been drilled at that site, the borehole depth. The information in the table constitutes a compact and usable data set.

If we computerize these data using a relational organizational scheme, we conceptually transform the physical table into a relation or a flat-file. The data describing seismic stations and associated boreholes would be stored in a file; in this example, the file is called STATION (Figure 4). Each record in the file contains data describing a specific (and unique) seismic station and (optional) borehole[1].

[1] This example is somewhat contrived to illustrate the point about null data elements. Because boreholes are seldom located precisely at a station location, borehole data (including latitude, longitude, and elevation) should be kept in a separate file.

The fields in each record contain data values such as the station's latitude, longitude, elevation, a brief description of the site geology, borehole identifier, and borehole depth. One field, the station's unique identifier, is also called the **primary key field**; other fields (such as the borehole identifier), which may or may not be unique, are called **secondary key fields.** (Key fields are used for data retrieval operations in the data base; however, it is not necessary that a file have keys.) Some attributes (such as borehole depth) may not contain data values in all records, perhaps because the data do not exist (in the example, boreholes were not drilled at all sites) or the data are not known; such empty data elements are called **null data elements.**

One principle employed in relational data base design is to eliminate duplication of identical attributes [columns] in different files wherever possible. Strict application of this principle eliminates the possibility of inconsistent data values for the same attribute in different files and reduces the amount of computer storage required for each record. Another design principle is to minimize the number of null data elements in the file. This is accomplished by eliminating attributes which have few occurrences of data compared to the number of null data elements. These data (which, although sparse, are often important) may be stored in a smaller, auxilliary file. This auxilliary file contains a field value that links the data in a record in the smaller file to an associated record in the larger

file (Figure 4). The field that permits the linking of records in different files is called a **pointer field.**

In the STATION example, say that the borehole data are removed from STATION and stored in a small file named BORE. The link between the two files is established in the BORE file by the pointer field containing a value that is identical to a value in a field in STATION. The station identifier, since it is unique, would be a good choice for a pointer to associate records in STATION and BORE. A record may contain multiple pointers; the principal data base design requirement for pointers is that they must not cause confusion during retrieval operations. For example, a pointer in one file should not point to multiple records in another file because retrievals attempted at various times might retrieve a different record each time. However, the same pointer value in several records pointing to just one record in another file is permissible because no ambiguity exists. Thus, for unique retrievals, **one-to-one** and **many-to-one** pointers are permissible but **one-to-many** pointers are not.

The many-to-one case is illustrated by the RESPONSE data file. There are two fields in RESPONSE (**station_id** and **event_id**) whose values are pointers to unique records in the STATION and EVENT files, respectively. In the RESPONSE file, each measurement of the average spectral ratio across the band is entered as a separate record; consequently, the values for **station_id** and the values for **event_id** are identical for each of the RESPONSE records of that station/event combination. Thus, the **station_id** pointers

in many RESPONSE records point to one STATION record and the event_id pointers in the same records point to one EVENT record.

Why couldn't the station identification, event identification, and a fixed number of mean spectral ratio fields be stored in a single RESPONSE record? There are two reasons why this suggestion is not feasible in the RESPONSE example: the need for flexibility and the need to eliminate null data elements. Establishing a fixed number of spectral ratio fields, one each for a predetermined frequency band, would preclude any band which did not fit the format. Further, the number of spectral ratio fields would have to be the largest number of fields to be expected, not just the number needed to describe the ratio spectrum; the larger the number of fields, the greater the likelihood of null data elements. In the preferred structure of RESPONSE, any bandwidth may be specified and there are only as many records as needed to describe the ratio spectrum.

DATA FILES IN THE DATA BASE

The data files and data structures that are used in the data base design are listed in Appendix A; Figure 6 shows how the data are linked by pointers.

Data files STATION and BORE are similar: they contain data characteristic of the site, such as the location and general geological description. Each record in the RESPONSE file contains a response measurement at one station from one event over one frequency band. Each record in EVENT contains location and origin time and other data regarding seismic sources such as explosions and earthquakes. BORE_GEO contains geological data

from a specific depth interval in the borehole and BORE_SEI contains seismic data (such as velocity and density) from a specific depth interval in the borehole. In the same way that a station identification field and an event identification field in each RESPONSE record point to associated records in STATION and EVENT, respectively, borehole identification fields in BORE_GEO and BORE_SEI point to associated records in BORE. A field in BORE containing the identifier of the nearest seismic station points to a record in STATION. A pointer **expt_id** in REFLECT and REFRACT links seismic reflection and seismic refraction experiment data to GEO_EXP in which records describe the location and geology of the experiment site.

The design of the RESPONSE, BORE_GEO, and BORE_SEI data files is flexible enough to allow documentation of single, multiple, and reduced measurements at a specific seismic response site or borehole site. For example, the response in a given frequency band for a particular station and event is usually a single measurement but in some instances, it may be a simple mean, weighted mean, or smoothed value of several measurements. Similarly, the design of INTENSIT allows for multiple observations of M.M. intensity to be documented for a specific site.

IMPLEMENTATION OF THE DATA BASE

A prototype urban hazards data base (UHDB) utilizing the relational data base principles described in this report has been implemented to manage the seismic hazards data for two urban areas currently under investigation: Wasatch Front, Utah and Puget Sound, Washington. The Wasatch Front hazards assessment

has entered the final stages and hence, most of the seismic hazards data has been acquired. Entry of these data into the files of the UHDB has permitted evaluation of the degree of soundness and appropriateness of the intital data structures. In addition, a user interface called GEOTEK was programmed using the dBASE III Plus language.

The UHDB is currently implemented on a number of computer systems, a USGS PRIME 9955 minicomputer located in Lakewood, Colorado, six systems located in Golden, Colorado.(a USGS VAX 11/750 minicomputer, a SUN Microsystems 3/60 workstation, and three microcomputers), and microcomputers in California and Nevada.

There are significant advantages to implementation on multiple computer systems. The microcomputers are used principally in the data acquisition and data analysis phases of projects, both in the field and in the office. After newly-acquired data are edited and proofed, the data sets are transferred to one microcomputer where the master data base is maintained. Copies of the master data base are installed on the two minicomputers and the workstation in Golden and distributed to other users as needed. Thus, the data are available for use by GIS and other applications software installed on those systems. In addition, the data files are accessible to many additional USGS personnel and to a large number of analysis programs not available on a microcomputer.

Since the dBASE III Plus software is installed on several field microcomputers, data entry, data editing, and data

retrieval are possible in the field as data are being acquired. Program and data design development are much easier using a software package such as dBASE III Plus; once the data base design has been settled on, implementation on the VAX 11/750 (which requires FORTRAN programming because data base management software is unavailable in the present VAX installation) should be simplified.

Multiple site implementation is feasible because it is possible to transfer data files easily between the various user sites, electronically by using either a modem or one of several existing computer networks or physically by transporting a diskette or magnetic tape containing the data. No data file conversion is required between similar systems (microcomputer-to-microcomputer). Between dissimilar systems, a dBASE III Plus conversion utility, a communications software package, and hardware connection (or modem) are required.

REFERENCES CITED

Borcherdt, R. D., Joyner, W. B., Warrick, R. E., and Gibbs, J. F., 1975, Response of local geologic units to ground shaking, in Studies for seismic zonation of the San Francisco Bay region: U. S. Geological Survey Professional Paper 941A, p. A52-A67.

Cluff, L. S., 1985, Firsthand experience of the M_S 8.1 earthquake that struck Mexico City on 19 September 1985: Bulletin Seismological Society of America, vol. 75, 1843-1846.

Hays, W. W. and King, K. W., 1982, Zoning of the earthquake ground shaking hazard, in International Earthquake Microzonation Conference, 3d, Seattle, Wash., 1982, Proceedings: p. 145-156.

Kagami, H., Duke, C. M., Liang, G. C., and Ohta, Y., 1982, Observation of 1- to 5-second microtremors and their application to earthquake engineering. Part II. Evaluation of site effect upon seismic wave amplification due to extremely deep soil deposits: Bulletin Seismological Society of America, v. 72, no. 3, pp. 987-998.

Kagami, H., Okada, S., Shiono, K., Oner, M., Dravinski, M., and Mal, A. K., 1986, Observation of 1- to 5-second microtremors and their application to earthquake engineering. Part III. A two-dimensional study of site effects in the San Fernando Valley: Bulletin Seismological Society of America, v. 76, no. 6, pp. 1801-1812.

Martin, James, 1977, Computer DataBase Organization (2nd ed.): Englewood Cliffs, N.J., PrenticeHall, 713 p.

Ohta, Y., Kagami, H., Goto, N., and Kudo, K., 1978, Observation of 1- to 5-second microtremors and their application to earthquake engineering. Part I. Comparison with long-period accelerations at the Tokachi-Oki earthquake of 1968: Bulletin Seismological Society America, v. 68, no. 3, pp. 767-779.

Rogers, A. M., Tinsley, J. C., and Borcherdt, R. D., 1985, Predicting relative ground response in Earthquake Hazards in the Los Angeles Region: U. S. Geological Survey Professional Paper 1360, p. 221-248.

APPENDIX A: URBAN HAZARDS DATA BASE FILE STRUCTURES

There are currently 16 data files in the urban hazards data base:

BORE [Borehole data]
BORE_GEO [Borehole geology data]
BORE_LOG [Borehole log data]
BORE_SEI [Borehole seismology data]
BUILDING [Building data]
EVENT [Seismic event data]
GEO_EXPT [Geophysical experiment data]
INTENSIT [Seismic intensity data]
MODEL [Model structure]
MODL_PAR [Model parameters]
RECORD [Seismic record]
REFLECT [Seismic reflection data]
REFRACT [Seismic refraction data]
RESPONSE [Seismic response data]
STATION [Seismic station data]
VEL_MODL [Velocity model]

The files and fields in the data base are:

BORE [Borehole data]
- Borehole identification
- Alternate borehole identification
- Owner
- Borehole location description
- Borehole latitude
- Borehole longitude
- Borehole elevation
- Quadrangle name
- Section/township/range description
- Logged by whom
- Casing
- Date(s) drilled
- Date closed
- Borehole (well) depth
- Depth to cementation
- Depth to water table
- Depth to bedrock (basement)
- Thickness Holocene sediments
- Thickness Quaternary sediments
- Total thickness sediments
- Preferred station (pointer to STATION)
- Distance to preferred station
- Preferred geophysical experiment (pointer to GEO_EXPT)
- Remarks
- Reference

BORE_GEO [Borehole geology data]
- Borehole identification (pointer to BORE)
- Minimum interval depth
- Maximum interval depth
- % silt and clay
- % sand
- % gravel
- Description of interval
- Texture
- Soil classification
- Age
- Grain size
- Liquid limit
- Plastic limit
- Plastic index
- Moisture content
- Density solids
- Dry density
- Void ratio
- Remarks
- Reference

BORE_LOG [Borehole log]
- Borehole identification (pointer to BORE)
- Minimum interval depth
- Maximum interval depth
- Color
- Field Description
- Unit name
- Remarks

BORE_SEI [Borehole seismology data]
- Borehole identification (pointer to BORE)
- Minimum interval depth
- Maximum interval depth
- P-velocity
- S-velocity
- Remarks
- Reference

BUILDING [Building data]
- Building identification
- Building location (name, address)
- Building latitude
- Building longitude
- Building elevation
- Building description
- Number of stories
- Remarks
- Reference

EVENT [Seismic source data]
- Event identification
- Event type (earthquake, nuclear shot, HE shot)
- Event date
- Event time
- Event latitude
- Event longitude
- Event elevation (focal depth, burial depth)
- Event size (magnitude, lbs. or tons TNT)
- Remarks
- Reference

GEO_EXPT [Geophysical experiments]
- Experiment identification
- Alternate experiment identification
- Experiment type (reflection, refraction)
- Experiment date
- Experiment location description
- Experiment latitude
- Experiment longitude
- Experiment elevation
- Experiment description
- Preferred station (pointer to STATION)
- Preferred borehole (pointer to BORE)
- Remarks

INTENSIT [Intensity data]
- Event identification (pointer to EVENT)
- Building identification (pointer to BUILDING)
- M.M. intensity value
- Number of observations
- Remarks
- Reference

MODEL [Model structure]
- Model identifier
- Model latitude
- Model longitude
- Model elevation
- Remarks

MODL_PAR [Model parameters]
- Model identifier [pointer to MODEL]
- Minimum interval depth
- Maximum interval depth
- P-velocity
- S-velocity
- Dip
- Density
- Shear modulus
- Bulk modulus
- Poisson's ratio
- Remarks

RECORD [Seismic record]
- Record identification
- Event identification (pointer to EVENT)
- Station identification (pointer to STATION)
- Event type
- Event extension
- VAX directory

REFLECT [Seismic reflection data]
- Reflection experiment identification (pointer to GEO_EXPT)
- Geometry description
- Length
- Azimuth
- CDPfold
- Source type
- Source spacing
- Source offset
- Source arrays
- Shots per shotpoint
- Geophone type
- Geophone frequency
- Geophone spacing
- Geophone arrays
- Recorder type
- Recording medium
- Recording format
- Sampling interval
- Record length
- Filters
- Number of files
- Remarks

REFRACT [Seismic refraction data]
- Refraction experiment identification (pointer to GEO_EXPT)
- Geometry description
- Length
- Azimuth
- Source type
- Shots per shotpoint
- Geophone type
- Geophone frequency
- Geophone spacing
- Recorder type
- Recording medium
- Recording format
- Sampling interval
- Record length
- Filters
- Number of files
- Remarks

RESPONSE [Seismic response data]
- Station identification (pointer to STATION)
- Event identification (pointer to EVENT)
- Minimum frequency of band
- Maximum frequency of band
- Relative response
- Number of measurements
- Standard deviation (for multiple measurements)
- Remarks
- Reference

STATION [Seismic station data]
- Station identification
- Alternate station identification
- Station location description
- Station latitude
- Station longitude
- Station elevation
- Quadrangle abbreviation
- Section/township/range description
- Surface geology of station (generalized)
- Preferred borehole (pointer to BORE)
- Distance to preferred borehole
- Nearest geophysical experiment (pointer to GEO_EXPT)
- Preferred model (pointer to MODEL)
- Remarks

VEL_MODL [Velocity model]
- Velocity model identification
- Depth to top of layer
- Depth to bottom of layer
- P-wave velocity
- S-wave velocity
- Vp/Vs ratio
- Two-way travel time P-wave
- Two-way travel time S-wave

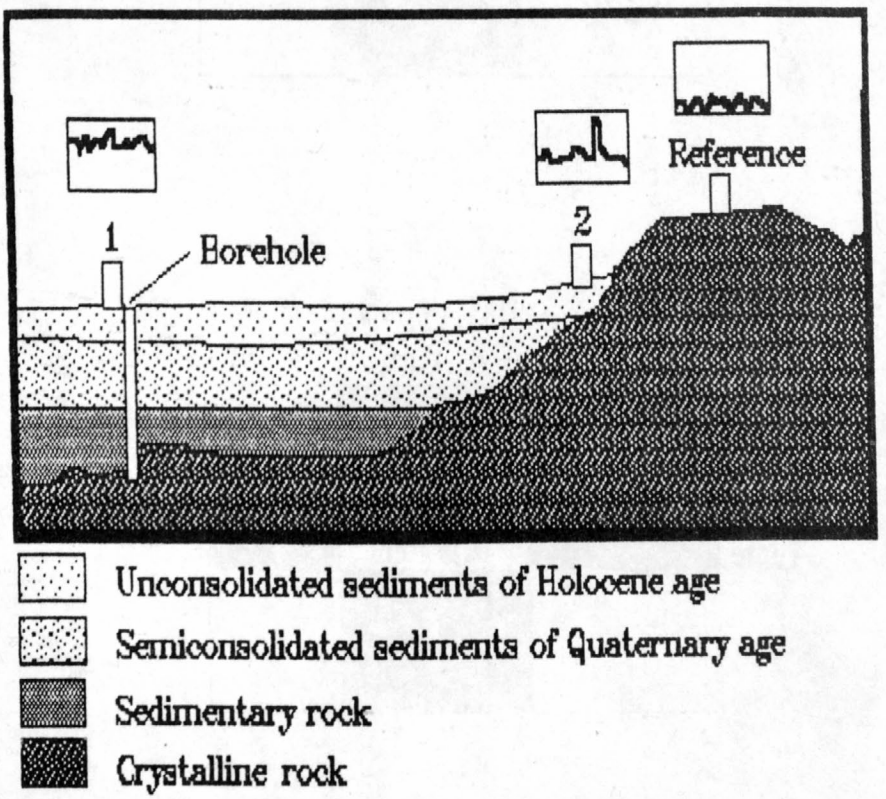

Figure 1.--Diagram showing cross-section of hypothetical seismic ground response study area. Three representative response sites are designated "Reference", "1", and "2"; small rectangles at each site designates a seismic station. Small rectangular diagram above each site represents a Fourier amplitude spectrum (Fourier amplitude versus frequency) of a typical seismogram recorded at each site. Spectrum examples show overall spectral level is elevated slightly at site "2" and more so at site "1"; high frequency resonance peak is shown in the spectrum at site "2".

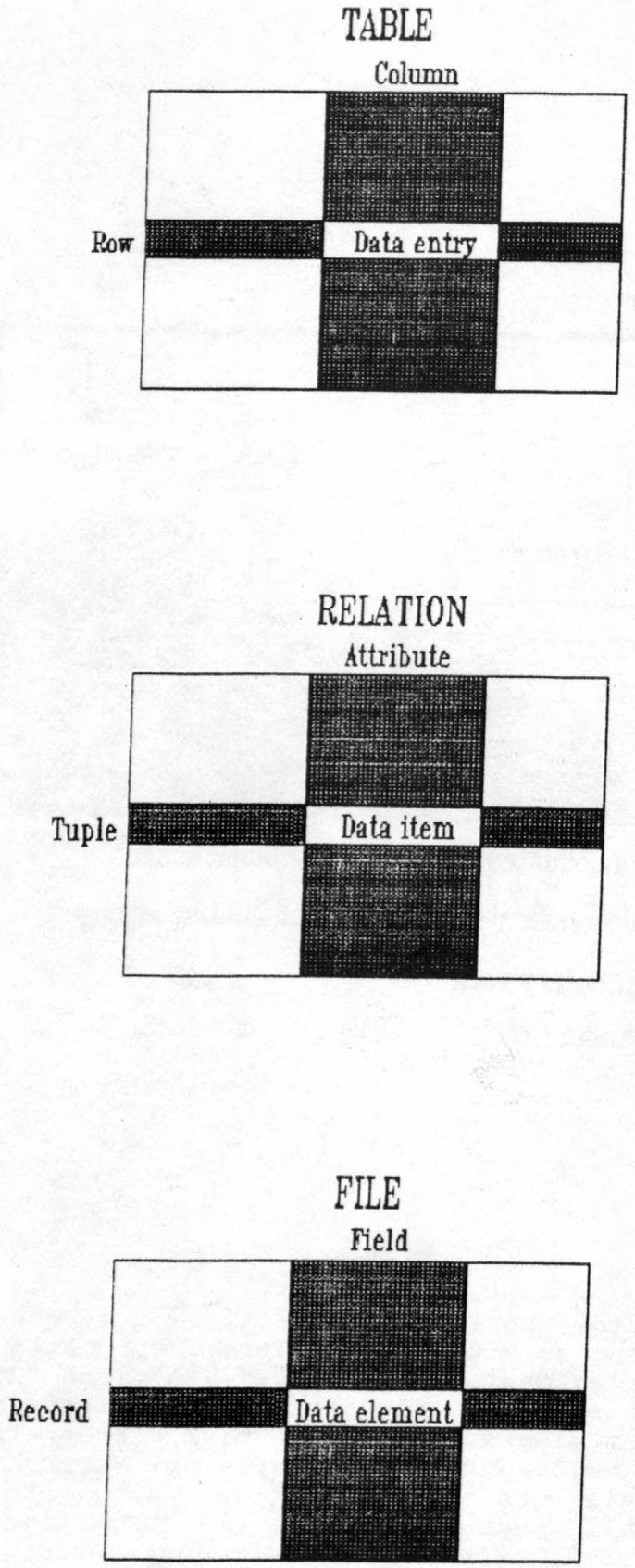

Figure 2.--Diagrams showing relationships of terms used in three different representations of data in a data base.

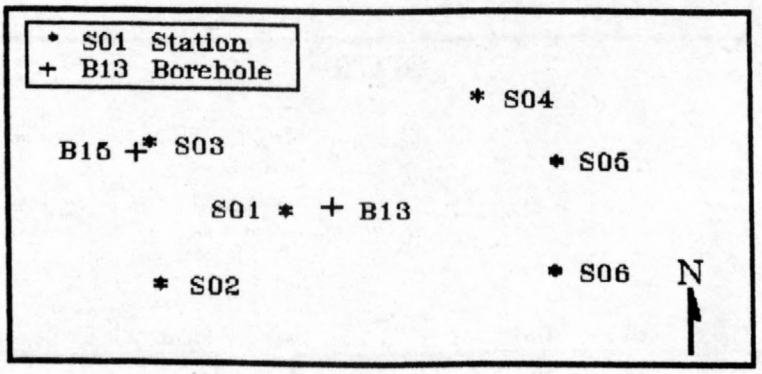

Figure 3.--Figure showing seismic stations (asterisks) and boreholes (crosses) in a hypothetical area where seismic response studies are conducted.

Ident	Latitude	Longitude	. . .	Bore-hole ID	Depth
S01	37.066	−117.987	. . .	B13	87.9
S02	37.113	−116.007	. . .		
S03	37.990	−117.803	. . .	B15	72.0
S04	36.012	−116.122	. . .		
S05	36.245	−116.098	. . .		
S06	37.112	−117.889	. . .		

STATION

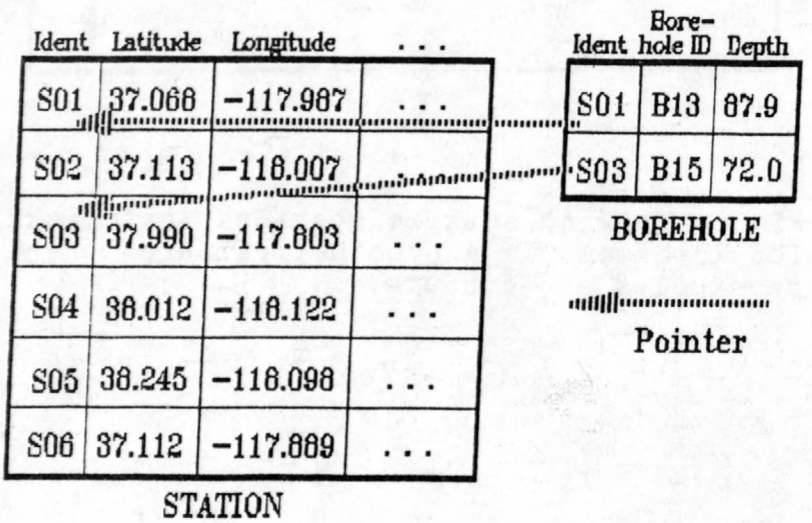

Figure 4.--Diagrams showing station and borehole data collected in a table (relation, file) called STATION (top) and two tables (relations, files) called STATION and BOREHOLE. Arrows designate pointers which link related borehole data to a station. Note that the combined physical size of the two lower tables (relations, files) is smaller than the upper table (relation, file) because of elimination of null data despite the need to duplicate the station identifiers in BOREHOLE.

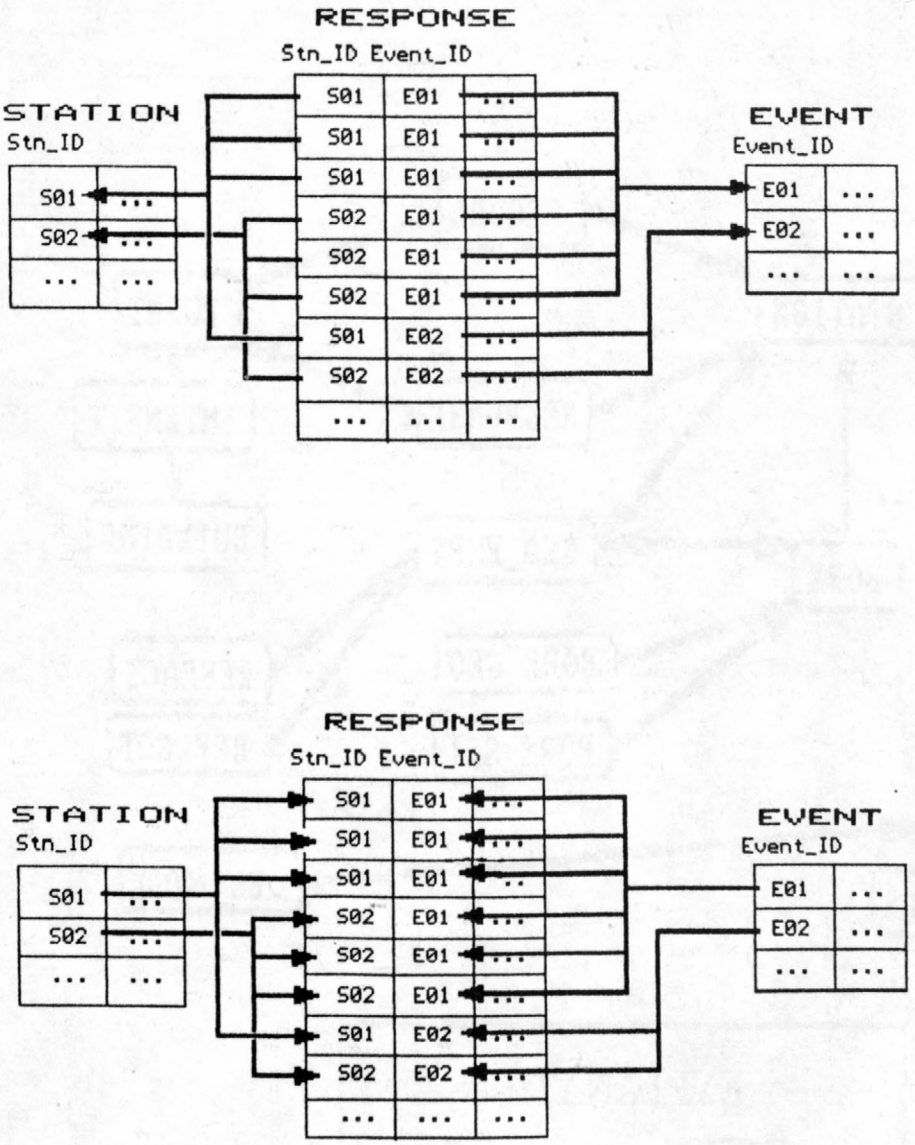

Figure 5.--Diagrams showing example of many-to-one (upper diagram) and one-to-many pointer (lower diagram) relationships among records in hypothetical STATION, RESPONSE, and EVENT relations. One-to-many pointers cause confusion in data retrieval operations of response records from station and event data because of the lack of uniqueness in the relationships; one-to-many pointers should be avoided in data base management.

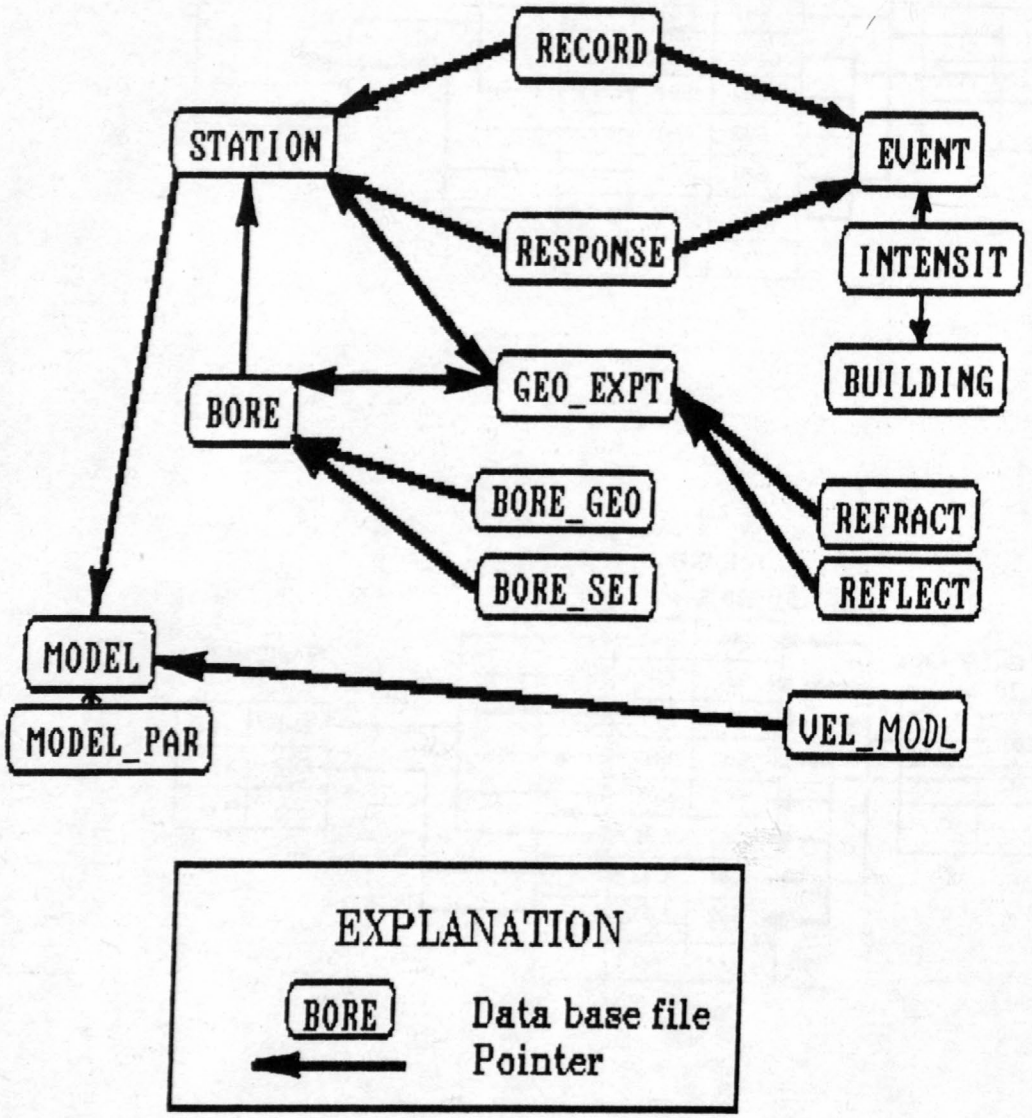

Figure 6.--Diagram showing relationship of data files (boxes) in the geotechnical data base to each other. Names of files within boxes are described in the text. Arrows designate pointers which link records within data files.

A MAPPING OF GROUND SHAKING INTENSITIES FOR SALT LAKE COUNTY, UTAH

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ABSTRACT

This paper documents development of maps of ground shaking intensity for microzones within an area of Salt Lake County, Utah, suitable for contiguous urban development. Measures of ground shaking are considered and a preference on Modified Mercalli Intensity (MMI) is established. Data and relationships relevant to a mapping of MMI are reviewed. Alternative methods for estimating spatial variation in MMI are described and compared. The findings resulting from application of the preferred method include the following: MMI with a 10% chance of being exceeded in a 10 year period range from V on bedrock above benches of Pleistocene Lake Bonneville to VIII+ on fine clays and silts of the Quaternary flood plain and delta complex at the valley's center. MMI with a 10% chance of being exceeded in a 50 year period range from VII at the valley's edge to X at the valley's center. MMI with a 10% chance of being exceeded in a 250 year period range from VIII at the valley's edge to XI at the valley's center. These results are specific to the ground shaking hazard and do not consider related hazards such as liquifaction, near-field directivity effects, rock fall, debris flow, fault rupture, seiches, and tectonic subsidence. These results are summarized in a set of maps developed with the use of a raster-based geographic information system. Photographic reductions of these maps are included as figures 9a-c.

INTRODUCTION

The purpose of this article is to explain the development and use of ground shaking intensity maps for an area of Salt Lake County, Utah, suitable for contiguous urban development. These maps show the degree of ground shaking to which this area is considered subject over a 10, a 50 and a 250 year period of exposure. The maps are developed with the use of a raster-based geographic information system (GIS) and are photographic reductions of computer-generated maps otherwise available at the 1:100,000 scale. Use of a GIS facilitates an integration of data on bedrock motion, relative site amplification and surficial geologic units. The integration of combined data permits a mapping of the ground shaking hazard at a degree of spatial resolution that begins to approach the detail needed for seismically attentive land use planning.

Ground shaking intensity maps use the Modified Mercalli Intensity (MMI) scale to represent

different degrees of shaking (Wood and Neumann, 1931). At each MMI level, a description of associated perceptions of ground motion and degrees of damage to common elements of the built environment is noted. (See Appendix A for an abbreviated description of the MMI scale.)

Maps of ground shaking intensity have many potential uses. These uses include estimating seismically related losses for insurance planning, designing seismic retro-fit programs for vulnerable structures, siting and designing critical facilities and lifelines, and planning for earthquake emergencies.

This article has four objectives. It enumerates viable approaches to computing spatial variation in MMI. It constructs and applies a subset of alternative computational methods for estimating MMI. It compares and evaluates this subset of alternatives, and it presents the results of a preferred methodology for MMI map development.

The article is divided into five additional sections with the following functions — to identify measures of ground shaking, to present a model for the assessment of ground shaking, to review prior studies and detail available data, to describe and compare alternative computational methods, and to present and discuss research findings.

THE MEASUREMENT OF GROUND SHAKING

In general, ground shaking increases with the magnitude of a seismic event and decreases with distance from its epicenter. However, significant variations from this generality are caused by sensitive soil conditions, topological conditions, and stratigraphic geometry. The study of ground shaking and its spatial variation requires measurement of ground shaking intensity. Measures of ground shaking are divided into two classes - instrumental measures and observational measures.

Instrumental Measures of Ground Shaking. Instrumental measures are most commonly taken from seismograph readings called accelerograms. An accelerogram measures lower frequency horizontal and vertical components of site acceleration during an earthquake. Velocity and displacement seismograms are developed from the data recorded on an accelerogram (Trifunac, 1970). Thus, the measures available from a seismograph reading include ground motion duration, displacement, velocity and acceleration at low frequencies (fig. 1). (Other measures available from seismograph readings, including earthquake magnitude, are discussed in Hays, 1980: 25-28.)

The duration of shaking above some standard threshold of perceptibility is the quake's measured duration. Up to a point, duration increases with epicental distance. Duration is longer on soft soils than on near-by rock sites. Controlling for other parameters of ground motion, longer duration implies greater damage. Greater durations also trigger liquifaction. Duration on soft soil

of a a Richter magnitude 7.0 earthquake has a standard variation of from 13 to 25 seconds at 25 kilometers epicentral distance (Krinitzsky and Chang, 1987a).

The maximal movement of soil particles from rest is a measure of displacement. Because of its relative insensitivity to geologic variations, ground displacement propagates more coherently than either velocity or acceleration. Displacement at the fault of a great earthquake probably does not exceed 200-400 cm while displacement at a 3-5 km distance probably does not exceed 20-40 cm (Trifunac and Brady, 1975).

The maximum speed attained by a seismically oscillating soil particle is its peak velocity. Peak velocity is measured in both horizontal and vertical directions. Oscillation causes a stretching and compressing of the soil and is noted as shear strain. The degree of shear strain to which the site is subject is proportional to the velocity of ground motion and inversely proportional to the shear wave velocity of its composite materials. Soft soils have a lower shear wave velocity than rock and are, therefore, subject to greater shear strain than are near-by rock sites. Richter magnitude 7.0 earthquakes induce a peak horizontal velocity (PHV) measured on soft soil in the range from 22 to 74 centimeters per second (Krinitzsky and Chang, 1987a).

An oscillating soil particle has a measurable acceleration. Peak acceleration occurs mid-way between oscillations. The peak horizontal accelerations (PHA) for most large earthquakes range from 110 to 510 centimeters per second per second, i.e., from 0.11 to 0.52 units of gravity (Krinitzsky and Chang, 1987a). Peak horizontal acceleration is widely used by structural engineers as a measure of the lateral forces on taller buildings. Usually peak vertical acceleration is roughly two-thirds peak horizontal acceleration (Werner and Ts'ao, 1975).

Peak horizontal acceleration is also used to define a comonly known instrumental measure of earthquake magnitude on the Richter scale (Richter, 1935). Richter magnitude (M_L) was defined as the logarithm of the maximum trace amplitude recorded on an accelerogram of a Wood-Anderson seismograph at an epicentral distance of 100 km. Corrections are used for observations made at distances other than 100 km (Hays, 1980).

These measures are important to assessing the risk of damage to structures. Each structure responds to ground shaking like an oscillating system with its own fundamental natural frequency. Buildings in excess of seven stories usually have a natural frequency less than 0.6 cycles per second. Buildings from three to seven stories resonate at from 0.6 to 2.5 cycles per second. One to two story buildings resonate at 2.5 cycles per second or more (Borcherdt, 1985, fig. 3.2). Larger earthquakes are known to have a greater proportion of their energy concentrated in lower frequency ranges and are, thus, relatively more hazardous to taller buildings. Lower frequency

seismic energy is also known to attenuate less rapidly with distance than does higher frequency seismic energy, so, *cæteris paribus*, taller buildings are subject to relatively more risk over a larger area than are shorter buildings. Yet the frequency-dependent effects of magnitude and distance are often secondary to the frequency-dependent effects of local site conditions. To better assess the risk of damage to structures, it is useful to know at which frequencies ground motion parameter will peak when given certain assumptions about magnitude,distance and local site conditions. It is also useful to know which classes of buildings resonate with the frequency ranges containing parameter peaks.

Transformations of ground motion time histories (seismograms) are used to generate a series of harmonic functions in the frequency domain. These define the maximum amplitude of harmonic oscillator response to a given ground motion history. The many response maxima defined across a wide frequency range are called response spectra.

For ground shaking studies, the pseudo-relative velocity (PSRV) response spectra is perhaps the most important of the several different kinds of response spectra used in seismology. At a given frequency, the PSRV response spectra measures the velocity of the center of mass of a simple resonant structure (responsive to that frequency) relative to the velocity of its base. PSRV is often useful to assess the amplification of bedrock motion by a resonant column of unconsolidated soil deposits. Thus, like other response spectra, the PSRV response spectrum often shows a maximal value at a specific frequency which is several times larger than the maximal value shown by a corresponding low frequency seismogram (fig. 2).

Pseudo-absolute acceleration, pseudo-relative velocity and relative displacement are often graphed together against the frequency of vibration as pseudo-response spectra. Pseudo-absolute acceleration is graphed over a high frequency range (from 2.5 to 33 cycles per second) and is used when considering the response of shorter buildings (roughly one to five stories high). PSRV is graphed over an intermediate frequency range (of 0.25 to 2.5 cycles per second) and is used when considering the response of buildings of intermediate height (roughly five to sixteen stories high). Relative displacement is graphed over a low frequency range (from zero to 0.25 cycle per second) and is used when considering the response of taller buildings. Thus reponse spectra are used in conjunction with data on local site conditions to estimate the frequency-specific effects of earthquakes of hypothesized magnitude and distance. Effects within given frequency ranges can then be related to the design of structures with known resonant frequencies.

Observational Measures of Ground Shaking. Observational measures of ground shaking intensity rely on human perception and observation of environmental indicators or engineering

factors. At each intensity level on an observational scale, there is a description of associated human perceptions of ground motion (e.g., felt by a few persons, felt by nearly everyone), a description of associated physical events (e.g., suspended objects may swing, unstable objects overturn, great damage to poory built structures) and, at the higher intensity levels, descriptions of associated geophysical events (e.g., sand boils, surface faulting, liquifaction, rock falls, seiches and tsunamis).

There are several observational scales of ground shaking intensity in use around the world today. They provide useful judgements about ground shaking intensity in areas without permenantly installed seismographs and are useful in providing information about historic events for which there were no instumental readings. Finally, most studies of the relationship between ground shaking and damage, loss or injury use observational measures of ground shaking rather than instrumental measures as the preferred independent variable. Researchers wishing to assess seismic loss potentials are bound by this fact to work with observational intensity measures. In this study, we use the Modified Mercalli Intensity (MMI) Scale.

In spite of the distinction between instrumental and observational measures of ground shaking intensity, it is necessary to work with both classes of measures. However, since there are real differences between instrumental and observational measures, caution must be used when converting from one class of measure to the other. First, MMI, PHA, PHV and displacement all have different rates of attenuation from epicentral distance. This makes it difficult to transform estimates of PHA, to PHV and then to MMI without compounding errors. Second, observational measures will sometimes fail to perceive the differences in dominant frequencies among seismic events and their effects on observerable damage or geophysical disturbance. This contributes to a partial tautology in the definition of seismic intensity based on subjective observations: often intensity is deemed to be high (low) because damage is great (slight) and not because dominant frequencies happened to resonate (not resonate) with a large proportion of local structures. Third, the response spectra corresponding to two site intensities thought to be identical on the MMI scale can vary considerably in their shape and in their peak frequencies. Thus, two sites might be thought to be equally hazardous on the basis of past observation when, in fact, their seismic responses are quit different: they could be used safely if structures to be located there were designed with instrumental data about their different response spectra in mind.

A GENERAL MODEL FOR THE ASSESSMENT OF GROUND SHAKING HAZARDS

A general model for the probabalistic assessment of regional ground shaking hazard involves

four steps. The first is to identify and characterize likely seismic sources. The source region needs to be larger than the subject region, because earthquakes outside the subject region can do considerable damage within the subject region. Along the Wasatch Front, any source capable of a large earthquake that is within at least 120 km of the subject area should be included in the source region. Seismic sources need to be characterized by the range of event magnitudes of which they are capable and the frequencies with which events of each magnitude are likely.

The second step is to construct a multiple-source-to-multiple-site geometry. This requires measuring the distances from each source to various locations within the subject region. Typically the subject region is divided into a grid and the distance from each source to the center of each grid cell is measured and recorded. This is repeated for all likely sources.

The third step is to attenuate ground motion from source to site. Each source is characterized by a distribution of event magnitudes (typically M_S or M_L). Each magnitude is characterized by a distribution of event frequencies. At each source, each event magnitude (weighted by its probability of occurrence during a specified time horizon) is converted to a measure of ground motion (typically PHA), and that measure is attenuated by distance from source to subject site.

Since there are several measures of ground shaking intensity, there are several approaches to the problem of source-to-site attenuation. Again, the most important division among approaches is between the direct attenuation of MMI and the attenuation of either PHA or PHV with conversion to MMI at site. The attenuation problem is exacerbated in the present case by the paupacy of regional data with which to construct regionally specific attenuation curves for either MMI, PHA or PHV. Recent studies by Hooper (1988) and by Algermissen and others (1988) correct this situation in part by their study and development of a regional MMI attenuation function.

The final step is to estimate the effects of site characteristics on ground motion (see Hays, 1983). Here the problem is principally one of adjusting for the possibility of ground motion amplification because of seismically sensitive soils and soil stratigraphies (fig. 3). Again, there are several approaches for addressing ground motion amplification. One option is to use attenuation functions specific to soil types. These typically distinguish between "hard" and "soft" soils but make no further distinction among soil conditions. Another option is to attenuate MMI directly from source to site and use intensity increments to adjust for the presence of amplifying soil conditions . This method typically distinguishes between three or four different soil types. A third option is to use site response functions empirically calibrated within the study area. Portable seismometers are deployed at numerous sites, and measurements are taken during seismic aftershocks or during a nuclear explosion at the Nevada Test Site. Ground motion parameters are

measured on different soils, and ratios of ground motion parameters - usually the ratios of PSRV - are found relative to a reference rock site. These ratios are then used as site specific ground motion amplification factors. A variation on this third option is to correlate site response functions to geologic and geotechnic variables so findings can be generalized to areas beyond that within which seimographic readings were originally taken.

In addition to these considerations is another site characteristic of particular importance. It concerns sub-basin geometry and the possibility of directivity (or focusing) effects (Benz and Smith, 1989). The directivity effect would be important to Salt Lake County in the event of a fault-rupturing earthquake on the Salt Lake Segment of the Wasatch Fault. Directivity refers to the likely effect which the great impedence contrasts between high density rocks to the east of the Wasatch Fault plane and the low density sediments to the west of the fault plane would have on directing seismic energy originating on that plane up the surface of the plane and concentrating strong ground motion along the surface expression of the fault. Thus, in addition to the soil amplification effects thought to be most severe in the center of the Jordan River Valley, one would also have near field directivity effects focused on areas adjacent to the surface expression of the Salt Lake Segment of the Wasatch Fault. The implications of the effect presented by Benz and Smith (1989) for the level of risk in Salt Lake County are interpreted in a related paper (Emmi, 1989).

POINTS OF DEPARTURE - DATA AND RELATIONSHIPS

Data and relationships relevant to a mapping of MMI for Salt Lake County are reviewed under three subheadings — one on source characteristics, another on ground shaking, and a third on ground motion intensities at site.

Source Characteristics and Recurrence Intervals. Studies of source characteristics for the Wasatch Fault Zone are numerous and ongoing. Early compilations were done by Williams and Tapper (1953) and again by Rogers and others (1976). Recent studies of recurrence relationships based on observational data and covering the complete range of seismic magnitudes are reviewed in Arabasz, Pechman and Brown (1987). Paleoseismologic investigations documented by Machette, Personius and Nelson (1987) add to the observational record. Estimates of the composite return interval for fault rupturing events located along the entire length of the Wasatch Fault Zone appear to be converging upon a concensus. Summarizing paleoseimic studies, Schwartz and Coppersmith (1984) report a return interval of 400-600 years, with a preferred estimate of 444 years. Updating Schwartz and Coppersmith with a review of subsequent paleoseimic studies, Lund (1987) reports

a preferred interval of 310-350 years. Using the University of Utah earthquake catolog of instrumental recordings (July 1962-December 1985), Arabasz, Pechman and Brown (1987) report a recurrence interval for $M_L \geq 7.0$ events of 120-630 years with a preferred estimate of 270 years. Young and others (1987) report a similar interval of 330 ± 90 years.

Ground Shaking Hazard. The Wasatch Front ground shaking hazard study by Rogers and others (1976) identifies sources, estimates recurrence intervals, and estimates the attenuation of intensities from sources to sites using three soil-specific attenuation curves based on a preliminary study of soil response factors. These curves accommodate soil amplification by the addition of intensity increments of 1.9 and 2.6 Modified Mercalli Intensity (MMI) units over bedrock. Hypothetical earthquakes of magnitude 7.5 at selected epicentral locations are posited. In all cases, MMI in Salt Lake County ranges from level VI to level IX - a range of three intensity units.

The study by Rogers and others (1976) illustrates the impact site response has on spatial variation in ground shaking intensities. Hays and others (1978) use a more extensive array of seismographs and measure site responses on soil and rock during nuclear explosions at the Nevada Test Site. They compute transfer functions (also called spectral ratios, site response factors and spectoral amplification factors) in both the 0.1 to 0.2 second and the 0.2 to 0.7 second period bands. They find site amplification factors ranging from 1.5 to over 10.0. (These correspond to MMI increments of up to three intensity units). They present their findings as point observations and generalize these observations to create isopleth maps showing contours within which they expect to find similar spectral ratios.

Algermissen and others (1982) contribute a study of map contours showing probabalistic estimates of PHA and PHV in rock for the contiguous United States. The maps show values which have a ten percent chance of being exceeded over 10, 50, and 250 year periods. (These correspond to expected return periods of 95, 475 and 2373 years, respectively.) The area along the Wasatch Front containing Salt Lake County has a 10 year, 10 % exceedence value for peak horizontal acceleration of 98 cm/sec^2 or 10 percent of gravity (0.10 g). The 50 year, 10% exceedence value is 274 cm/sec^2 or 0.28 g. The 250 year, 10% exceedence value is 686 cm/sec^2 or 0.70 g. (See Appendix B - The Interpretation of Technical Statements of Risk - for an explanation of the meaning of such risk statements.)

Algermissen and Steinbrugge (1984) use these estimates together with spectoral ratios for the 0.2 to 0.7 second band from Hays and others (1978) to generate a map for Salt Lake City of expected MMI levels for a hypothesized $M_S = 7.5$ earthquake. The areas of the city where spectral

ratios are less than 1.5 have an estimated MMI level of VII, while areas where spectral ratios are greater than 10.0 have an estimated MMI level of X. Intensities are larger by one unit over those shown by Rogers and others (1976). The low-to-high intensity range is the same - three intensity units. The low-to-high intensity range of two to three intensity units is confirmed by Oaks (1987) in a study of intensities from historic damaging earthquakes in Salt Lake City and Across the Jordan River Valley..

Soil properties such as soil void ratios, densities, and shear wave velocities correlate well with spectral amplification ratios (Rogers, Tinsley and Hays, 1983). These properties can be captured reasonably well by surficial geologic units. Rogers and others (1984) offer correlations between three broadly defined surficial geologic units and the spectral amplification ratios published by Hays and others (1978). Silts and clays have a mean amplification factor of 6.2, sands and gravel a factor of 3.7 and rubble a factor of 2.7. With these correlations, one can estimate more readily site effects in areas on the Wasatch Front where specific site response studies have not been conducted, but where soil types are known. Use of correlations with surficial geologic units permits a generalization and extension of analytical results. However, because of the limited number of soil classifications and the different and sometimes weak correlations, the findings reported by Rogers and others (1984) must be used with particular caution.

The study of seismic risk to state government property, fuel lines, and water lines by Taylor and others (1986) begins with a re-assessment of the ground shaking hazard. They identify and characterize likely seismogenic sources and then attenuate PHV in rock from each of several sources to sites in four Wasatch Front counties using a velocity attenuation curve published by Campbell (1984). They compute PHV in soil using the three surficial geologic units identified by Rogers and others (1984) and convert to MMI using a function develped by Wiggins and Taylor (1981). They find that MMI in Salt Lake County for a hypothetical $M_L = 7.3$ earthquake on the Salt Lake segment of the Wasatch Fault ranges from below VII at the valley's edge to X or more in the valley center – again a range of three intensity units.

Advances in paloeseismic investigations, plus innovations in probabalistic assessments of seismic hazards, prompted further investigation by Young and others (1987). This study is regarded as being among the most complete and sophisticated assessment of ground shaking hazard yet done for any region. It includes an inventory of seismic sources with ten segments of the Wasatch Fault, five segments of the Oquirrh Mountains Fault, two segments each of the East Cache Valley Fault, the Hansel Valley Fault and the East Bear Lake Fault, the West Valley Fault, and a generalized background source. The study focuses on PHA in soil and on pseudo-absolute

acceleration as preferred measures of ground shaking intensity. Local site effects are addressed by using attenuation functions and spectral amplification functions for rock and soil conditions calibrated on California data. The authors note (pp. M-57-58): "The applicability of these relationships to areas of [Bonneville] lake clays and silts is questionable, but alternative relationships are not available at present. The relationships used in the analysis may underestimate response spectra of longer-period motions in areas of soft lake deposits." Despite this conservative bias, estimates of PHA by Young and others (1987) for Salt Lake County are generally greater than earlier estimates by Algermissen and others (1982). Their estimate of PHA on rock with a 10 % chance of being exceeded over a 10 year period is 86 cm/sec^2 or 0.09 g. Their corresponding estimate for a 50 year period is 353 cm/sec^2 or 0.36 g, while their estimate for a 250 year period is 823 cm/sec^2 or 0.84 g.

Converting Acceleration to Intensity at Site. Lacking a functional relationship with which to compute the direct attenuation of seismic intensities from source to site while simultaneously addressing site characteristics, we face the alternative problem of converting smaller scale estimates of PHA on rock to larger scale estimates of MMI on soil sites with varying seismic sensitivities. Young and others (1987) provide the most accurate and spatially detailed estimates of PHA exceedence values. However, using their findings introduces a further complication — the need to account more accurately for site characteristics than they are able to do with hard and soft soil attenuation functions. This need is met by converting PHA on hypothetical rock sites to MMI on hypothetical rock sites and then accounting for the alteration of MMI on rock by various site characteristics. There are several ways to convert from PHA to MMI values, and there are several ways to account for site characteristics. Below, these problems are discussed as are combinations of approaches that promise reasonable results.

Two methods have been used to link PHA to MMI. The first is a continuing effort to define a direct and reliable relationship between acceleration and MMI (see the references cited in fig. 4). A second approach indirectly links acceleration to MMI by way of ground motion velocity as an intermediate variable. The second path must be considered for two reasons: velocity is thought to be more sensitive to site characteristics than acceleration, and site-specific spectral amplifications of pseudo-relative velocity (PSRV) should be applied to regional estimates of PHV (not PHA) when using spectral amplification factors to estimate spatial variation in MMI (Taylor, p.c.).

A search of the literature yields ten functional relationships between PHA and MMI (figs. 4a and 4b) and seven relationships between PHV and MMI (fig. 5). The parameters in some of these

relationships are adjustable depending upon hypotheses concerning magnitude and distance. Other relationships are, in fact, suites of relationships controlled for variation in distance or soil-versus-rock conditions. The relationships are converted to an identical functional form so their slope and intercept coefficients can be readily compared. Outlying relationships are discarded. A suite of relationships by Krinitzsky and Chang (1987) is chosen for use in converting acceleration to intensity. A function by Wiggins and Taylor (1981) is retained for use in converting velocity to intensity. When needed, a relationship provided by Donovan (1983) is used to convert PHA to PHV given appropriate values for soil-versus-rock conditions, expected magnitude, and epicentral distance.

Given data and relationships presently available for this region, three general methodologies can be discerned with which to address local variation in site conditions. One way is to start with PHA on rock, convert either directly or indirectly to MMI on rock and then, following Borcherdt, Gibbs and Fumal (1979), add intensity increments associated with the relative site response contours provided by Tinsley (1988). This procedure yields a localized estimates of MMI. Call this option the Intensity Increment Option.

Borcherdt, Gibbs and Fumal (1979) define a relationship between shear wave velocity and intensity increments measured on the San Francisco intensity scale. They also define a relationship between shear wave velocity and ground motion amplification. Implied, with proper conversion among intensity scales, is a relationship between ground motion amplification and Modified Mercalli Intensity Increments (fig. 6). This relationship is more consistent with historical observations and instrumental measurements than the comparable equation given earlier in Borcherdt and others (1975) (fig. 7).

Evernden, Kohler and Clow (1981) invert this procedure. They start with PHA on alluvial soil, convert to MMI on soil and apply MMI decrements for stiffer geologic units. This approach will not serve the present situation since alluvial deposits are not the most seismically sensitive soils in Jordan River Valley.

A second option is to convert from PHA on rock to PHV on rock, apply amplification factors (Rogers and others, 1984, or Tinsley, 1988) and then compute microzonal MMI values using Wiggins and Taylor's (1981) equation. Since this is a variation of the method used by Taylor and others (1986), call this option the Taylor Variation.

A third option is a variation on a method employed by Krinitzsky (1988). It uses two starting points, two soil-specific conversion equations, and interpolates values in between. First start with PHA on soil for the valley center and convert to MMI on soil using an equation specific to soft

soils. Next start over with PHA on rock for the valley edge and convert to MMI on rock using an equation specific to hard soils. Then interpolate between these extreme values for site-specific MMI values. Call the Krinitzsky Option.

These options are explored below. In addition to the issues raised here, several challenges remain. These include clarifying the relationship between soil properties and site amplification (see Tinsley, 1988), applying response spectral attenuation relationships that control for detailed geotechnical properties (Joyner and Fumal, 1985), developing and applying regionally-specific MMI attenuation equations (see Algermissen and others, 1988), specifying basin geometric and directivity effects on relative ground motion (Benz and Smith, 1989), and merging results to further refine localized estimations of MMI.

A COMPARISON OF ALTERNATIVE METHODS

Alternate Methods. Different methods for converting acceleration to intensity are detailed below. Each is described and results are discussed and compared (table 1 and fig. 8). Different methods are explored to better understand the range of likely results and to better control for spurious results. The comparison also helps clarify the logic of each approach.

The Intensity Increment Option is used to develop Method #1 and Method #2. For Method # 1, begin with estimates of PHA on rock which have a 10% chance of being exceeded over 10, 50 and 250 year period (Young and others, 1987). Use appropriate equations from Kinitzsky and Chang (1987b) to convert to MMI on rock. Note the relative ground shaking factors in the 0.2 to 0.7 second period band (Tinsley, 1988), truncate at factors above eight (because of a possible non-linear response above a factor of eight), and then apply the corresponding intensity increments given in Figure 6. This procedure yields for the intermediate (50 year) time horizon MMI values of VII for rock at the valley edge and MMI values of X for soft clays at the valley center.

For Method #2, begin with estimates of PHA on rock (Young and others, 1987), convert to PHV on rock (Donovan, 1983), estimate MMI on rock (Krinitzsky and Chang, 1987b), note appropriate relative ground shaking factors, and apply the corresponding intensity increments given in Figure 6. This procedure yields MMI values for rock at the valley edge and for soft clays at the valley center of VI+ and IX+ for the intermediate (50 year) time horizon.

The Taylor Variation is used to develop Method #3 and Method #4. For Method #3, begin with estimates of PHA on rock (Young and others, 1987), and convert to PHV on rock (Donovan, 1983). Apply Tinsley's (1988) relative ground shaking factors to find velocities at site, and convert

to MMI estimates using a equation provided by Wiggins and Taylor (1981). This procedure yields MMI values for rock at the valley edge and for soft clays at the valley center of VII+ and X for the 50 year time horizon.

For Method #4, proceed as above except replace Tinsley's relative ground shaking factors with those provided by Rogers and others (1984) for surficial geologic units. Results derived by this method are essentially the same as in Method #3.

The Krinitzsky Option is used to develop Method #5 and Method #6. For Method #5, begin with estimates of PHA on rock and PHA on soil. Convert from PHA on rock to MMI on rock and from PHA on soil to MMI on soil using functions from Krintizsky and Chang (1987b). Estimate intensities on sites with surficial deposits having densities somewhere between hard rock and soft soil by interpolation between these two points. Rock and soft soil MMI values derived by this method are VII+ and VIII+ over the 50 year time horizon.

For Method #6, begin with PHA on rock and PHA on soil, and convert to velocities. Then convert from PHV to MMI on rock and to MMI on soil using Krintzsky and Chang (1987b). Rock and soft soil values derived by this method are VII and VIII over the 50 year time horizon.

Results for the 10, 50 and 250 year time horizons by generalized Jordan River Valley location are given in Figure 8. Note that the valley edge location refers to bedrock sites with a site amplification ratio of 1.0 while valley center locations refer to sensitive soil sites with the highest site amplification ratio possible under each method.

Evaluation of Alternative Methods. Results from Methods #1, 2, 3 and 4 have similar ranges. The range of results from Methods #5 and 6 are notably narrower. In view of historical observations (Oaks, 1987) and instrumental measurements on various soils in Jordan River Valley, Methods #5 and 6 must be regarded as offering an unacceptably narrow range of results by location. Apparently the use of simple PHA-to-MMI and PHV-to-MMI functions for rock and soft soils fails to fully account for the range of site characteristics found locally. By averaging a broad range of ground motion responses to two points on a broad spectrum of response and referring to each point respectively as "a rock response" and " a soil response" destroys information and ignores differences that are notable at the geographic scale of this analysis. For these reasons, Methods # 5 and 6 are excluded from further consideration.

Method #1 employs a direct conversion of acceleration to intensity. It has the simplest logic and, thus, appears least likely to propagate errors through extended chain models. However, Method #1 relies on an estimate of the relationship between ground motion amplification and

Modified Mercalli Intensity increments from Borcherdt, Gibbs and Fumal (1979). Because of numerous intensity scale conversions (San Francisco to Rossi-Forell to MMI), this relationship is of questionable reliability.

Methods #2, 3 and 4 convert from velocity to MMI: this is preferred on theoretical grounds. However, Method #2 yields uniformly lower estimates of intensities, while Method #4 yields a uniformly smaller range of intensities by location. The choice is narrowed to Methods # 1 and 3. Results from Method # 1 tend to be higher than most others. Method #1 relies on a theoretically less preferred conversion from acceleration on rock directly to MMI on rock, and it uses a relationship between spectal amplification ratios and MMI increments that is of questionable reliability. For these reasons, Method #3 is preferred over Method #1.

A Variation on the Preferred Method. Method #3 uses Tinsley's (1988) map of relative ground shaking factors. One difficulty in using his map is the manner in which his isopleth contours ignore differences in surficial geologic units known to influence site response. (Work in progress by Tinsley will correct this feature.) Rogers and others (1984) sought to address this issue by correlating three different surficial geologic units with site response factors, but a problem with using Rogers's surficial geologic units is the loss of both range and spatial resolution due to the small number of geologic units considered.

To resolve this problem, develop a schedule of six surficial geologic units collapsed from a larger number of units represented on Davis's 1983 map compilation. Assign to each of the six geologic units a spectral amplification factor (table 2). Confirm the reasonableness of the assigned amplification factors through review of the literature, correlation with standard cone penetrometer test scores, and corroboration with geologist familiar with the problem (Christensen, pc, Currey, pc, and King, pc).

Digitize these six units, digitize Tinsley's relative ground shaking factors map and use a geographic information system to create a composite map from the two underlying digital map planes so that the polygons in the composite map have site response scores which equal the square root of the product of the polygon scores from the two underlying map layers. This results in a modified site response surface that combines with equal weight both Tinsley's isopleth contours and surficial geologic units. The resulting map constructively combines information in the underlying map planes and offers a finer-grained representation of site characteristics. Use this surface in Method #3 in place of Tinsley's isopleth contours. The range and magnitude of results are the same but the degree of spatial resolution is improved. (Methodological details are discussed

in Appendix C.— Use of Computer Mapping and GIS Methodologies.)

A Mapping of Seismic Intensities. The objective of this study is to create maps showing spatial variation in the seismic intensities which have a ten percent chance of being exceeded over a 10, a 50 and a 250 year period. Two digital map planes and a set of relationships are used as inputs. These include maps of PHA by Young and others (1987), the composite site response surface described above, and the relationships among PHA, PHV, site amplification and MMI used in Method #3. Define for each exposure time period a digital map plane in which MMI is a logrithmic function of the product of two input digital map planes - one defining spatial variation in PHA and the other defining spatial variation in relative site response. The result is a set of maps depicting spatial variation in MMI exceedence values for each of three time horizons (figs. 9a-c).

Figure 9a shows Modified Mercalli Intensities which have a 10% chance of being exceeded in a 10 year period. Refer to this map when addressing concerns about the internal contents of structures. Figure 9b shows the same information for a 50 year period. Refer to this map when addressing concerns about the structural integrity of ordinary buildings. Figure 9c shows the same information for a 250 year period. Refer to this map when addressing concerns about the structural integrity of lifelines, critical facilities and structures containing hazardous materials.

Specific reservations must be noted about the use and interpretation of these maps. They refer only to the ground shaking hazard as understood through an analysis of ground motion amplification. They do not consider the near-field directivity effects recently noted by Benz and Smith (1989). They do not consider the induced effects of ground failures such as liquifaction, slumps, slides, flows, falls and subsidence (Anderson and others, 1986; Keaton, 1986; Case, 1987). They do not include the effects of fault rupture and surface displacement (McCalpin, 1987). The polygon boundaries drawn on these maps should be regarded as having a range of uncertainty extending over a few hundred meters.

In spite of these reservations, the maps do have useful applications. They can be used for regional loss estimations, regional calculation of insurance premiums, and in the overall design of earthquake emergency reponse systems. They can be used to help frame discussion of seismic retro-fit policies and generalized land use policies. They can be used to guide the general siting and design of lifelines, critical facilities and large capacity structures. They serve as a basis for the study of related geologic hazards activated by various intensities of ground shaking.

To improve this line of inquiry, further research needs to be done on several topics. Results need to be compared with those produced through the direct attenuation of intensity from source to

site. Correlations of PSRV with the physical characteristics of surface and subsurface geology need to be detailed. Further study of directivity effects in the near field are needed to clarify the nature of this hazard. Critical intensities triggering liquifaction and other ground failure hazards in differentially sensitive soils need to be mapped. Also needed are loss estimations by building use and frame type based on a large scale mapping of ground shaking intensities and related ground failure hazards. The current study can serve, in part, as a basis from which to address some of these research and application needs.

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REFERENCES CITED

Algermissen, S. T. and Perkins, D. M., Thenhaus, P. C., Hanson, S. L., and Bende, B. L., 1982, Probabalistic estimates of maximum acceleration and velocity in rock in the contiguous United States: U.S. Geol. Survey Open-File Report 82-1033, 99 pp.

Algermissen, S. T. and Steinbrugge, K.V., 1984, Seismic hazard and risk assessment: some case studies: The Geneva Papers on Risk and Insurance, v. 9, p. 8-26.

Algermissen, S. T., Arnold, E. P., Steinbrugge, K. V., Hooper, M. G. and Powers, M. S., 1988, Earthquake losses in Central Utah, in Gori, P. L. and Hays, W. W. (editors), Assessment of Regional Earthquake Hazards and Risk along the Wasatch Front, Utah: U.S. Geol. Survey Open-File Report 88-680, v.3, p. X-1-62.

Anderson, L. R., Keaton, K. R., Spitzley, J. E. and Allen, A. C., 1986, Liquifaction potential map for Salt Lake County, Utah: Department of Civil and Environmental Engineering, Utah State University, Logan, and Dames and Moore, Salt Lake City, Utah, 48 pp.

Arabasz, W. J., Pechmann, J. C. and Brown, E. D., 1987, Observational seismology and the evaluation of earthquake hazards and risk in the Wasatch Front area, Utah, in Gori, P. L. and Hays, W. W. (editors), Assessment of Regional Earthquake Hazards and Risk along the Wasatch Front, Utah: U.S. Geol. Survey Open-File Report 87-585, v.1, p. D-1-39.

Benz, H. M. and Smith, R.B. 1989, Elastic wave propagation and site amplification in the Salt Lake Valley, Utah, from simulated normal faulting earthquakes, Bull. Seismol. Soc. Am.

Bernreuter, D. L., 1981, Seismic hazard analysis: Application of methodology, results and sensitivity studies: U.S. Nuclear Regulatory Commission Report MUREG/CR-3756, Washington, D.C.

Borcherdt, R. D., Joyner, R. E., Warrick, R. E. and Gibbs, J. F., 1975, Response of local geologic units to ground shaking, in Borcherdt, R. D. (editor), Studies for Seismic Zonation of San Francisco Bay Region: U.S. Geol. Survey Professional Paper 941-A, p. 52-67.

Borcherdt, R. D., Gibbs, J. F. and Fumal, T. E., 1979, Progress on ground motion predictions for the San Francisco Bay region, in Brabb, E.E. (editor), Progress on Seismic Zonation in the San Francisco Bay Region: U.S. Geol. Survey Circular 807.

Borcherdt, R. D. 1985, Predicting earthquake ground motion: an introduction, in Ziony, J. I. (editor), Evaluating earthquake hazards in the Los Angeles region: U.S. Geol. Survey Prof. Paper 1360, p. 93-99.

Case, W. F., 1987, Rock fall hazard susceptibility due to earthquakes, central Wasatch Front, Utah, in Gori, P. L. and Hays, W. W. (editors), Assessment of Regional Earthquake Hazards and Risk along the Wasatch Front, Utah: U.S. Geol. Survey Open-File Report 87-585, v.2, p.

V-1-36.

Campbell, K.W., 1984, Near-source attenuation of strong ground motion for moderate to large earthquakes - an update and suggested applicaiton to the Wasatch Fault Zone on north-central Utah, in Hays, W.W. and Gori, P.L. (editors), A Workshop on "Evaluation of Regional and Urban Earthquake Hazard and Risk in Utah", U.S. Geol. Survey Open-File Report 84-763, p. 483-499.

_____ 1986, An empirical estimate of near-source ground motion for a major $m_b = 6.8$ earthquake in the eastern United States, Bull. Seismol. Soc. Am., 76, p. 1-17.

_____ 1987, Predicting strong ground motion in Utah, in Gori, P. L. and Hays, W. W. (editors), Assessment of Regional Earthquake Hazards and Risk along the Wasatch Front, Utah: U.S. Geol. Survey Open-File Report 87-585, v. 2. p. L-1-90.

Christenson, G., 1988, Telephone and personal conversations with the author: Salt Lake City, Utah, November.

Currey, D. R., 1988. Personal conversations with the author: Salt Lake City, Utah, November.

Davis, F., 1983, Geologic map of the Central Wasatch Front, Map No. 54-A: Utah Geologic and Mineral Survey, Salt Lake City, Utah.

Donovan, N., 1983, A practitioner's view of site effects on strong ground motion, in Hays, W. W. (editor), A Workshop on "Site Effects of Soil and Rock on Ground Motion and the Implicaitons for Earthquake-Resistant Design," U.S. Geol. Survey Open-File Report 83-845, p. 68-79.

Emmi, P. C., 1989, An interpretation of recent findings on the directivity effects of a surface-faulting earthquake on the Salt Lake Segment of the Wasatch Fault, Department of Geography, Univeristy of Utah, Salt Lake City, Utah.

Evernden, W. M. Kohler, W. M. and Clow, G. D., 1981, Seismic intensities of earthquakes of conterminous United States - their prediction and interpretation: U.S. Geol. Survey Professional Paper 1223, 56 pp.

Hays, W. W., 1980, Procedures for estimating earthquake ground motion: U.S. Geol. Survey Prof. Paper 1114, 77 p.

_____, (editor), 1983, A Workshop on "Site Effects of Soil and Rock on Ground Motion and the Implications for Earthquake-Resistant Design," U.S. Geol. Survey Open-File Report 83-845, 357 p.

_____ , 1987, Site amplification in the Salt Lake City - Ogden - Provo urban corridor and the implications for earthquake-resistant design, in Gori, P. L. and Hays, W. W. (editors),

Assessment of Regional Earthquake Hazards and Risk along the Wasatch Front, Utah: U.S. Geol. Survey Open-File Report 87-585, v.2, p. K-1-69

Hays, W. W., Algermissen, S. T., Miller, R. D, and King, K. W., 1978, Preliminary ground response maps for the Salt Lake City area: International Conference on Microzonation, 2nd, San Francisco, Proceedings, v. 2. p. 487-508.

Hooper, M. G., 1988, Isoseismals of some historical earthquakes affecting the Wasatch Front Area, Utah, in Gori, P. L. and Hays, W. W. (editors), Assessment of Regional Earthquake Hazards and Risk along the Wasatch Front, Utah: U.S. Geol. Survey Open-File Report 88-680, v.3, p. Y-1-28.

Joyner, W. B. and Fumal, T. E., 1985, Predictive mapping of earthquake ground motion, in Ziony, J. I. (editor), Evaluating earthquake hazards in the Los Angeles region: U.S. Geol. Survey Prof. Paper 1360, p. 203-220.

Keaton, J. R., 1986, Evaluation of potential consequences of earthquake induced tectonic subsidence along the Wasatch Front, North-Central, Utah: Dames and Moore, Salt Lake City, Utah, pp. 52.

King, K. W., 1988, Telephone conversation with the author: Salt Lake City, Utah, October.

King, K. W., Williams, R. A. and Carver, D. L., 1987, Relative ground response in Salt Lake City and areas of Springville-Spanish Fork, Utah, in Gori, P. L. and Hays, W. W. (editors), Assessment of Regional Earthquake Hazards and Risk along the Wasatch Front, Utah: U.S. Geol. Survey Open-File Report 87-585, v. 2. p. N-1-48.

Krinitzsky, E. L., 1988, Empirical earthquake ground motions for an engineering site with fault sources - Tooele Army Depot, Utah: Waterways Experiment Station, U.S. Army Corps of Engineers, Vicksburg, Miss., 79 pp.

Krinitzsky, E. L. and Chang, F. K., 1987a, State-of-the-art for assessing earthquake hazards in the United States; Report 25, Parameters for specifying intensity-related earthquake ground motions: Geotechnical Laboratory, Waterways Experiment Station Miscellaneous Paper S-73-1, U.S. Army Corps of Engineers, Vicksburg, Miss., 43 pp.

_____ 1987b, State-of-the-art for assessing earthquake hazards in the United States; Report 26, Parameters for specifying magnitude-related earthquake ground motions: Geotechnical Laboratory, Waterways Experiment Station Miscellaneous Paper S-73-1, U.S. Army Corps of Engineers, Vicksburg, Miss.,

Lund, W. R., 1987, 1986-1987 Paleoseismic trenching program summary: Wasatch Front Forum, v.4, no. 1-2, p. 1-7.

Machette, M. N., Personius, S. F. and Nelson, A. R., 1987, Quaternary geology along the Wasatch Fault Zone: segmentation, recent investigations, and preliminary conclusions, in Gori, P. L. and Hays, W. W. (editors), Assessment of Regional Earthquake Hazards and Risk along the Wasatch Front, Utah: U.S. Geol. Survey Open-File Report 87-585, v.1, p. A-1-72.

McCalpin, J., 1987, Recommended setbacks from active normal faults: Proceedings of the 23rd Symposium on Engineering Geology and Soils Engineering, Logan, Utah, April 6-8, p. 35-56.

Murphy, J. R. and O' Brien, L. J., 1977, The correlation of peak ground acceleration amplitude with seismic intensity and other physical parameters, Bull. Seismol. Soc. Am., 66, p. 915-935.

Neumann, F. 1954, Earthquake Intensity and Related Ground Motion: Seattle, Washington Univ. Press, 40 p.

Oaks, S. D., 1987, Effects of six damaging earthquakes in Salt Lake City, Utah, in Gori, P. L. and Hays, W. W. (editors), Assessment of Regional Earthquake Hazards and Risk along the Wasatch Front, Utah: U.S. Geol. Survey Open-File Report 87-585, v.2, p. P-1-95.

Richter, C. F., 1935, An instrumental earthquake magnitude scale: Seismol. Soc. Am. Bull., v. 25, p 1-32.

Rogers, A. M., Algermissen, S. T., Hays, W. W., and Perkins, D. M. (geologic portions), Van Strien, D. O., Hughes, H. C., Hughes, R. C., Lagorio, H. J. and Steinbrugge, K. V. (engineering analysis), 1976, A study of earthquake losses in the Salt Lake City, Utah, Area: U.S. Geol. Survey Open-File Report 76-89, 357 p.

Rogers, A.M., Carver, D.L., Hays, W.W., King, K.W. and Miller, R.D., 1984, Preliminary estimates of geographic variation in relative ground shaking in the Wasatch Front urban corridor, in Hays, W.W. and Gori, P.L. (editors), A Workshop on "Evaluation of Regional and Urban Earthquake Hazard and Risk in Utah", U.S. Geol. Survey Open-File Report 84-763, p. 547-556.

Rogers, A. M., Tinsley, J. C., and Hays, W. W., 1983, The issues surrounding the effects of geologic conditions on the intensity of ground shaking, in Hays, W. W. (editor), A Workshop on "Site Effects of Soil and Rock on Ground Motion and the Implicaitons for Earthquake-Resistant Design," U.S. Geol. Survey Open-File Report 83-845, p. 32-67.

Rojahn, R. L., 1985. Earthquake damage evaluation data for California, ATC-13: Applied Technology Council, Redwood City, Calif., 492 pp.

Schwartz, D.P. and Coppersmith, K.J., 1984, Fault behavior and characteristic earthquakes from the Wasatch and San Andreas Faults: Journal of Geophysical Research, v. 89, no. B7, p. 5681-5698.

Taylor, C. E., 1988, Telephone communication with the author: Salt Lake City, Utah, October.

Taylor, C. E., Wiggins, J. H., Haber, J. M. and Ward, D. B., 1986, A systems approach to Wasatch Front seismic risk problems: NTS Engineering Report to the U.S. Geol. Survey, Redondo Beach, Calif.

Tinsley, J. C., 1988, Quaternary framework for earthquake studies, in Jacobson, M. L. (editor), National Earthquake Hazards Reduction Program, Summaries of Technical Reports, U.S. Geolgical Survey Open-File Report 88-434, v. 26, p. 528-532.

Trifunac, M. D., 1970, Low frequency digitization errors and a new method for zero baseline corrections of strong ground motion accelerograms: Pasadena, Calif., California Inst. of Technology, Earthquake Eng. Reseach Lab. Rept. EERL 70-07, 30 p.

Trifunac, M. D. and Brady, A. G., 1975, On the correlation of seismic intensity scales with the peaks of recorded strong ground motion, Bull. Seismol. Soc. Am., 65, p. 139-162.

Werner, S. D. and Ts'ao, H. S. 1975, Investigation of vertical ground motion characteristics for nuclear plant design: Agbabian Assoc. report to Reactor Reseach and Devel. Div. , Energy Research and Devel. Adm., SAN/1011-107, 29 p.

Wiggins, J. H. and Taylor, C. E., 1981, Earthquake hazards and risk mitigation - identification and evaluation methods: J. H. Wiggins Co. Report to F.E.M.A., Redondo Beach, Calif., three volumes.

Williams, J. S. and Tapper, M. L., 1953, Earthquake history of Utah, 1850-1949: Seismol. Soc. Am. Bull., v.43, p. 191-218.

Wood, H. O. and Neumann, F., 1931, Modified Mercalli intensity scale of 1931, Seismol. Soc. Am. Bull., v. 21, p. 277-283.

Young, R. R., Swan, F. H., Powers, M. S., Schwartz, D. P. and Green, R. K., 1987, Probabalistic analysis of earthquake ground shaking hazard along the Wasatch Front, Utah, in Gori, P. L. and Hays, W. W. (editors), Assessment of Regional Earthquake Hazards and Risk along the Wasatch Front, Utah: U.S. Geol. Survey Open-File Report 87-585, v.2, p. M-1-110.

APPENDIX A.— ABBREVIATED DESCRIPTION OF THE MODIFIED MERCALLI SCALE

I. Not felt but by a very few under especially favorable conditions.

II. Only felt by a few persons at rest, especially on upper floors of buildings.

III. Felt noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing cars may rock slightly. Vibration similar to the passing of a truck. Duration can be estimated.

IV. Felt indoors by many and outdoors by a few. At night some are awakened. Dishes, windows and doors are disturbed. Walls make cracking sound. Standings cars rock noticeably.

V. Felt indoors by practically all. Many are awakened. A few run outdoors. Some dishes are broken. Small or unstable objects overturn.

VI. Felt by all, indoors and out. Many are frightened, many run outdoors. Persons made to move unsteadily. Dishes and glassware is broken in considerable quantity. Some heavy furniture is moved. Some plaster may fall.

VII. All are frightened and run outdoors. Many find it difficult to stand. Sand and gravel stream beds cave in. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures. Some chimineys are broken. Fall of plaster is considerable to large amounts. Loose brickwork and tiles are shaken down. Waek chimneys are broken at the roof-line. Cornices fall. Heavy furniture is overturned and damaged.

VIII. General fright. Alarm approaches panic. Sand and mud is ejected in small amounts. Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Panel walls are thrown out in frame strucutres. Damage is great in poorly built structures. Chimneys, factory stacks, columns, monuments and walls twist and fall. Very heavy furniture is moved and overturned.

IX. General panic. Ground cracks conspicuosly. Damage considerable in masonry structures; well-designed frame structures are thrown out of plumb. Damage is great in substantial buildings which may partially collapse. Frame buildings are shifted off their foundations. Underground pipes are broken. Reservoirs are compromised.

X. Cracked ground, especially when loose and wet: yard-wide fissures run parallel to canal and stream banks. Landslides are considerable. Sands and mud shift horizontally on flat land. Some well-built wooden structures are destroyed. Destroys most masonry and frame

structures as well as their foundations. Buried pipelines are torn apart or crushed end-wise. There are open cracks and wavy folds in cement pavement and asphalt roads.

XI. Ground disturbances are many and widespread including fissures, slumps and slides. Water charged with sand and mud is ejected in large amounts. Seiches and tsunamis of significnt magnitude occur. Damage is great to dams, dikes and enbankments. Damage is great to wood frame structures. Few if any masonry structures remain standing. Bridges are destroyed by the wrecking of supporting piers and pillars. Rails are bent greatly. Buried pipelines are put completely out of service.

XII. Damage is practically total. Moving waves are actually seen on the ground surface. Objects are thrown into the air.

Figures A-1 and A-2 depict expected damage to common structures in the built environment as a function of Modified Mercalli Intensity. These figures are bases on data from Applied Technology Council (Rojahn, 1985).

Appendix B.— THE INTERPRETATION OF TECHNICAL STATEMENTS OF RISK

Risk is defined as the chance of injury, damage or loss. Technical statements of risk try to specify the degree of risk. Risky events which are dichotomous - they either happen or not - are easy to quantify. One needs simply to state the probability of their occurence during some relevant time period. However, most risky events vary in the severity or intensity of their occurence. In such instances, any effort to quantify risk must deal simuntaneously with three aspects of risk.

First is a measure of the severity or intensity with which a dangerous event can occur. In the present context, a measure of ground shaking intensity - the Modified Mercalli Intensity Scale (MMI) - is used.

Second is a time horizon over which exposure is considered. In the present context, three time horizons - a 10 year, a 50 year and a 250 year time period - are used. These correspond to the time frames that should be considered when addressing respectively the security of the internal contents of structures, the integrity of ordinary buildings and the seismic performance of lifelines, critical facilities, and hazardous installations.

Third is the probability with which a specified intensity is expected to be matched or exceeded over a stated time horizon. It is customary to set this probability at the ten-percent level and then state the intensities which correspond to the three time horizons. In this way, one can specify the degree of danger one should have in mind when making certain kinds of design and siting decisions. For example, knowing that there is a 10% chance of MMI $\geq$ VIII+ over a 250 year period would have important design implications were the University of Utah to propose installing a Class IV biological laboratory capable of producing pathological organisms for which no cure is known.

For purposes of exposition, we try to reduce statements of risk to simple numbers. Clearly risky events which vary in their severity or intensity are not adequately described by a single number. A curve or a functional equation can be used to help clarify the degree of risk if one is willing to focus exclusively on a certain degree of intensity. However, representing the risk of dangeous events capable of various intensities requires a family of curves or functional equations (fig. B-1).

Figure B-1 presents this concept graphically. Ground shaking are classified into hypothetical intensity ranges of low, medium, and high intensity. The risk of experiencing a low level of ground shaking intensity is described by a hypothetical curve that shows high probabilites of being exceeded over various exposure times. The curve intersects a horizontal line marking the 10 percent exceedence probability at the 10 year time horizon. But the curve for low intensity ground

shaking arcs upward rapidly to define other exceedence probabilities over longer exposure times. It shows a very high 92 percent chance of a low level of ground shaking intensity being exceeded over a 250 year exposure time.

The curve for medium intensity ground shaking intersects the horizontal line marking the 10 percent exceedence probability at the 50 year time horizon. It also describes the chance of experiencing an intermediate level of ground shaking intensity over other time horizons. Someone concerned with the design of a structure expected to last a 100 years might determine from this curve that such a structure has about a 19 percent chance of being subject to at least an intermediate level of ground shaking. Stated otherwise, roughly one in every five 100-year periods will be witness to at least an intermediate level of ground shaking. If, with standard design, the structure could not withstand such an event, then earthquake insurance over the useful life of the structure should cost at least one-fifth the structure's value. If, with proper design and limited expense, the structure can be made to withstand such an event, one would then be advised to adopt such designs in lieu of bearing the risk or carrying earthquake insurance.

The curve for high intensity ground shaking intersects the horizontal line marking the 10 percent exceedence probability at the 250 year time horizon. The probability of high intensity ground shaking over a 100-year time horizon is about 4 percent. Thus, only one out of every twenty-five 100-year time periods is likely to have high intensity ground shaking. The possibility should be kept in mind only when considering a limited class of important or hazardous structures.

Making comprehensible statements about seismic risk in the Jordan River Valley is difficult not simply because of the inherent complexity of representing risk but because of the wide range of ground shaking intensities associated with each of the three time horizons. Figures 9a-c indicate that the ground shaking intensities included in the three intensity classes broadly overlap. Structures on seismically sensitive soils can be subject to high intensities of ground shaking with intermediate levels of probability and to intermediate levels of ground shaking with high probability. In addition to severity, time horizon, and exceedence probability, one must consider the further aspect of site conditions which vary considerably by location.

Appendix C.— USE OF COMPUTER MAPPING AND GIS METHODOLOGIES

All GIS operations are done on a PC/AT compatible with a raster-based software package by ERDAS. Tabular data input is through tape and floppy disk drives, while mapped data input is through an E-size digitizing table. Mapped output is through a color dot-matrix printer or throught photographs of a VGA standard color monitor.

A base map is digitized from a USGS Intermediate (1:100,000) Scale Topographic Map of Salt Lake County, Utah, with both UTM zone 12 and Utah State Plane Coordinate ticks. The study area includes the central valley of Salt Lake County suitable for contiguous urbanization. This is bounded on the north by the Davis County boundary, on the east by the Wasatch National Forest boundary, on the south by the Utah County boundary and on the west by the boundaries of Census tracts which intersect the increasingly steep slopes approximately marked by the 6000 foot topographic contour. Freeways, highways and major surface roads are added to provide informal locational reference.

In digital form, the base map contains aver 260,000 picture elements (pixels). Each pixel represents approximately 80 by 100 meters or about half of an acre.

Maps published by Young and others (1987) with PHA values having a 10% chance of being exceeded over a 10 year, a 50 year and a 250 year period are photographically enlarged, transferred to the base map using a reflecting projector, and digitized. Full 1:100,000 scale spectral amplifications maps from Tinsley (1988) sent to us directly by the author are digitized at scale as are the relevant geologic units interpreted from Davis's (1983) map compliation.

In digital form, Tinsley's spectral amplification ratios are used as our first digital map plane. Amplification ratios assigned to selected surficial geologic units from Davis's compilation are used as our second digital map plane. These two map planes are combined to create a composite site response surface. This is done with a program written in Pascal language which reads the first pixel from the first digital map plane, reads the first pixel from the second digital map plane, and computes a value for the first pixel of a third digital map plane as the square root of the product of the prior two pixel values. It writes this value as the value of the first pixel of a composite site response map and then repeats the cycle for all successive pixels. In this manner a composite site response surface is built up as an algebraic function of the two underlying map planes (fig. C-1).

The composite site response surface is then used in conjunction with each of three digital maps on PHA on rock. PHA on rock with a 10% chance of being exceeded in a 10 year period is used as the first map plane. The composite site response surface is used as the second map plane. Functional relationships between PHA on rock, site amplification, and MMI as specified in the

previous description of Method # 3 are collapsed into a single functional equation. This equation has PHA on rock and composite amplification ratios as independent variables and MMI as the dependent variable. A second Pascal language program uses this equation to compute MMI values with a 10% chance of being exceeded over a 10 year period for each pixel on a third map plane. The process is repeated to create maps showing MMI values with a 10 % chance of being exceeded over a 50 year and a 250 year period.

Maps of MMI exceedence values are put out to a color dot-matrix printer at 1:100,000 scale. Maps shown in Figure 9. a-c are reductions prepared from these larger scale maps by cartographer Steven Thomas of the University of Utah, Department of Geography, DIGIT Lab.

Table 1. Estimates of Modified Mercalli Intensity (MMI) for the edge and center of Jordan River Valley, Utah, using the six different methods of estimation discussed in this study. [The valley edge location assumes a crystalline rock site while the valley center location assumes a site with silt/clay Quaternary floodplain and deltaic deposits.]

		Method Number					
Time Horizon	Location	1	2	3	4	5	6
10 years	Edge	6.1	5.6	6.0	6.0	5.4	5.1
	Center	8.9	8.3	8.7	8.4	5.9	6.4
50 years	Edge	7.0	6.7	7.4	7.4	7.3	6.9
	Center	10.1	9.6	10.2	10.0	8.7	7.8
250 years	Edge	8.6	8.0	8.3	8.3	9.0	8.3
	Center	11.7	10.8	11.1	10.8	11.4	9.5

Table 2. A Cross-Classification of Surficial Geologic Units used by Davis (1983) and in this Study with Site Amplification Factors Assigned by the Author to Each Unit.

Surficial Geologic Units Used by Davis (1983)	Surficial Geologic Units Used in this Study	The Unit's Assigned Amplification Factor
Quaternary flood plain and delta complex	Fine clays and silts	8.0
Quaternary Lake Bonneville plus Jordan River flood Plain deposits	Coarse clays and silts	5.6
Quaternary alluvium plus active and abandoned flood plain deposits on Jordan River tributaries	Fine sand and gravel	4.2
Quaternary Bonneville and Provo shore facies plus Qua; ternary Bonneville and Alpine complex	Coarse sand and gravel	3.2
Quaternary morraines and talis	Rubble	2.0
Quaternary Hawkers fanglomerate plus older rocks	Rock	1.0

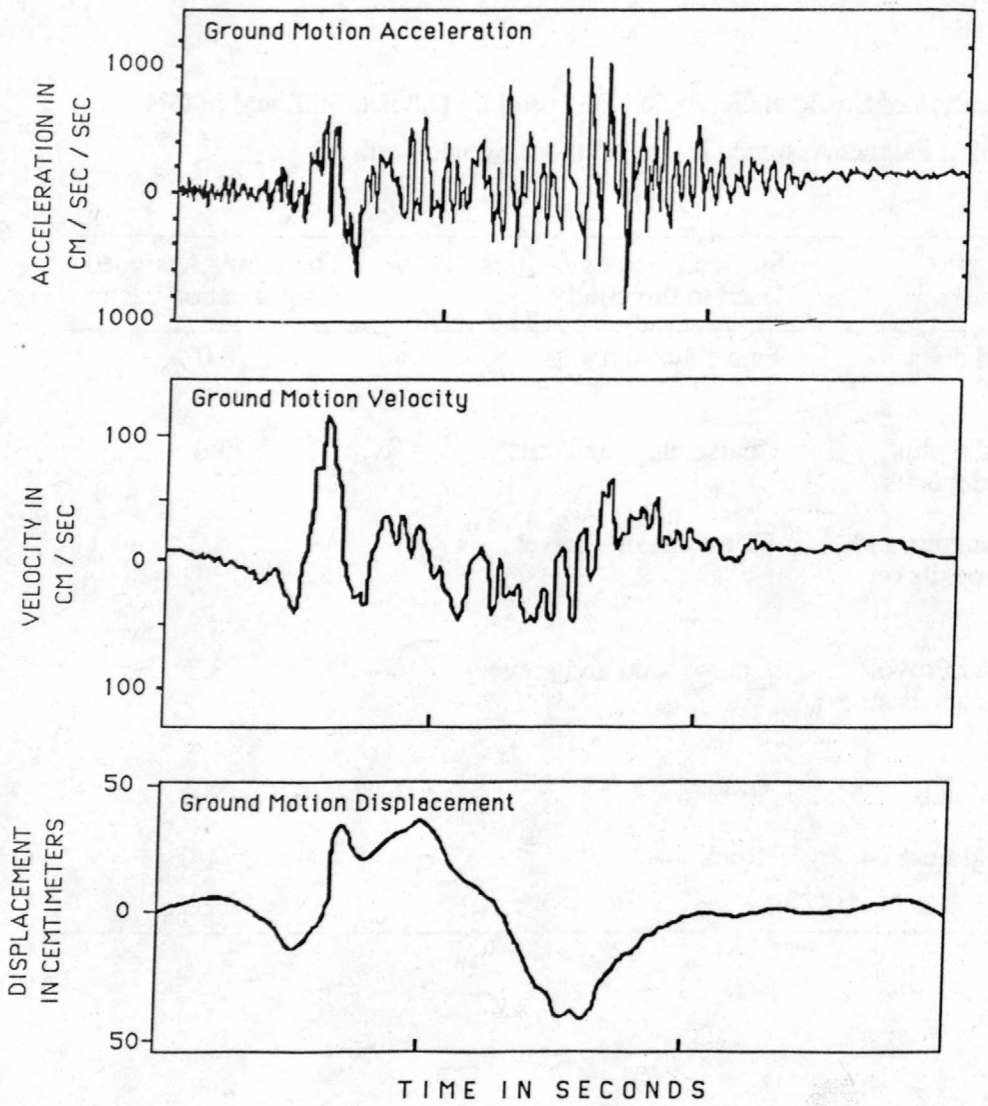


Figure 1.– S.16°E. component horizontal accelerogram recorded at Pacoima Dam and the velocity and displacement seismograms derived from it; 1971 San Fernando, Calif., earthquake (adopted from Hays, 1980: 28).

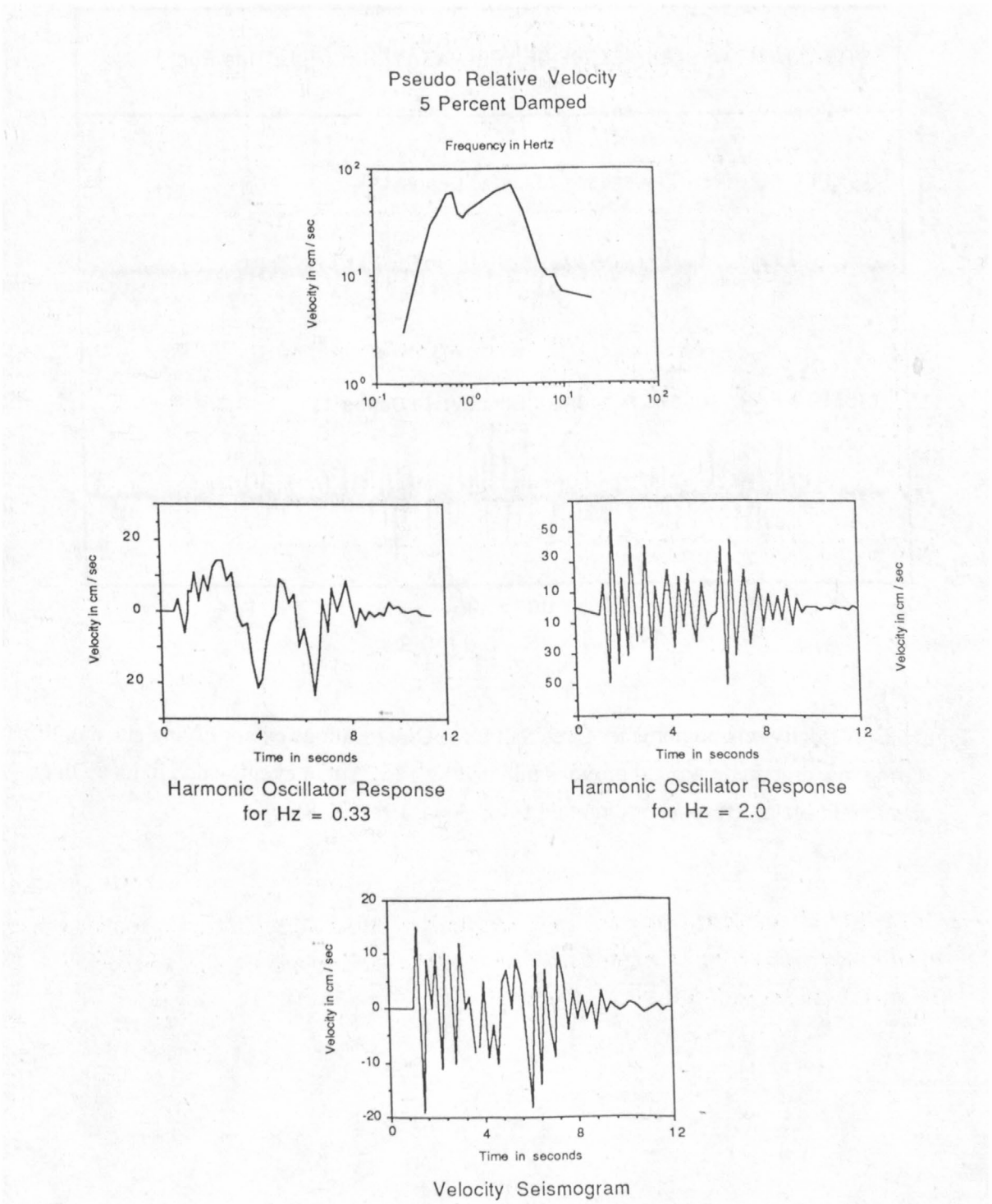


Figure 2.– The derivation of harmonic oscillilator response at 0.33 hertz and 2.0 hertz frequency from a velocity seismogram and their role in the construction of a pseudo-relative velocity response spectrum (adopted from Hays, 1980: 38).

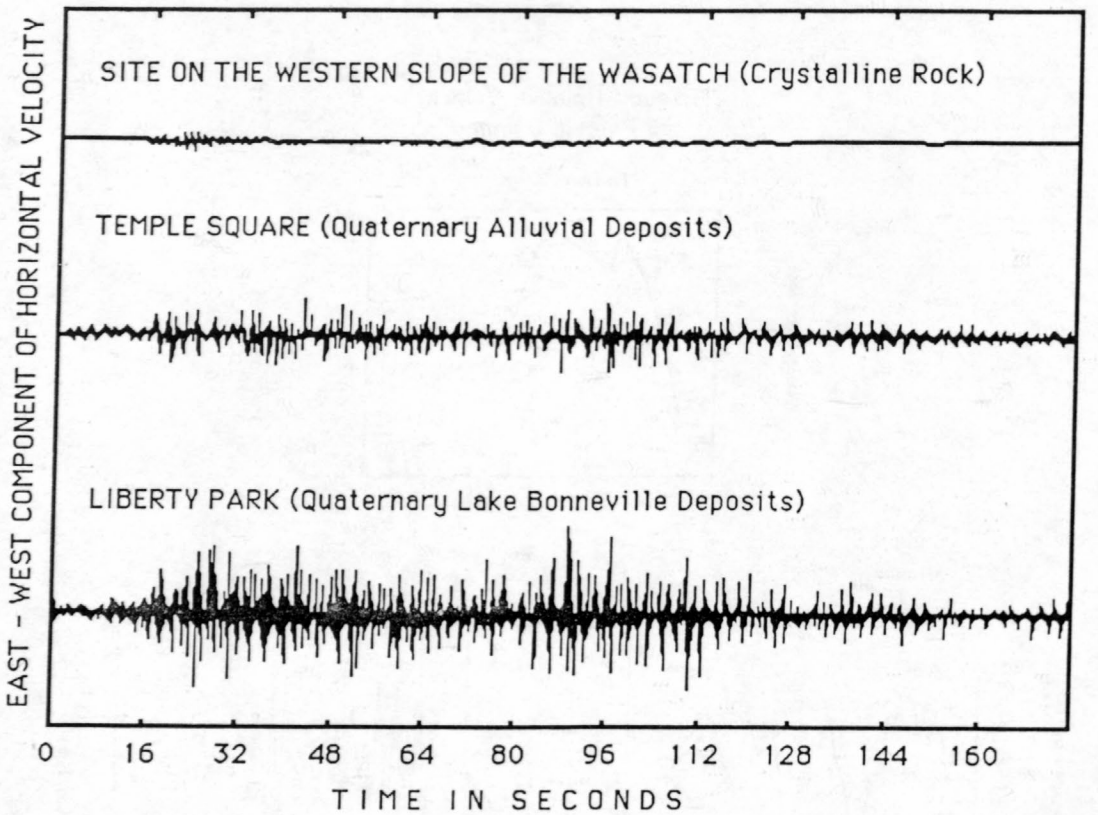
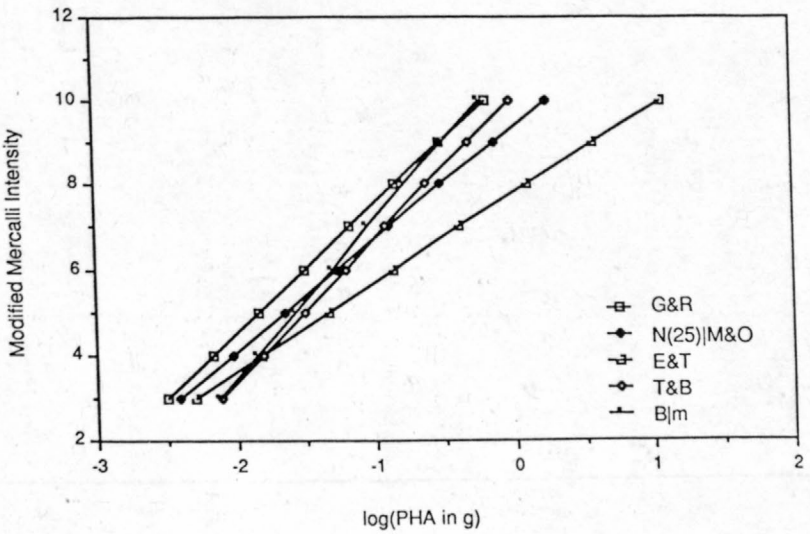
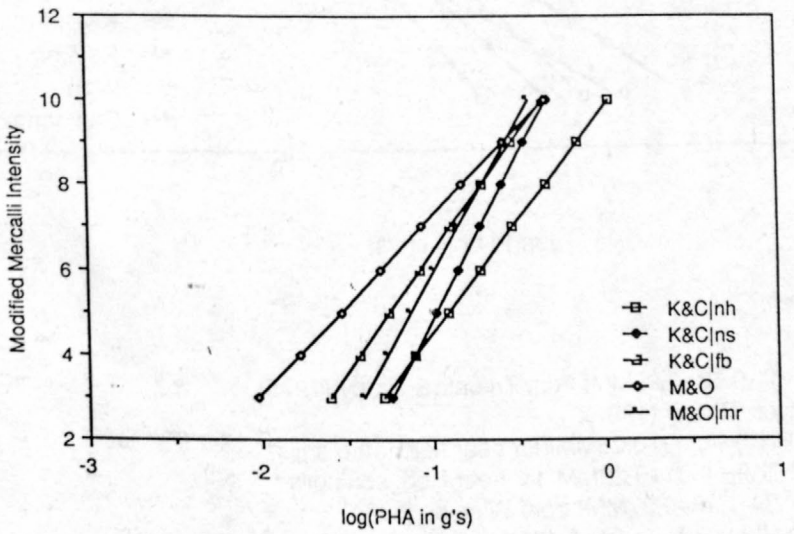


Figure 3.– Velocity seismograms for three Salt Lake City locations exemplifying site amplification during low amplitude ground motions initiated by a low strain event which induced linearly elastic relative site responses (adopted from Hays, 1987: K-8).

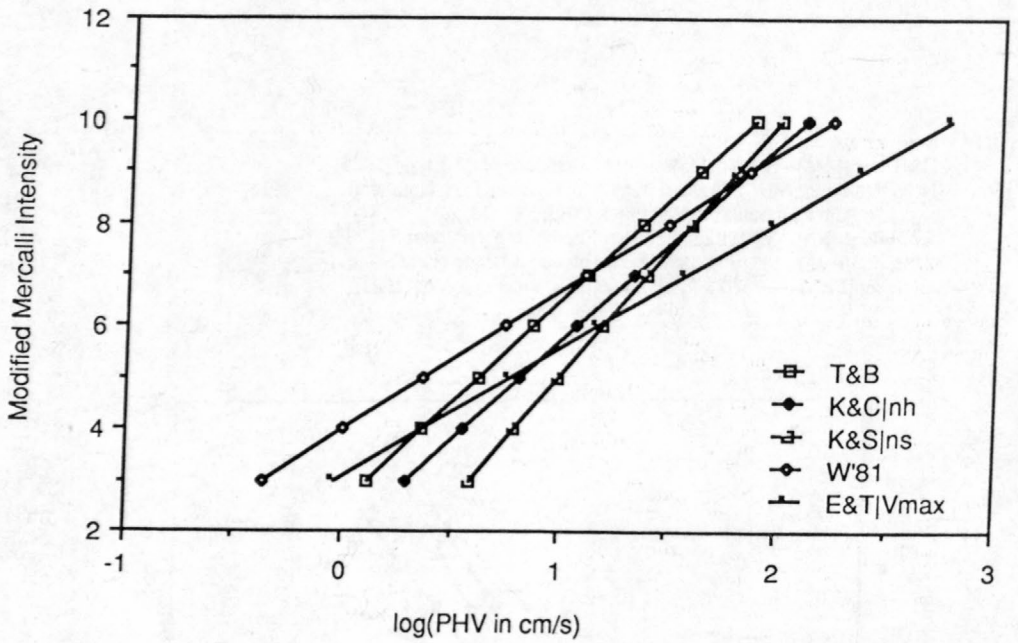


Sources:
G&R: log(PHA)=-3.49+0.33MMI from Gutenberg and Richter (1956)
N(25)|M&O: log(PHA)=-3.55+0.38MMI for R=25km from Neumann (1954) as modified by Murphy & O'Brien (1978)
E&T: log(PHA)=-3.74+0.48MMI from Evernden & Thompson (1985)
T&B: log(PHA)=-3.01+0.30MMI from Trifunac & Brady (1975)
B|m: log(PHA)=-2.93+0.27MMI for M=6.5 from Bernreuter (1981)



Sources:
From Krinitzsky & Chang (1987)
K&C|nh: log(PHA)=-1.86+0.19MMI for near field, hard soil
K&C|ns: log(PHA)=-1.63+0.13MMI for near field, soft soil
K&C|fb: log(PHA)=-2.15+0.18MMI for far field, both soils
From Murphy & O'Brien (1978)
M&O: log(PHA)=-2.74+0.24MMI
M&O|mr: log(PHA)=-1.83+0.14MMI for R=24km and M=6.25

Figure 4 a and b.– Graphs suggested by various authors of functional relationships between Modified Mercalli Intensity and the logarithm of peak horizontal acceleration measured in units of gravity.



Sources:
T&B: log(PHV)=-0.63+0.25MMI from Trifunic & Brady (1975)
From Krinitzsky & Chang (1987):
K&C|nh: log(PHV)=-0.49+0.26MMI for near field, hard soils
K&C|ns: log(PHV)=-0.01+0.20MMI for near filed, soft soils
W'81: log(PHV)=-1.48+0.37MMI from Wiggins (1981)
E&T|Vmax: log(MaxHV)=-1.24+0.40MMI, Everndon & Thompson (1985)

Figure 5.– Graphs suggested by various authors of functional relationships between Modified Mercalli Intensity and the logarithm of peak horizontal velocity measured in centimeters per second.

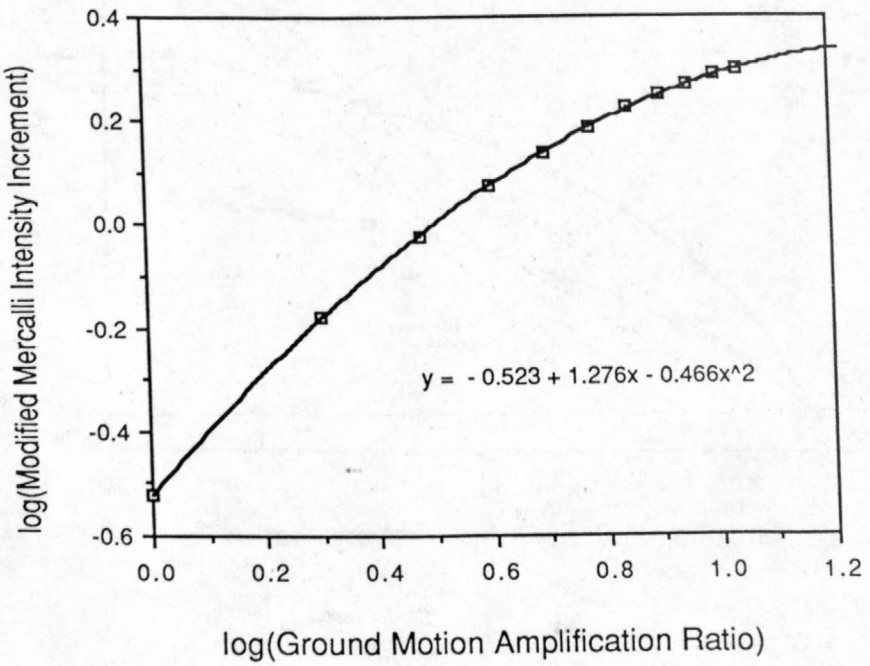


Figure 6.– A functional relationship between ground motion amplification ratios (relative to a reference rock site) and intensity increments for nearby soil sites that can be added to estimates of Modified Mercalli Intensity at the reference rock site to obtain MMI estimates for soil sites. (Based on relationships in Borcherdt and others, 1979.)

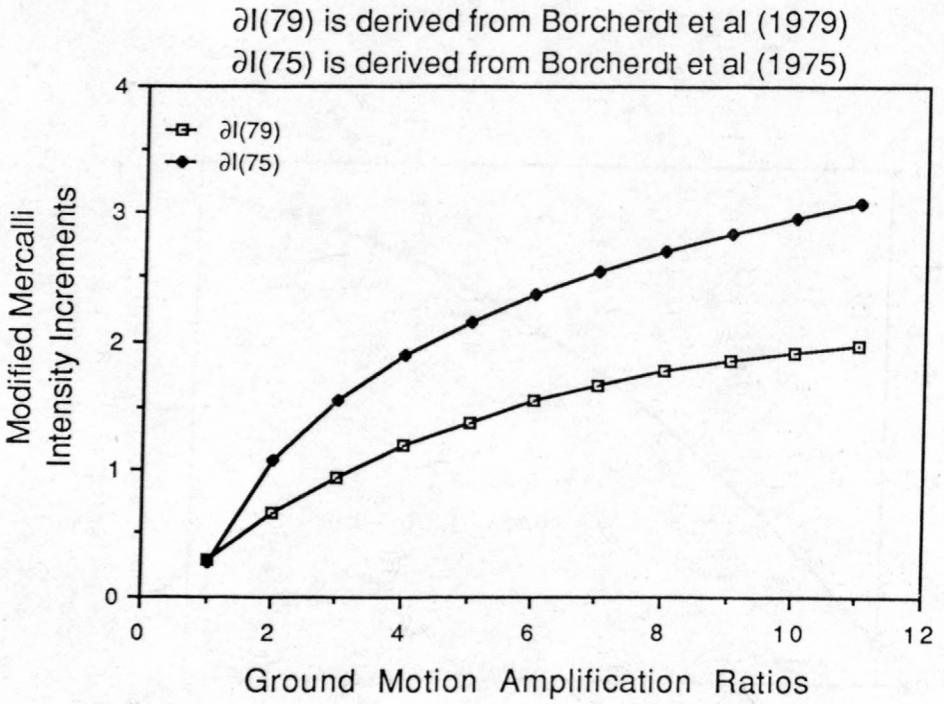


Figure 7.– A comparison of curves defining the relationship between ground motion amplification ratios and rock-site intensity increments (measured on the Modified Mercalli Intensity scale) from material presented in Borcherdt and others (1975) and in Borcherdt and others (1979).

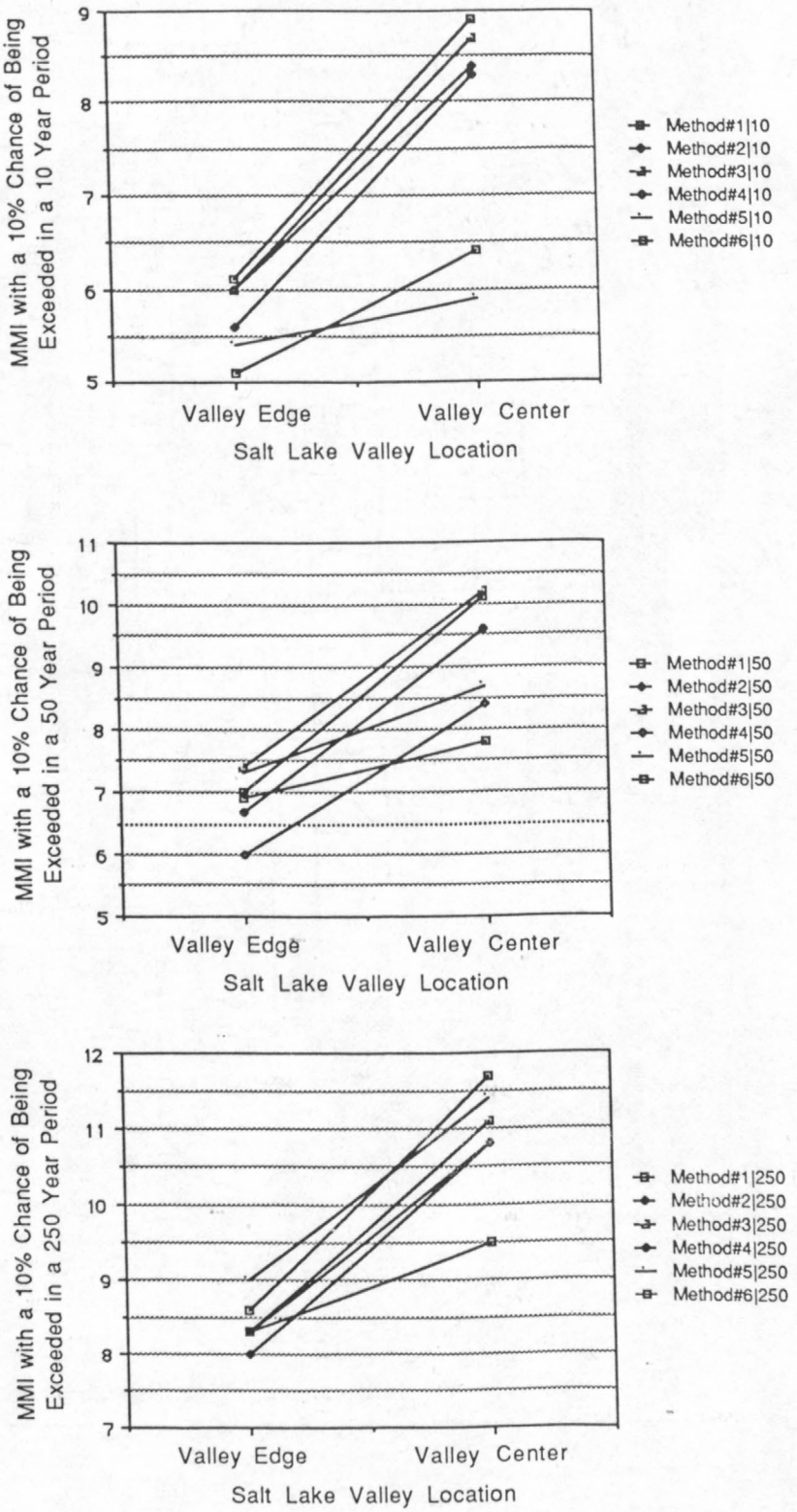


Figure 8.– A comparison of estimates of Modified Mercalli Intensities with a ten percent chance of being exceeded over a ten, a fifty and a two-hundred and fifty year exposure period by valley location within Salt Lake County, Utah.

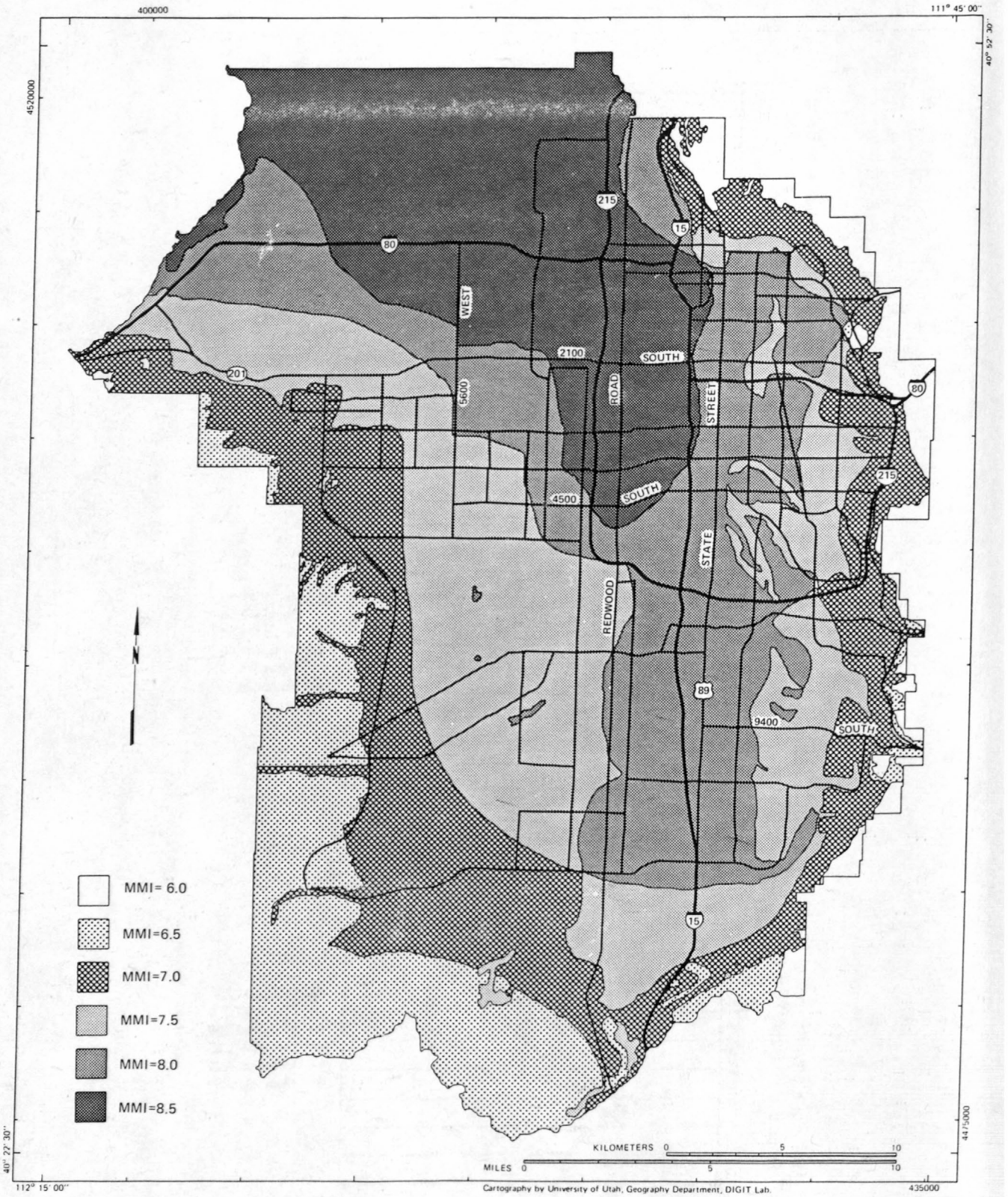


Figure 9a.– A mapping of Modified Mercalli Intensities (MMI) with a ten percent chance of being exceeded over a ten year exposure period for the urbanizable area of Salt Lake County, Utah. These maps do not account for the effects of ground failure (liquifaction, slumps, slides, falls, flows, and fault rupture) or the focusing effects expected of a near-field event on the Salt Lake Segment of the Wasatch Fault.

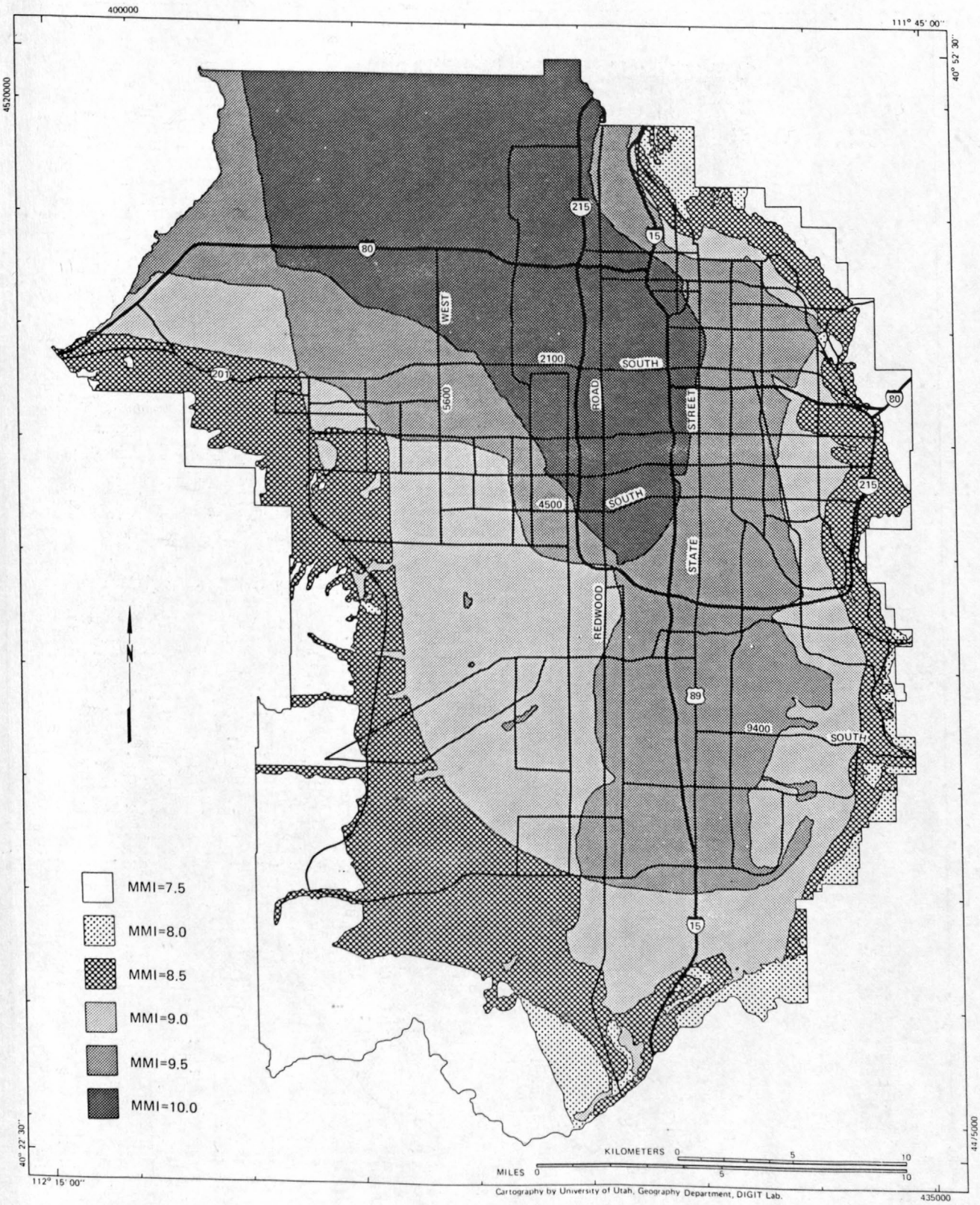


Figure 9b.– A mapping of Modified Mercalli Intensities (MMI) with a ten percent chance of being exceeded over a fifty year exposure period for the urbanizable area of Salt Lake County, Utah. These maps do not account for the effects of ground failure (liquifaction, slumps, slides, falls, flows, and fault rupture) or the focusing effects expected of a near-field event on the Salt Lake Segment of the Wasatch Fault.

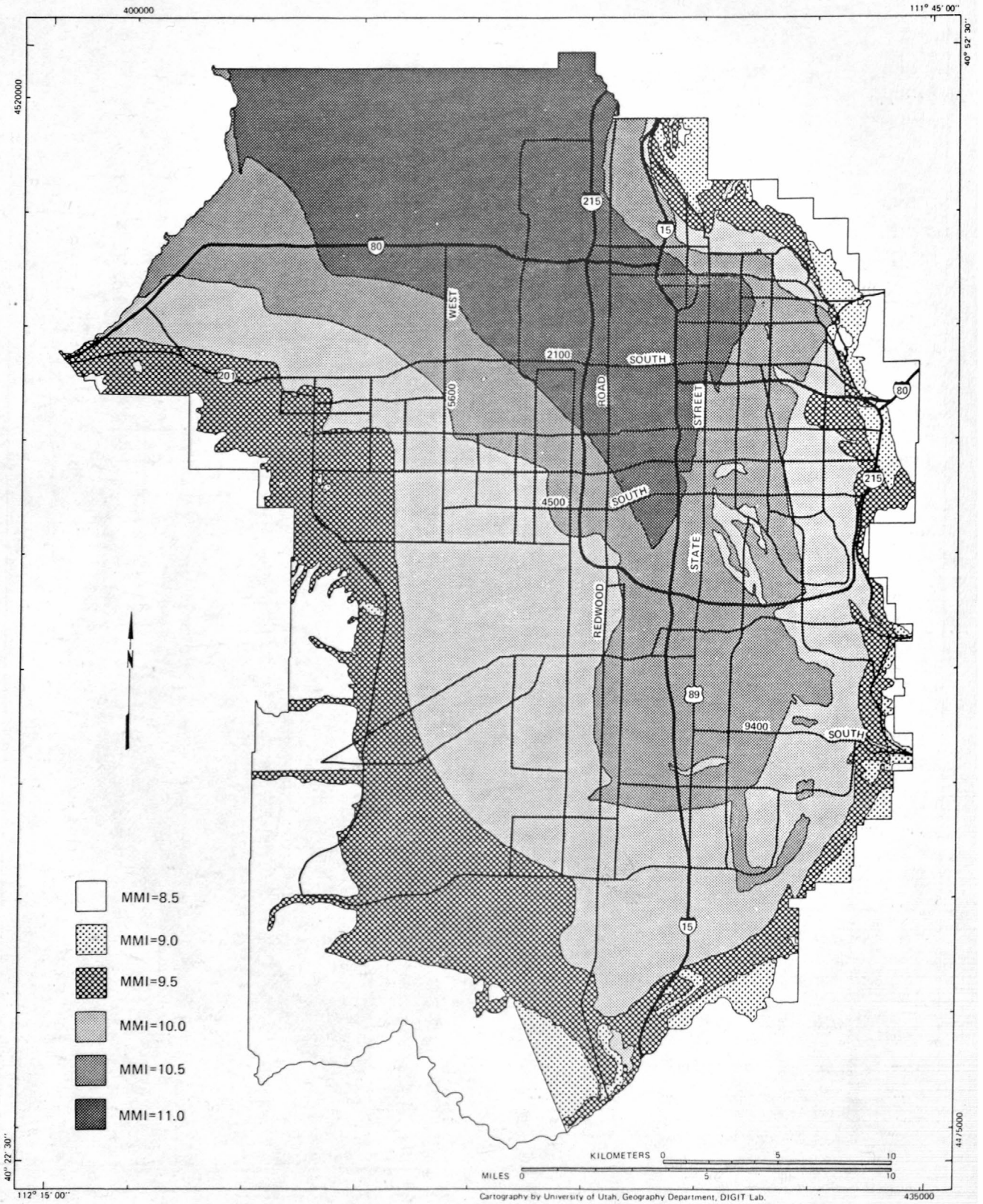


Figure 9c.– A mapping of Modified Mercalli Intensities (MMI) with a ten percent chance of being exceeded over a two-hundred and fifty year exposure period for the urbanizable area of Salt Lake County, Utah. These maps do not account for the effects of ground failure (liquifaction, slumps, slides, falls, flows, and fault rupture) or the focusing effects expected of a near-field event on the Salt Lake Segment of the Wasatch Fault.

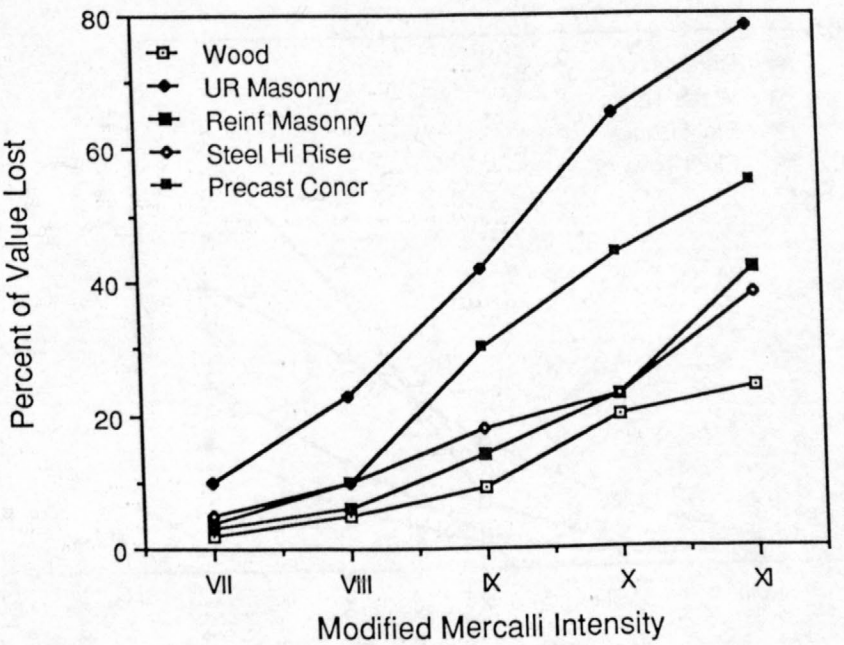


Figure A-1.– Estimated loss to selected structures as a function of Modified Mercalli Intensity based on relationships given in ATC-13 (Rojahn, 1985).

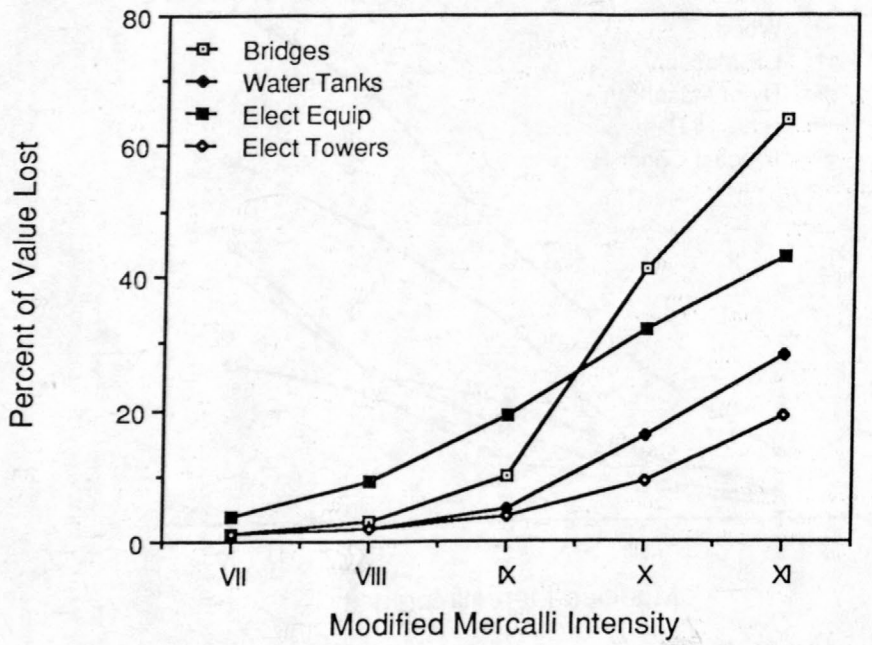


Figure A-2.– Estimated loss to selected lifelines as a function of Modified Mercalli Intensity based on relationships given in ATC-13 (Rojahn, 1985).

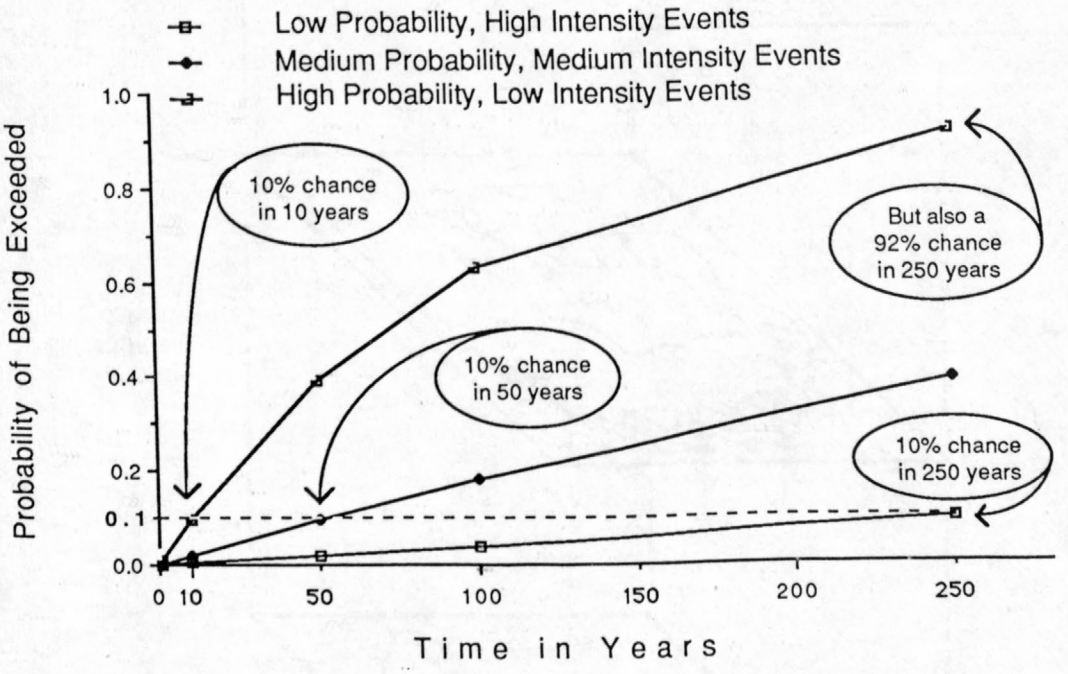


Figure B-1.– Functions describing the probabilities with which events of different intensity might occur over various exposure periods.

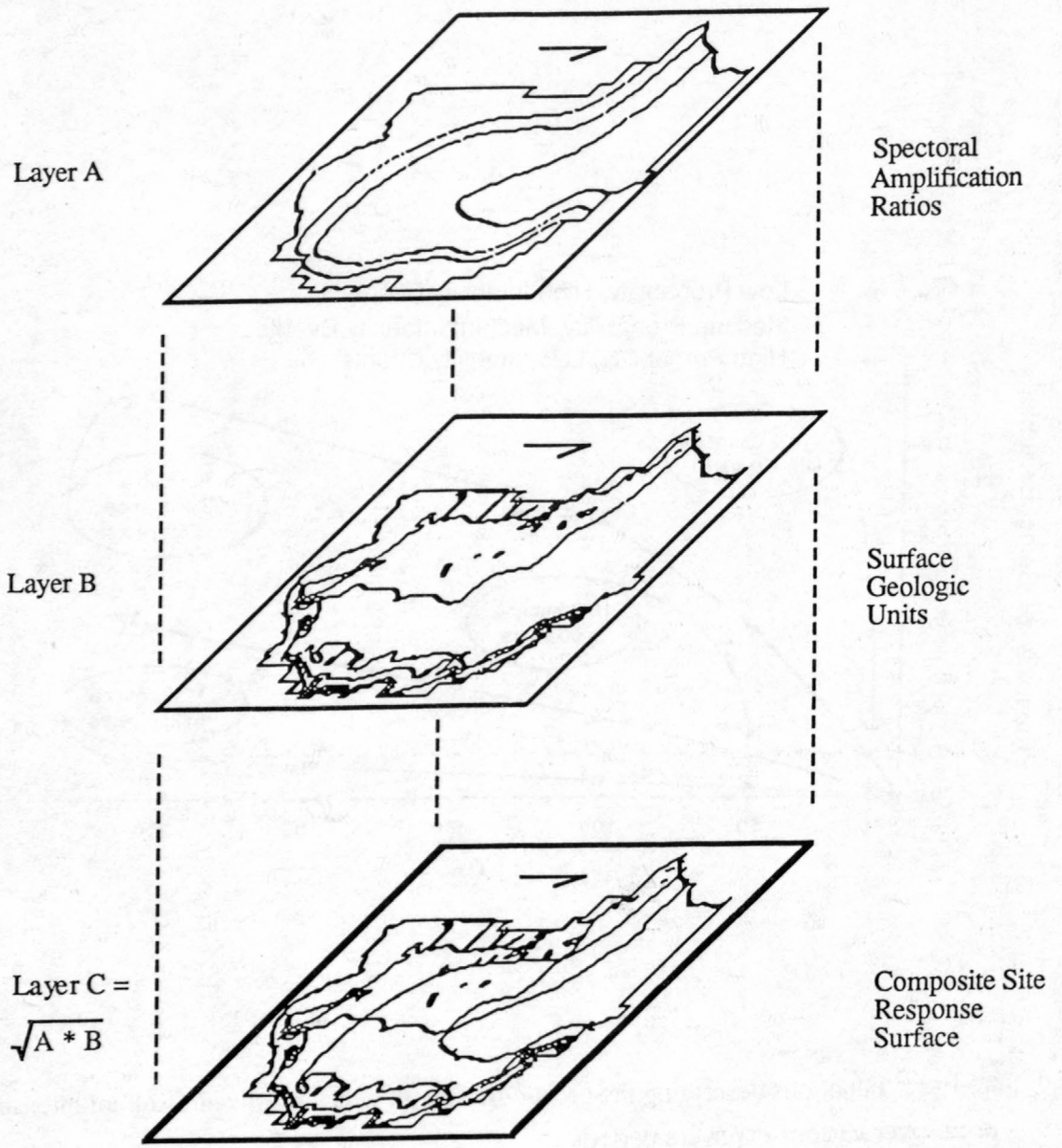


Figure C-1. – An illustration of a graphic overlay techniques using a geographic information system to combine Tinsley's (1988) spectoral amplification ratios (Layer A) with the spectoral amplification ratios assigned by the author to surficial geologic units from Davis's (1983) mapped compilation (Layer B) to create a composite site response surface (Layer C) as the square root of the product of the scores from Layers A and B.

Wasatch Front County Hazards Geologist Program

by

Gary E. Christenson

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ABSTRACT

The Wasatch Front County Hazards Geologist Program was initiated and conducted by the Utah Geological and Mineral Survey (UGMS) with funding from the U.S. Geological Survey under the National Earthquake Hazards Reduction Program (NEHRP). The purpose of the program was to aid in the use of geologic information, particularly earthquake hazards information produced under the NEHRP, to reduce hazards. The rationale behind the program was that local governments have the responsibility to regulate land use, and that geologic information and expertise would be most effective in reducing hazards if provided at the city and county levels. Three geologists were placed in five Wasatch Front counties (Weber-Davis, Salt Lake, and Utah-Juab counties) for a term of three years beginning in June, 1985. The geologists were a part of the county's planning department staff, but were available to other departments and to cities for educational, advisory, and review services.

The principal duties of the geologists were to: 1) produce geologic hazards maps, 2) assist in writing geologic hazards ordinances, 3) review

engineering geologic reports, and 4) provide other technical services as needed. Hazards maps were produced for inclusion in ordinances which require site investigations prior to development in hazard areas. Site investigation reports are reviewed and approved by the county geologist prior to issuance of building permits. The work of the geologists was coordinated by the UGMS which also provided support and technical supervision. At the end of the program in June 1988, counties were in various stages of completing mapping and adopting ordinances; all three of the county geologists were retained and funded by the counties. The program has demonstrated the value of a staff geologist in populated, highly-developed counties in high-hazard areas such as the Wasatch Front.

INTRODUCTION

Geologic hazards play a significant role in life along the Wasatch Front and have caused hundreds of millions of dollars in property damage and at least one fatality during the last 8 years. The Wasatch Front is particularly vulnerable because of the variety of hazards and concentration of population in the area. Although a great number of techniques are available to reduce geologic hazards, one of the most effective is proper long-range land-use planning based on an assessment of the hazards and their potential impacts. However, planning with respect to geologic hazards along the Wasatch Front has been difficult because of a lack of hazards information, particularly in the form of translated hazards maps at suitable scales, and a lack of an effective way to assist planners in incorporating

this information into the planning process.

Because of the general lack of necessary hazards information and maps on which to base planning decisions, land use has progressed in many areas without proper consideration of hazards and the risks they present. Some of the damage incurred in recent wet years, for example, could have been avoided through proper land use with respect to the rise of Great Salt Lake, stream flooding, debris flows, and landslides. Although damage was extensive, that which will result from a large earthquake along the Wasatch Front is much greater, and can be significantly reduced by wise land-use practices.

The Utah Geological and Mineral Survey has long advocated the consideration of geologic hazards in planning. It has been available to local governments to provide hazards information and review engineering geologic reports, but these services have not been fully used. The UGMS has no regulatory authority to implement recommendations made in report reviews. Therefore, effective influence on land use can best be accomplished by geologists in local governments where decisions are made and enforced.

Geologists at the local level can become involved in projects earlier and follow the process further. The purpose of the Wasatch Front County Hazards Geologist Program was to provide geologic expertise at the local government level in order to better use geologic hazards information to reduce casualties and damage. The scope of work of the county geologists was to: 1) compile geologic hazards information and produce maps to

delineate hazard areas, 2) advise planners regarding hazards ordinances, 3) review engineering geologic reports, and 4) provide geologic expertise as required, including performing site investigations for critical public facilities and investigating hazardous geologic events. Emphasis of the program was on geologic hazards, and the geologists did not perform other services typically provided by a county geologist such as resource evaluations or waste disposal siting except when specifically requested.

DESCRIPTION OF THE PROGRAM

To provide geologic expertise to local governments, several options are available: 1) a permanent, full-time city or county geologist, 2) a circuit-rider geologist serving several governments simultaneously (Thorsen, 1981), 3) a geologist employed by an umbrella agency (regional association of governments, state survey) but dedicated to serve local governments, or 4) a private consulting geologist on retainer or otherwise under contract with local government. Any one may be appropriate, depending upon population served, development pressure, extent of hazards, and other needs for geologic expertise. Option 1 is most appropriate where a need exists for a full-time geologist as is the case for those counties in the Wasatch Front area.

The UGMS received USGS funding under the National Earthquake Hazards Reduction Program to place three geologists in Wasatch Front counties for a three-year pilot program. To set up the program, UGMS met with the county

commissioners and planning department directors of the most populous counties; we also contacted regional associations of governments (Wasatch Front Regional Council) and county councils of governments (composed of all mayors of cities in the county and representatives of the county commission) to solicit support and advice. Based on these discussions, it was decided that the three geologists should cover five Wasatch Front counties (Weber, Davis, Salt Lake, Utah, and Juab counties) (fig. 1).

Figure 1 next page

They would be placed in one of the county planning departments under the direct supervision of the planning director; the UGMS would provide technical supervision and other support, as needed. One geologist (Mike Lowe) covered both Weber and Davis counties, maintaining an office in each county and dividing his time evenly between the two. Another geologist (Robert M. Robison) covered both Utah and eastern Juab counties, maintaining a permanent office in Utah County with periodic visits to Juab County, as needed. The third geologist (Craig V. Nelson) worked for Salt Lake County. The geologists were hired through the county personnel departments. The UGMS assisted in evaluating résumés and participated in interviewing and selecting candidates. The three geologists selected had similar backgrounds including bachelor's degrees in geology and master's degrees or work experience in engineering geology. Because the positions were temporary, geologists were hired as contractors rather than merit employees, although they received all of their county's fringe benefits.

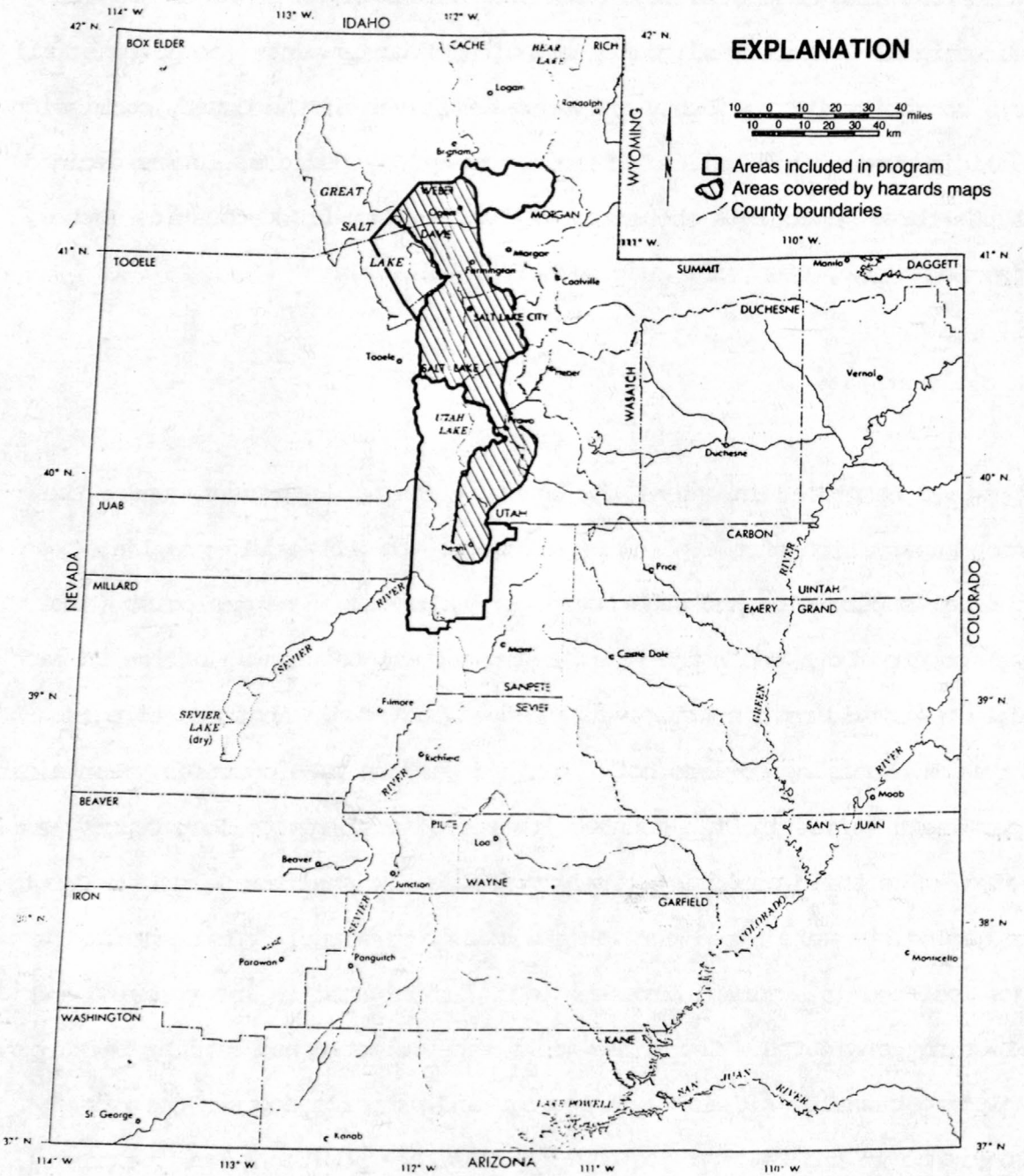

Figure 1. Location map.

The program was broken into three one-year phases. The first year consisted chiefly of data collection and literature research as in-house geological libraries were established in each county. During the second year, this information was compiled to produce basic-data maps needed to derive hazard maps. During the third year, hazard map compilation was begun and explanatory "translated" texts were developed which clearly explained the hazard and gave recommendations on how to address each hazard in planning.

Technical supervision by the UGMS included monthly or semi-monthly meetings to discuss issues, encourage cooperative efforts, and provide a uniform approach. All reports, report reviews, and other products prepared by the county geologists were reviewed by the UGMS. The county geologists were included in UGMS activities and information was freely exchanged. Quarterly meetings were also held between Davis and Weber counties regarding the work of the geologist that they shared. The UGMS provided about a third of one of its geologists' time for technical supervision of the program; many other staff members also contributed.

ACCOMPLISHMENTS

Data Collection

A principal goal during initial work was to identify and, if possible, collect library copies of all existing engineering geologic information.

Published literature was relatively easily identified and collected. Unpublished literature in the files of government agencies and private consultants constituted a large source of information not easily obtained. To collect this, all agencies and companies likely to possess information were contacted and visited. Information was collected to the extent possible. Where not possible, its existence was noted for future reference in case the need arose to consult it. All references were indexed into a subject card catalog, and organized into an easily accessible library in each county planning department.

A series of index maps showing locations of studies was compiled. For site investigations, locations were plotted on 1:24,000 scale topographic quadrangles. More regional studies were plotted on smaller-scale county-wide maps at scales of 1:100,000 or larger. Four such county-wide maps were compiled showing general geology, soils, landslide, and earthquake references. This information will be incorporated into the UGMS statewide computerized hazards bibliography.

Hazards Mapping

The principal goal of the final two phases of the program was to produce county-wide hazards maps for use in planning. These were done at the 1:24,000 scale, covering the urbanizing parts of the counties in valley floors and extending up to the crest of the Wasatch Range (fig. 1). Thus, eastern Weber County (Ogden Valley), Cedar Valley and eastern Utah County, and western Juab County were not included in the mapping.

Maps depicting each of the major hazards were prepared or, where already in existence, identified and evaluated. The county geologists have prepared or are preparing surface fault rupture, ground-shaking, landslide, debris-flow, and rock-fall hazards maps. Some of the needed maps have already been prepared under the NEHRP, and these were evaluated and recommended for adoption as official county maps, where appropriate. These included liquefaction potential, seismic slope stability (Salt Lake and Davis counties), shallow ground water, tectonic subsidence, and dam failure inundation maps.

The purpose of the maps is to show hazard areas where detailed site investigations need to be performed prior to development. Texts were prepared to accompany each map to explain the hazard, including its location, approximate recurrence time (where appropriate), and consequences. A discussion of possible engineering and site design techniques for mitigation was included, as well as guidelines for the types of information that should be included in site investigation reports. Copies of maps and explanatory texts will be distributed to each municipality for use in urban planning, and will also be available for consultants, developers, and the general public. Both maps and texts will be updated continuously as new information becomes available. Examples of these products are included in this volume.

Ordinances and report reviews

Another goal of the program was to assist local government planners in using hazards maps and information to reduce casualties and damage. This has been accomplished in many ways, with emphasis on developing and improving hazard reduction ordinances. The general approach recommended in such ordinances is outlined in UGMS Circular 79 (Christenson, 1987). It essentially consists of requiring engineering geologic site investigation reports in hazard areas (delineated on generalized hazards maps) prior to development, with approval of the permit dependent on a favorable review of the report by a geologist acting on behalf of the local government. The Salt Lake County Planning Department has drafted a geologic hazards ordinance which follows this approach closely, and is being used by various Wasatch Front cities and counties as a model. Although drafting and adoption of a new ordinance is a time-consuming process, it is now underway in Weber, Salt Lake, and Utah counties. The city of Washington Terrace in Weber County has already adopted a sensitive areas ordinance addressing geologic hazards using this approach.

Many of the larger cities in all counties have already adopted ordinances addressing geologic hazards, and the county geologists are aiding them in administering these ordinances by providing the needed geologic expertise in identifying hazard areas and reviewing engineering geologic reports. Completion of an engineering geologic report for a site does not necessarily mean that hazards affecting the site will be avoided or mitigated. Engineering geologic reports reviewed by the county geologists are commonly inadequate when initially submitted, and must be revised and amended before they are acceptable (Nelson and others, 1987).

Prior to the county hazards geologist program, engineering geologic reports were occasionally reviewed by UGMS, when requested. This was not regularly done and had little effect on the overall quality of reports. Now that reports are reviewed on a regular basis and returned for additional work when inadequate, a noticeable improvement in their quality has occurred.

Site Investigations

The siting and construction of public waste-disposal facilities (landfills and incinerators) and critical facilities (fire stations, municipal buildings, water tanks, and water-storage reservoirs) is another important function of local governments. Waste disposal facilities must be sited to avoid contamination of the environment. Critical facilities must continue to operate or be quickly returned to service after an event such as a damaging earthquake. Therefore, it is important to consider geologic hazards in siting. The county geologists have performed detailed site investigations for both types of facilities, as well as field investigations after damaging geologic events. These studies generally include a field reconnaissance, literature review, air photo interpretation, and in some cases, subsurface investigation. A report is written addressing the geologic hazards at the site, and it is used by local governments in planning and making decisions. The UGMS has compiled a volume containing all of the site investigation reports written during the contract period (see Black and Christenson, 1988).

Many types of site investigations have been performed for a variety of

agencies. County flood control and emergency management agencies have requested aid in responding to hazardous geologic events and in assessing hazard potential, particularly flooding and landsliding. Health departments have requested on-site investigations to evaluate potential soil and ground-water problems as they relate to septic tank systems. The county engineer's office has asked for reviews of sites for bridges and help in reducing hazards which may affect county roads and other public facilities. Building officials have requested assistance in inspecting excavations for evidence of faulting or ground failure, evaluating unstable slopes, and recommending reduction techniques. Workshops and field trips highlighting geologic hazards for building officials have also been conducted. Building inspectors have become principal users of geologic services. Various cities and counties have used the county geologist to evaluate geologic hazards affecting proposed or existing public facilities such as water-storage tanks. The county geologist aided Davis County in evaluating the gravel resource potential and best use of its property on the Salt Lake Salient, and in evaluating geologic hazards affecting the North Davis Refuse Disposal and new burn-plant sites.

Other Services

An important service is also provided to the public by the county geologist. Prospective real-estate buyers seeking hazards information often visit the planning office where hazards maps, geologic and emergency preparedness literature, and geologic advice are available. Community awareness about geologic hazards has also been increased through a slide-

lecture program the geologists have presented to local community councils, civic groups, and local government organizations.

The county geologists also assist in other hazards projects underway in the county. In Salt Lake County, West Valley City is completing an earthquake-hazards reduction study involving a computerized compilation of seismic hazards data for the city for use in municipal planning. In another project, researchers from the University of Utah Geography Department are integrating seismic hazards data into a computer-based geographical information system for use in seismic risk assessment and loss estimation throughout Salt Lake County. Also in Salt Lake County, the geologist is advising Utah State University researchers in polling public officials and private citizens regarding their perceptions of earthquake hazards and government responsibilities.

The Utah State Division of Comprehensive Emergency Management and Utah County initiated a comprehensive hazards mitigation project in the Provo-Orem area to aid emergency response personnel and planners. This project included geologic hazards map compilation and interpretation by the county geologist, UGMS, and other agencies (Robison and others, 1987). Copies of the project maps are housed with the county geologist for dissemination and updating.

Time and Task Breakdown

The relative percentage of time spent on various tasks by each

Table 1. Percentage of time spent on various tasks by the county geologists.

Task	Weber/Davis	Salt Lake	Utah/Juab
UGMS coordination	7	7	9
County administration	7	11	9
Data collection	28	29	35
Aid to cities	12	7	3
Aid to counties	31	20	23
Hazards mapping	13	21	20
Public education (inquiries, lectures)	2	5	1

geologist (from June 1985 to March 1988) is shown in table 1. These percentages are based on available time after removing time spent for leave and professional activities. The category entitled "UGMS coordination" included chiefly biweekly meetings, preparation of time records, and writing of articles for UGMS publications such as Survey Notes and the Wasatch Front Forum. "Aid to cities" and "aid to counties" include all of those activities performed at specific request such as aid in writing ordinances, review of engineering geologic reports, and site investigations. Nearly all such requests were honored in an attempt to demonstrate the various applications of geology to government functions and demonstrate the need for a county geologist.

Time spent in each activity varied from county to county, as did the types of jobs. Part of the reason for this is that there is a different relationship between each county planning department and the cities in the

county. Another reason is a county's approach to development in unincorporated areas. For example, in Davis and Utah counties, no services are provided to unincorporated areas, so development is in large part restricted to incorporated cities which provide water, sewer, and other services. In general, an area must be annexed by a city before development can occur, so geologic hazards information is used both by the cities and county to evaluate incorporation plans. In contrast, considerable development occurs in unincorporated Salt Lake and Weber counties because services are provided, therefore geologic services are of particular interest to the county as well as to the cities in planning for development. Most of the larger cities in the five counties maintain their own planning departments, while the smaller cities generally contract with the county for planning services. Under the county geologist program, the geologists provided services to larger cities as well, and many used them to review reports, particularly Ogden, Layton and Salt Lake City. As is apparent in table 1, Weber and Davis counties made considerably more use of the county geologist's services for special projects than did Salt Lake, Utah, or Juab counties.

EVALUATION AND SUGGESTIONS

The need for geologic services at the local government level has now been demonstrated in many areas, but initiation of a program to provide these services still requires that local government officials be made aware that they exist and be convinced that they are needed. In each case, this

generally means that the need and usefulness must be demonstrated. In attempting to establish a county geologist position, initial funding from outside sources is a very effective and perhaps necessary first step. It is unlikely that counties could have been convinced to fund a geologist without such a demonstration program. This program also helped to determine the need and the best way to provide the services.

One aspect of the county geologist program that contributed to its success was the placement of the geologist in the planning department. Because the program was directed at geologic hazards and the protection of life and property through planning, it was most effective to make the geologists part of the review and permitting process for all new development, which is principally a planning function. In the initial plan review, the geologist (or administrator using maps prepared by the geologist) needs to identify that certain geologic hazards exist and must be addressed in site investigation reports. In final review, the geologist must review and approve these reports prior to permitting (Nelson and others, 1987). Other departments in which the geologist may be placed include engineering, health, flood control, building inspection, or a separate and independent office of the county geologist. These departments are perhaps a logical place for a county geologist in areas where waste disposal is a major problem, large public works projects are underway, or geologic services other than hazards are emphasized. The principal reason for preferring planning departments is because of their more active role in long-range planning rather than short-term problem solving. A separate office of the county geologist may be the most effective means of getting

geologic services to all departments, but leaves the geologist without an affiliation and requires development of a network of contacts and considerable effort in making services known and seeing that they are used. With an introductory program such as this, we believed than an unaffiliated geologist may be more vulnerable to budget cuts than one which is a part of an existing department.

The close association between the county geologists and the UGMS was very important to the success of the program both in maintaining consistency of approach from county to county and in providing guidance and technical support. One concern of planning directors and regional association of government personnel was that ordinances and approaches to geologic hazards be consistent among jurisdictions along the Wasatch Front; the UGMS facilitated this uniformity of approach. In terms of helping maintain quality technical work, local governments employ few scientists and maintaining state-of-the-art expertise is difficult. Contact with other geologists is necessary, and the UGMS staff worked with the county geologists on many occasions to foster the exchange of new ideas, information, and technology. On occasion, county geologists make recommendations which may be unpopular with local government officials; strong technical support from a state agency enhances their credibility.

One difficulty in administering the program was encountered in the counties where a geologist was shared. Under outside funding, one county took responsibility for handling the salary pass-through, and a memorandum of agreement and contract were written and signed by both counties outlining

how his time was to be divided between them. This worked well during the period of outside funding, but when the counties took over funding it became difficult to arrange for the geologist to be a merit employee of two different counties. Such a shared arrangement is better handled through a contract, circuit-rider program, or umbrella agency.

CONCLUSIONS

The principal goal of the project was to demonstrate the usefulness of geologic expertise at the local government level such that the counties would retain the geologists with county funding when the outside funding expired. This goal was achieved in three of the five counties. Salt Lake, Utah, and Davis counties all hired the geologists as permanent merit employees on their planning department staffs. Weber County worked out a funding plan to continue for another year under the same shared program with Davis County, but Weber County's contribution was entirely from outside sources, i.e. no contribution from the county, and all indications were that Weber County would not continue the funding after 1989. The Weber County plan also required continuation of contract rather than merit employment. Davis County offered a full-time staff position, so it was decided that the geologist should stay with Davis County. Juab County is a very sparsely populated county with no permanent planning department and was not able to justify having a geologist on its staff.

Little has changed in terms of the goals and administration now that

counties are funding the county geologists. Most counties still provide services to cities, although Salt Lake County has worked out a fee schedule to charge cities for time spent reviewing reports. UGMS continues to provide technical supervision, but plays a less active role. Maps by the county geologists will be used by UGMS in compiling statewide hazard maps, and data collected by them is being incorporated in the UGMS computerized hazards bibliography.

The program has done much to advance local government awareness and concern with regard to geologic hazards, particularly earthquake hazards, along the Wasatch Front. Planning departments are now routinely requiring site-specific reports in hazard areas, and the systematic review of those reports by county geologists has improved their quality. The County Hazards Geologist Program is a very important part of both the UGMS and USGS efforts to translate and transfer geologic hazards information to users for hazard reduction. The program was originally conceived as an experiment to demonstrate that a geologist at the local government level could be effective in carrying out these goals, and it has been a success. Much progress has been made in the production of "translated" hazards information usable by planners and others, and in transferring this information to users. The development and adoption of effective geologic hazards ordinances to protect people and reduce property damage is now underway and is just one example of this success.

ACKNOWLEDGEMENTS

The idea that county geologists would be one of the most effective ways to implement geologic hazards information in loss reduction along the Wasatch Front was first proposed by William R. Lund (UGMS). Genevieve Atwood (Director, UGMS) and Don R. Mabey (former Deputy Director, UGMS) solicited support from the counties and provided for the administration of the program. Planning department directors Graham Shirra (Weber County), Rick Mayfield (Davis County), Jerold Barnes (Salt Lake County), Jeff Mendenhall (Utah County), and Juab County Commissioner Thomas Fowkes ensured the program worked and convinced their planning commissions and county commissions to support it. Particular thanks go to Graham Shirra and Jeff Mendenhall for taking key responsibility for payroll and administration for the geologists serving Davis and Juab counties, respectively. Principal credit for the success of the program goes to the county geologists -- Mike Lowe, Craig V. Nelson, and Robert M. Robison, whose diligence and dedication demonstrated to the counties the value of a staff geologist and the need to consider geologic hazards in development.

Walter W. Hays and William J. Kockelman of the U.S. Geological Survey (USGS) provided information and reviewed work products. Michael Machette, Alan Nelson, and Steve Personius (USGS) provided advance copies of fault maps, and along with David P. Schwartz (USGS) have lent support in report reviews and trench investigations. During data collection phases of the project, information was obtained from state and federal agencies and private consultants too numerous to list. Don Mabey, Mike Lowe, Craig Nelson, Robert Robison, and Bill Kockelman all reviewed this paper.

REFERENCES CITED

Black, B.D., and Christenson, G.E., compilers, 1988, Technical reports of the Wasatch Front County Geologists, June 1985-June 1988: Utah Geological and Mineral Survey Report of Investigation No. 218, 154 p.

Christenson, G.E., 1987, Suggested approach to geologic hazards ordinances in Utah: Utah Geological and Mineral Survey Circular 79, 16 p.

Nelson, C.V., Christenson, G.E., Lowe, Mike, and Robison, R.M., 1987, The review process and adequacy of engineering geologic reports, Wasatch Front, Utah, in McCalpin, James, ed., Proceedings of the 23rd Annual Symposium on Engineering Geology and Soils Engineering: Logan, Utah, Utah State University, p. 83-85.

Robison, R.M., Christenson, R.E., Knight, R.V., Dewsnup, Wes, and Johnson, Mike 1987, Earthquake and slope failure hazards, Utah County Comprehensive Hazard Mitigation Project, Utah, in McCalpin, James, ed., Proceedings of the 23rd Symposium on Engineering Geology and Soils Engineering: Logan, Utah, Utah State University, p. 499-521.

Thorsen, G.W., 1981, The circuit rider geologist: Final Report for U.S. Geological Survey Project No. 9-7020-26001, 29 p.

SURFACE FAULT RUPTURE: A GUIDE FOR LAND-USE PLANNING, UTAH AND JUAB COUNTIES, UTAH

by

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ABSTRACT

Surface fault rupture may be one of the most damaging effects of large-magnitude earthquakes in Utah and Juab Counties, Utah. Much research has been conducted to identify and evaluate the location and effects of surface faulting, and this paper is a compilation of the most current information available. It is presented as an example of translated information from various sources, primarily the U.S. Geological Survey's National Earthquake Hazards Reduction Program. The principal purpose of this paper is to help identify and suggest mitigation measures for lowering the risks associated with surface-faulting earthquakes.

Large-magnitude earthquakes (M_L 6.5 +) with accompanying surface faulting have occurred repeatedly in Holocene (past 10,000 yr) time along the 213 mi (343 km) trace of the Wasatch fault zone. Evidence from past earthquakes suggests a potential for surface offset of 6-9 ft (2-3 m) and scarp heights of 9-15 ft (3-5 m). The Wasatch fault zone is a dip-slip (normal) fault which commonly has a graben (downdropped block) or zone of deformation along the downthrown side. This disturbed zone may extend hundreds of feet (meters) from the main fault trace. Recent mapping by the U.S. Geological Survey indicates that there may be 10 or 11 segments along the Wasatch fault zone, each with its own recurrence interval

and rupture characteristics, which give a combined recurrence rate for a surface-faulting earthquake somewhere along the Wasatch fault zone every 340-415 yr. Recurrence on any particular segment varies from hundreds to several thousands of years. Because of uncertainties in the timing of the most recent events and apparent irregularity in recurrence intervals, a surface-faulting earthquake could occur at any time on any of the segments in Utah and Juab counties.

In Utah County, special study zones have been delineated along mapped traces of the Wasatch fault zone to identify areas where more detailed study is recommended prior to development. These study zones are 250 ft (76 m) wide on the upthrown side of the fault and 500 ft (153 m) on the downthrown side. Because surface ruptures generally occur along existing fault traces, we use minimum setback distances from traces identified in special studies to help avoid loss of life, property damage, and to reduce the cost of geotechnical investigations. Setbacks of 50 ft (15 m) from the 30 percent slope break on the top of the scarp and 50 ft (15 m) from the 30 percent slope break at the bottom of the scarp are recommended. If the scarp does not attain a slope of 30 percent, then the 50 ft (15 m) setback on both the top and the bottom of the scarp is measured from the midpoint of the scarp. If antithetic scarps or backtilting are present, then the setback is measured from the antithetic scarp farthest from the main fault or back-tilt inflection point, and the entire zone of deformation should be avoided. If construction is proposed within the setbacks or zone of deformation, then a site-specific investigation is needed to accurately locate the faults and deformed strata before placement

of buildings are recommended. If a building site is within the special study zone on sediments younger than 10,000 yr., then site specific investigations would be required to prove that no faults are below the proposed structure in sediments younger than 10,000 yr.

INTRODUCTION

Surface faulting has been identified as a potential hazard in Utah and Juab counties, Utah. This paper is an effort to address the problems associated with surface faulting, to suggest investigation methods, and propose certain mitigation procedures. Much of the specific information on faults is from various studies by the U.S. Geological Survey and the Utah Geological and Mineral Survey. Machette (1989) has prepared maps to show the known areas in Utah County where a hazard exists from surface fault ruptures. The purpose of this report is to discuss the nature of the hazard, its potential consequences, and to give recommendations regarding the use of the maps and how the hazard should be addressed in land-use planning, development, and regulation. This work is one of several translated documents addressing natural hazards which are designed for planners and other decision-makers who have a limited geology background.

Utah and eastern Juab counties are in north-central Utah (figure 1) and along the base of the central portion of the Wasatch range. The range and the adjoining basin, of which Utah Valley is a part, are the result of millions of years of faulting which caused the mountains to be uplifted and the basins to be downdropped along the Wasatch fault zone. Although no surface

ruptures have occurred along this fault zone in historic time, evidence gathered from detailed geologic studies of existing scarps indicates that large-magnitude earthquakes and accompanying surface ruptures have occurred repeatedly within the past 10,000 yr and earlier.

Figure 1 next page

Earthquakes are generated by movement along faults at depth. During large-magnitude earthquakes (Richter magnitude 6.5+), ruptures generally propagate to the surface as one side of the fault is uplifted and the other side downdropped (figure 2); the resulting (normal) fault scarp has a near vertical slope. Broad subsidence of the valleys accompanying surface faulting may affect areas several miles (km) away from the fault. These effects are not considered here, but are covered in a separate report (Robison, this volume) entitled "Tectonic subsidence hazard, a guide for land use planning, Utah and Juab counties, Utah".

Figure 2 next page

CHARACTERISTICS OF THE WASATCH FAULT ZONE

The Wasatch fault zone extends from near Malad City in southern Idaho to Fayette in central Utah, a distance of about 213 mi (343 km) (Machette anbd others, 1989). The fault zone trends roughly north-south and dips steeply to the west at the surface as shown in figure 3. The Wasatch fault zone is not a single fault plane, but is a zone of deformation containing many individual

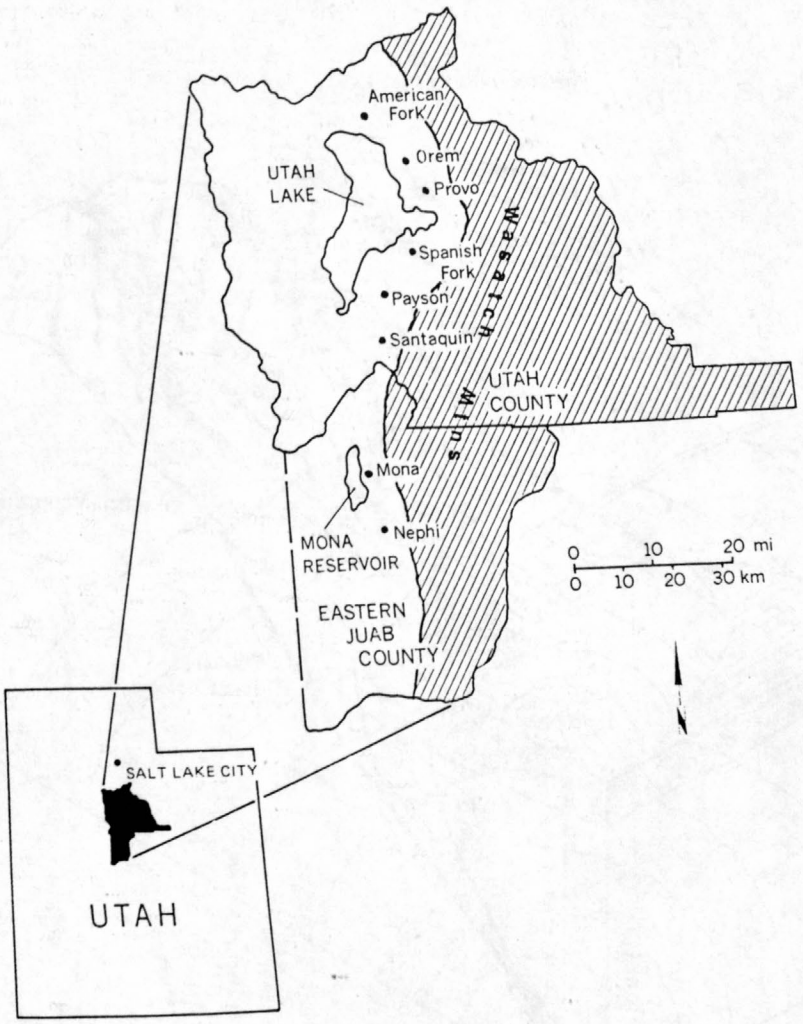


Figure 1. Map showing the location of Utah and eastern Juab Counties, Utah. The Wasatch fault zone is located at the western base of the Wasatch Mountains.

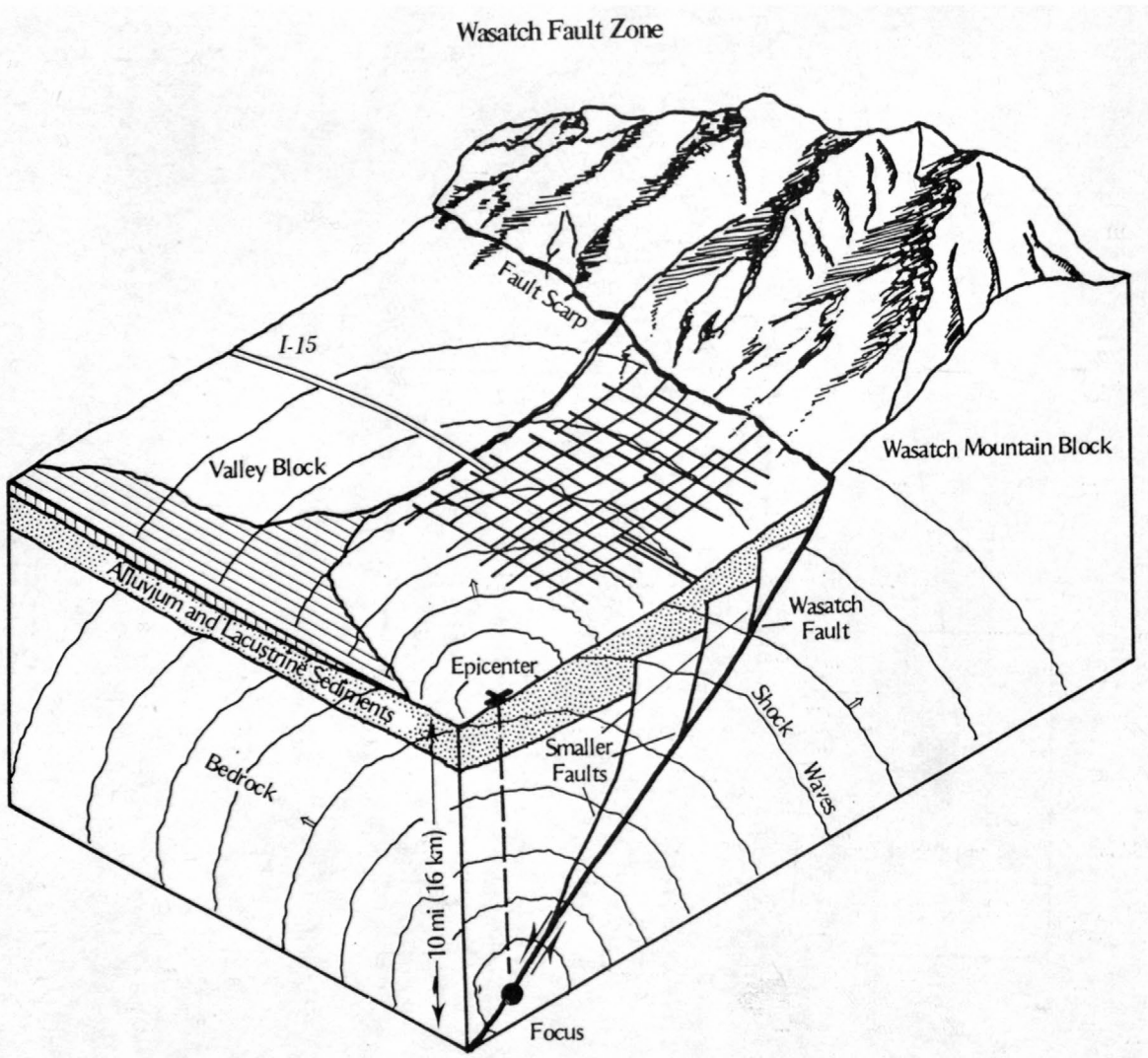


Figure 2. Schematic diagram of the Wasatch fault zone showing the relation of the epicenter to the focus and the trace of the surface fault rupture (fault scarp). The plane of the fault probably dips at 50-60 degrees toward the valley. The epicenter of the earthquake is located in the valley (downthrown block), not on the trace of the surface rupture. Adapted from a special poster by the Utah Museum of Natural History.

subparallel faults. Where the zone intersects the surface, it commonly consists of one main down-to-the-west fault with a disturbed area, generally to the west on the downthrown side, as much as several hundred feet wide, or possibly a series of down-to-the-west faults. This disturbed area, commonly termed the zone of deformation, contains small cracks and tilted or displaced blocks and may include a graben that is bounded on the west by a scarp formed by a down-to-the-east (antithetic) fault (figure 3).

Figure 3 next page

The entire length of the Wasatch fault zone is not expected to rupture in any one earthquake. Instead, discrete segments of varying lengths rupture independently. Originally, 6 segments were proposed, but more recent studies indicate there may be as many as 10 or 11 (figure 4; Schwartz and Coppersmith, 1984; Machette and others, 1987, Machette and others, 1989). The most important aspect of the concept of segmentation is that segments control the length of the expected surface rupture, the starting or stopping points of ruptures, and place physical constraints on the maximum magnitudes of potential earthquakes.

Figure 4 next page

Several diferent analyses of the history of the WFZ suggest an event every 200 to 415 yrs. From a study which considered the number of surface-faulting earthquakes on the original six segments over the past 8,000 yr, Schwartz (1988) suggests that such

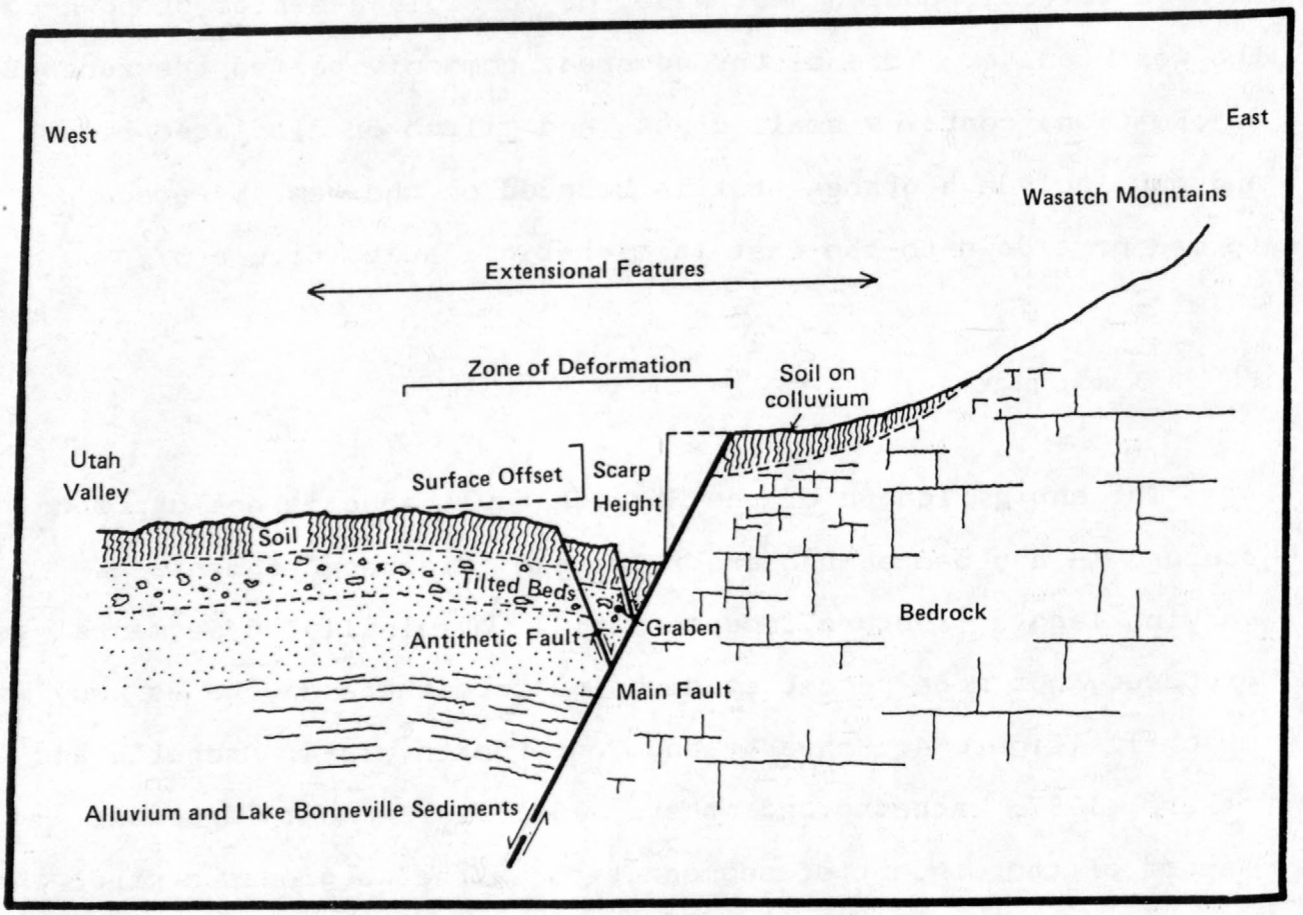


Figure 3. Schematic diagram of a normal fault showing features typical of the Wasatch fault zone near the ground surface. Sketch is not to scale, but surface offset is usually about 6 to 9 ft (2 to 3 m). Note that the scarp height is commonly greater than the surface offset.

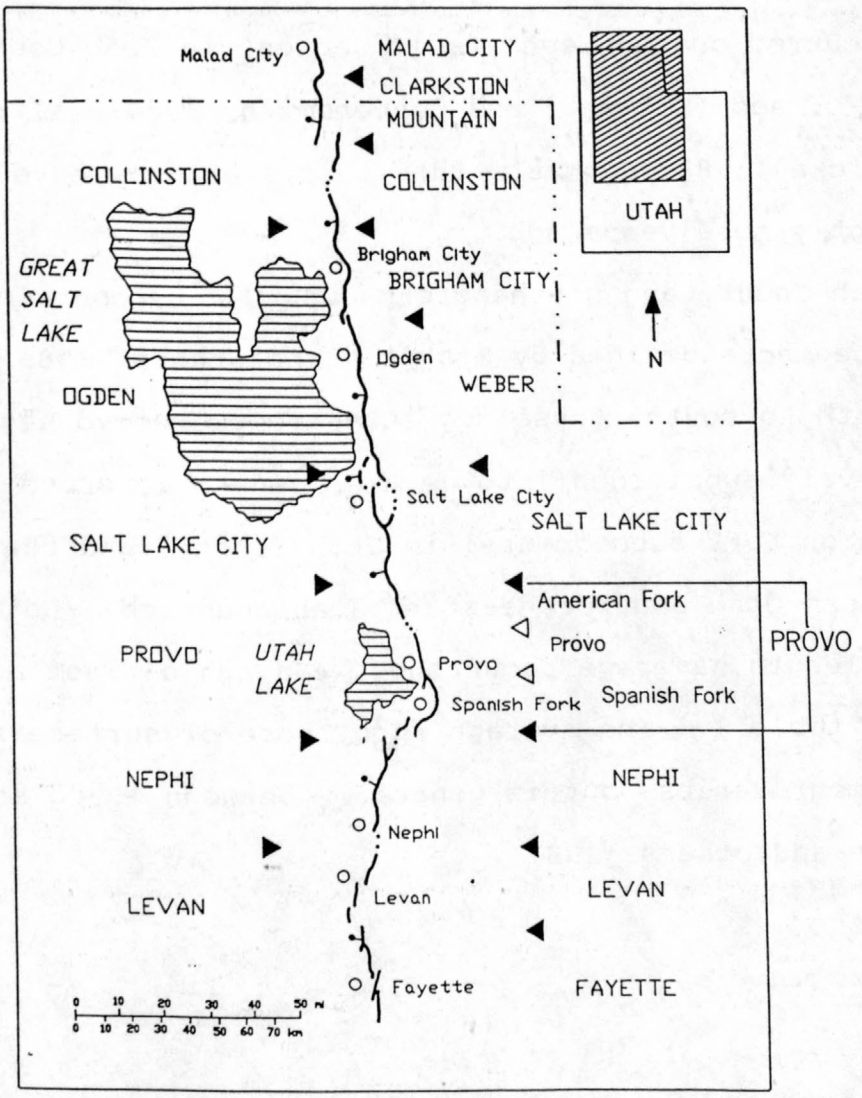


Figure 4. Map showing boundaries and names for the Wasatch fault zone segments. Segment boundaries are noted by solid arrows. The left column is from Schwartz and Coppersmith (1984) and the names on the right are from Machette and others (1989). The total number of identified segments has increased from 6 to 10, possibly 11, depending on the persistence of the subsegment boundaries (represented by hollow arrows). The total number of segments determines the amount of potential generative earthquake zones. Adapted from Machette and others (1989).

earthquakes occur on the average every 200-400 yr, and studies which assessed 10 or 11 segments arrived at a similar recurrence of 340-415 yr (Machette and others, 1989; W. R. Lund, oral commun., 1988). The most recent rupture along the Wasatch fault zone may have occurred on the Nephi fault segment in Juab County, between 300-500 yr ago (Schwartz and Coppersmith, 1984), although Jackson and Ruzicka (1988) suggests that this event may have occurred 500 or slightly more years ago.

Utah County and northeastern Juab County contain 2 (or more) of the segments defined by Machette and others (1989) (figure 4). From north to south, these segments are the Provo segment (tentatively subdivided into he American Fork, Provo, restricted, and Spanish Fork subsegments) in Utah County, and the Nephi segment in southern Utah and northeastern Juab counties. Details of segment length, average recurrence, and age of last movement are given in table 1. The average recurrence of surface faulting along each segment varies, but is generally between 1,300 and 2,700 yrs (Machette and others, 1987).

Table 1 next page

Schwartz and Coppersmith (1984) did not defferentiate subsegments for the Provo segment. The most recent studies (Machette and others, 1989; Machette, 1989), which should be consulted for a more complete discussion of segments and faulting, indicate that this segment may consist of subsegments (table 1), which have non-persistent boundaries. The Provo segment extends about 43.4 mi (70 km) from the boundary of Utah and Salt Lake

[a]WASATCH FAULT (Segment or subsegment)	[a]LENGTH (MI/KM) (Surface trace)	[a]LENGTH (MI/KM) (End to end)	RECURRENCE INTERVAL (Average, yr)	DISPLACEMENT PER EVENT (ft/m)	AGE OF MOST RECENT SURFACE FAULTING	REFERENCE
Provo (segment)	43.1 / 69.5	36.9 / 59.5				
American Fork (subsegment)	14.0 / 22.5	13.0 / 21.0	2,425	7.6-8.6 / 2.3-2.6	about 550 yr	Machette, 1988
Provo (restricted, subsegment)	11.5 / 18.5	10.5 / 17.0	-	-	>660 - 1000 yr	Machette and others, 1989
Spanish Fork (subsegment)	19.5 / 31.5	14.9 / 24.0	-	5.3-7.6 / 1.2-2.3	550 - 700 yr	Lund, W.R., 1987, personal communication
Nephi (segment)	26.4 / 42.5	23.3 / 23.3	1,700 - 2,700	6.6-8.3 / 2.0-2.5	about 400 yr	Jackson and Ruzicka, 1988; Schwartz and Coppersmith, 1984

[a] All segment names and length data were taken from Machette and others, 1989.

Table 1. Data for the Wasatch fault zone in Utah and northeastern Juab Counties. Segment names, lengths, recurrence intervals, displacement, and age information is taken from the reference given, and should be consulted for detailed explanations of the derivation of each parameter. Specific segment data are given in the text. See figure 4 for relation of listed segments to the entire Wasatch fault zone.

Counties south to Payson Canyon (Machette and others, 1989) and includes the American Fork, Provo (restricted), and Spanish Fork subsegments.

The American Fork subsegment is 14.0 mi (23 km) long and extends from the middle of the Traverse Mountains to the mouth of Provo Canyon (Machette and others, 1987). Lake Bonneville deposits south of American Fork Canyon are offset 50-65 ft (15-20 m). Trenching investigations about 0.5 mi (0.8 km) south of the canyon revealed evidence for 3 surface faulting events in the past 5,300 yr, and the most recent one was probably about 550 yr ago (Machette, 1988).

The Provo (restricted) subsegment extends from the Provo River south to Springville, where it overlaps the Spanish Fork subsegment, a total distance of about 11.5 mi (18.5 km) (Machette and others, 1987). A trenching study at the mouth of Rock Creek Canyon indicated that the most recent surface rupture occurred between about 500 and 1,000 yr ago. Surface offset in the trench was about 7 ft (2 m) and had an additional 8 ft (2.5 m) of tilt and deformation, which produced a 15 ft (4.5 m) high scarp.

The Spanish Fork subsegment extends from the north side of Springville City about 19.6 mi (31.6 km) south to the mountains behind Woodland Hills City. This segment was trenched about 1 mi (1.2 km) northwest of Hobble Creek (Swan and others, 1981; Schwartz and others, 1984), where evidence for 6 or possibly 7 surface faulting events within the past 13,500 yr was found. A multiple-trench investigation on the Spanish Fork segment near Mapleton revealed dates for the most recent event of 550-700 yr ago (W.R. Lund, oral commun., 1988). However, the U.S. Bureau of Reclamation

found evidence for two events within the past 1,000 yr, which could suggest that the Spanish Fork subsegment had moved during earthquakes on both the Provo and Nephi segments.

The Nephi segment of the Wasatch fault zone extends about 26.4 mi (42.5 km) from near Payson in southern Utah County to Nephi in Juab County. This segment was first trenched at the mouth of North Creek, and exhibits what is probably the most (about 300-500 yr old recent rupture along the entire Wasatch fault zone) (Schwartz and Coppersmith, 1984). Jackson and Ruzicka (1988) trenched at Rock Creek near Nephi and reported three faulting events with the most recent event at 500 yr or older, which roughly agrees with previously published age estimates for the segment.

On individual segments of the Wasatch fault zone, ruptures may occur from every few hundred to a few thousand years. Detailed studies on the central segments of the fault zone indicated periods between surface faulting events which range from less than 1,000 yr to over 3,000 yr with an individual segment average of 2,035 to 2,070 yr (Machette and others, 1989). However, it must be understood that the data are incomplete, imprecise and that events do not necessarily occur at regular intervals; recurrence on individual segments is quite variable (Schwartz, 1988). Thus, considering the previously mentioned recurrence interval, 200 to 415 yr for all central segments, and the time since the most recent event (300 to 600 yr), earthquakes may be expected somewhere along the fault at any time.

There is some evidence that earthquakes on different segments may cluster in time and occur so closely together that they appear as one event in the geologic record. If clustering occurs, groups

of earthquakes with very short time-intervals (possibly weeks, months or years) between events could occur sequentially along the WFZ. If this occurs, then the average recurrence calculated for the entire fault (200-666 yr) could be misleading, and events may have occurred in more closely spaced clusters with larger periods between clusters. This, however, would not change the recurrence estimates for earthquakes on individual segments.

Other faults, perhaps capable of surface rupturing, have been located in Utah County. Dustin and Merritt (1980) reported faults beneath Utah Lake in an investigation of the hydrogeology of the lake (see Machette, 1989, map). These faults may be 18 mi (29 km) long, are roughly parallel to the Wasatch fault, and exhibit evidence for movement within the past 15,000 yr. The faults do not pose a surface-fault rupture hazard to urbanized areas, but further work is needed to define recurrence intervals because ground shaking from an earthquake generated by these faults would significantly affect Utah Valley. Fault scarps also were noted in western Juab Valley (Robison, 1987, unpublished data), but little is known about these features.

CONSEQUENCES OF SURFACE FAULT RUPTURES AND REDUCTION OF HAZARDS

Studies along the Wasatch fault have indicated that during a "characteristic" earthquake which produces surface faulting, offsets of 6 ft (1.8 m) or more (average 6.6 ft; 2 m) may occur on the main trace of the fault zone (Schwartz and Coppersmith, 1984). This offset will result in formation of a near-vertical scarp,

generally in unconsolidated surficial deposits, that begins to ravel and erode-back to the materials angle of repose (33-35 degrees) soon after formation. Antithetic faults west of the main trace may also form, generally exhibiting a lesser amount of offset, but sometimes as much as several ft (m) (figure 3). The zone between these two faults may be complexly faulted and tilted with offset along minor faults of several inches or more. In some cases, a broad zone of flexure may form west of the main fault in which the surface is tilted downward toward the fault zone. An example of this warping is preserved south of the mouth of Hobble Creek where back tilting extends over 650 ft (200 m) from the fault with a maximum dip of 3 degrees to the east.

It is difficult, both technically and economically, to design a structure to withstand 6 ft (2 m) or more of offset through its foundation. Youd (1980) indicates that displacements through a building's foundation of 2.5 feet (0.76 m) or more could cause collapse. Thus, avoidance of the main trace of the fault, and preparedness to respond and rebuild, are the principal reduction techniques that can be taken reasonably.

In some areas, adjacent to the main trace but still within the zone of deformation, avoidance may not be necessary. Less damaging (smaller) offsets and tilting may occur and structural measures may be taken to reduce casualties and damage. However, structural damage may still be great, and buildings in the zone of deformation may not be safe for occupants following a large earthquake.

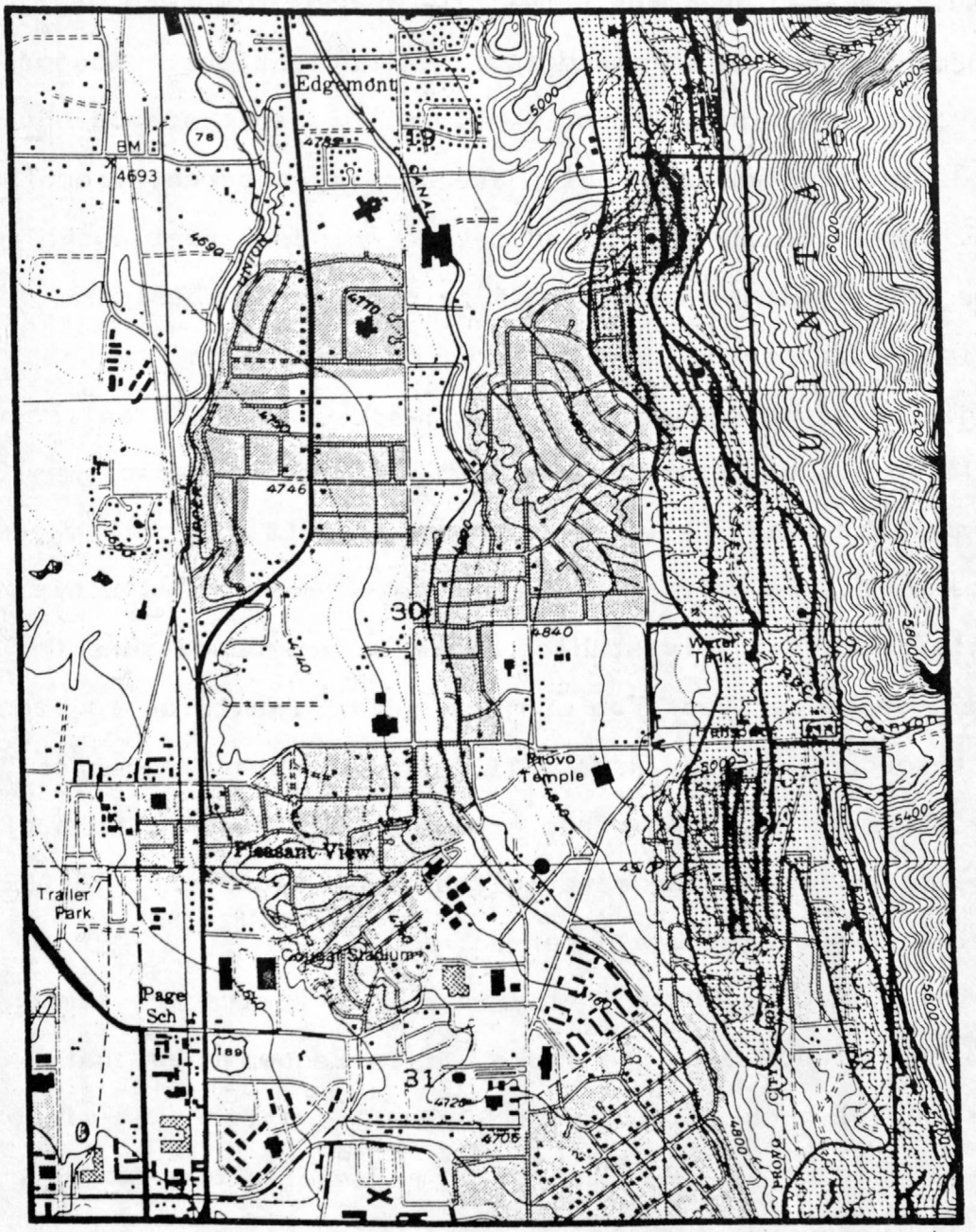
USE OF SPECIAL STUDY ZONE MAPS

M.N. Machette (1989) of the U.S. Geological Survey has prepared a map that shows the main traces of the Wasatch fault zone in Utah County. This map is presently in preliminary-form at a scale of 1:50,000, but clearly indicates the areas where surface fault rupture hazards need to be considered. I have used this map as the basis to prepare the special study zone maps (figure 5). The special study zone follows the mapped trace of the Wasatch fault zone's surface ruptures, and is about 250 ft (76 m) wide on the upthrown side of the fault zone and 500 ft (153 m) wide on the downthrown side. The purpose of this zone is to delineate areas where site-specific investigations addressing surface fault rupture hazards are recommended. Because the fault maps used to delineate these zones were prepared at a scale of 1:50,000 (1 in = 0.79 mi), they are not detailed enough to delineate all fault traces and zones of deformation at a particular location, thus site specific investigations are recommended in the study zone.

Figure 5 next page

SCOPE OF SITE INVESTIGATIONS

The scope of site investigations will vary depending on the proposed land use, nature of faulting, and amount of preexisting disturbance of the surface. Prior to construction, a geotechnical report delineating the location of the faults and a suggested setback distance will be required. At undisturbed sites, the initial phase of the surface-faulting investigation should include mapping and topographic profiling of all suspected faults and scarps. Mapping consists chiefly of identifying fault scarps or



SCALE

0 .5 1 mi

0 .5 1 km

EXPLANATION

Wasatch Fault, bar and ball on downthrown side

Surface fault rupture hazard special study area

Figure 5. Map showing the Wasatch fault zone at the mouth of Rock Canyon, Utah. Study zone surrounds the mapped trace of the fault and is 250 ft (76.3 m) wide on the upthrown side and 500 ft (152.5 m) wide of the downthrown side. Setback recommendations are discussed in the text.

other fault-related geomorphic features based on interpretation of aerial photographs and detailed field investigations. Topographic profiles (two dimensional cross-sections) of fault scarps should be made to define the features which are usually apparent from these profiles. Profiles should extend several hundred feet above and below the main fault scarp in order to provide the basic information needed to define standard fault setbacks.

In disturbed or geologically young areas, such as an active stream floodplain or farmed areas, the surficial material may be regraded or less than 10,000 yr old, and of sufficient thickness to conceal older faulted deposits and faults. These areas would require that site specific studies contain recommendations for setback distances derived from projections of faults on adjacent property through the study area. If setback distances cannot be determined from projections, then trenching may be done to a depth that encounters undisturbed material which is older than 10,000 yr, to determine if faulting had occurred.

Studies by McCalpin (1987) indicate that faults are commonly located at the midpoint of its scarp. It is recommended that structures be set back a minimum of 50 ft (15 m) from the midpoint of the scarp (figure 6 A), if the scarp angle does not reach 30 percent. If the scarp slope is 30 percent or greater, then the setback should be taken from the 30 percent slope break at the top and bottom of the scarp (figure 6 B). By following these recommendations, we should be able keep structures from straddling the main, and potentially most dangerous, trace of the fault, but it will not remove them from the entire zone of deformation. If profiles indicate that backtilting, secondary faulting, or graben-

bounding antithetic faults are present and a wide zone of deformation exists, a 50-ft (15 m) setback should be taken from the outermost antithetic fault (figure 6 C) or, in areas of flexure and backtilting, from the area where the original pre-fault surface slope is regained. It is recommended that construction in the zone of deformation not be allowed unless detailed studies involving trenching are performed to define the hazard. Fault-trench investigations are used to accurately locate, characterize, and in some cases, date past events at a specific location and to delineate the zone of deformation. Based on data from trenches, further recommendations can be made for variances from these minimum setback guidelines.

Figure 6 next page

At sites where the surface is disturbed, but the causative faults cannot be located on the basis of surface evidence, trenching of proposed locations of structures is recommended. In some cases, it would be advisable to offset trenches (along the strike of the fault) from actual building foundations to avoid adversely affecting soil foundation conditions with trench backfill. Utah Geological and Mineral Survey Miscellaneous Publication N (Utah Section of the Association of Engineering Geologists, 1987) lists guidelines for performing surface-fault-rupture investigations and preparing reports; it should be consulted prior to performing such studies. Recommendations include consulting the county geologist to further clarify the scope of investigation and types of information that should be

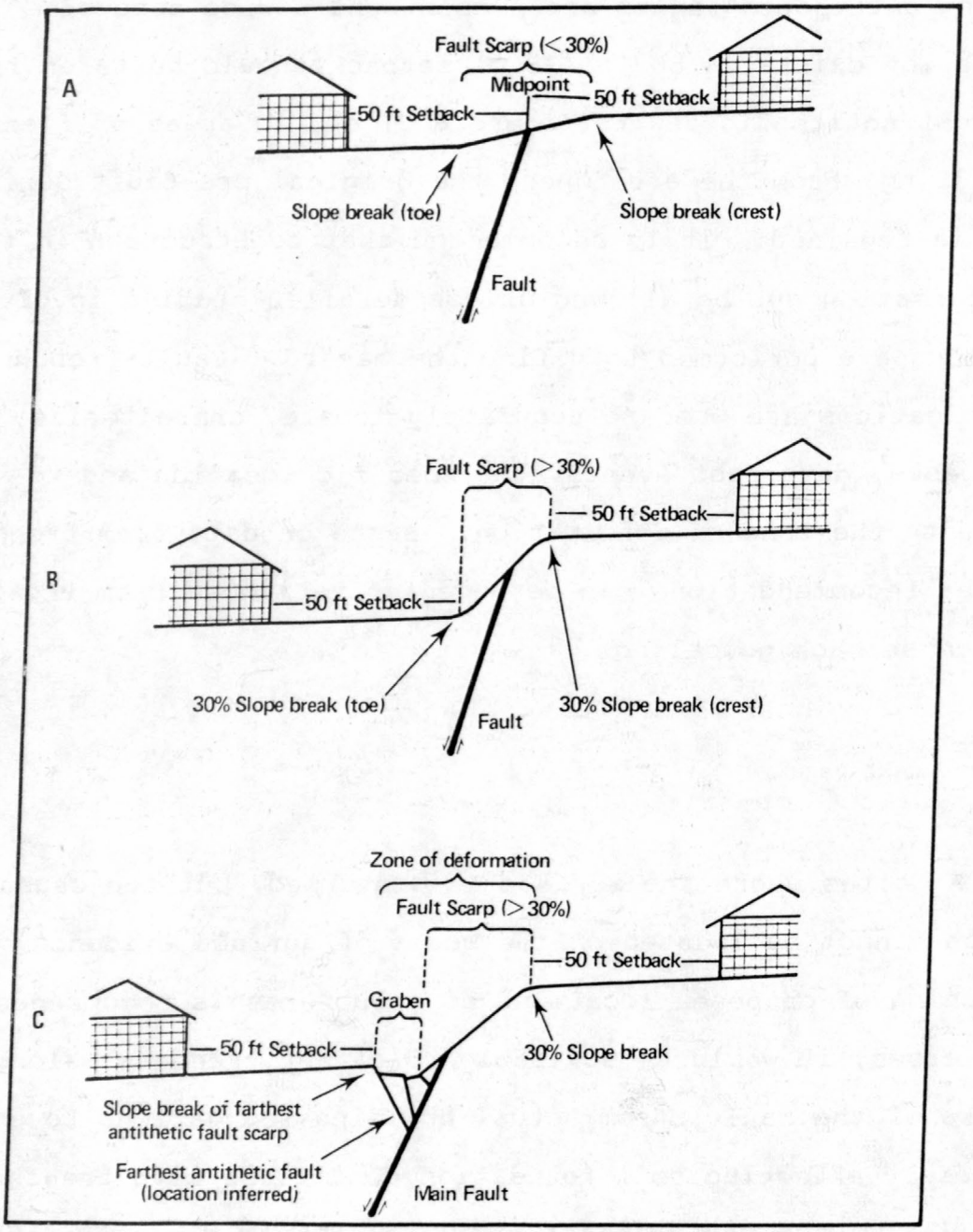


Figure 6. Schematic diagram of recommended minimum setback distances relative to fault scarps in areas where trenching studies are not performed. Recommended setback distances are: A. 50 ft (15.25 m) from the midpoint of a scarp that does not have a 30 degree slope; B. 50 ft (15.25 m) from the top and bottom slope break on a scarp which has 30 degrees or more slope; and C. for scarps where a graben is present, 50 ft (15.25 m) from the 30 percent slope break at the top and 50 ft. (15.25 m) from the farthest antithetic fault scarp.

obtained from such a study. Once site-specific reports have been completed, they should be reviewed by the county geologist and any problems discussed and resolved prior to submittal to the planning commission for approval. The information in this paper is the most accurate available as of August, 1989. Much research is being conducted along the Wasatch Front, and the text which accompanies the surface fault rupture hazard zone maps will be updated periodically as necessary. New and more accurate fault locations will also be added to the accompanying maps as they become available. The text and maps are kept on file at the Utah County Planning Office and Utah County Recorders office.

ACKNOWLEDGEMENTS

This paper was reviewed by Gary E. Christenson (UGMS), Michael N. Machette and William J. Kockleman (USGS), Craig Nelson (Salt Lake County Geologist), and Mickael V. Lowe (Davis County Geologist). William Lund (UGMS) provided pertinent information as well as technical data in his review. Michael N. Machette also graciously furnished preliminary mapping from the Wasatch Front portion of the National Earthquake Hazards Reduction Program in addition to technical information. William D. Black (UGMS) prepared the figures.

SELECTED REFERENCES

Arabasz, W.J., 1984, Earthquake behavior in the Wasatch Front area--Association with geologic structure, space-time occurrence, and stress state: U.S. Geological Survey Open-File Report 84-763, p. 310-339.

Bucknam, R.C., and Anderson, R.E., 1979, Estimation of fault scarp ages from a scarp-height-slope-angle relationship: Geology, v. 7, p. 11-14.

Colman, S.M., and Watson, Ken, 1983, Ages estimated from a diffusion equation model for scarp degradation: Science, v. 221, p. 263-265.

Dustin, J.D., and Merritt, L.B., 1980, Hydrology of Utah Lake with emphasis on Goshen Bay: Utah Geological and Mineral Survey Water Resources Bulletin 23, 50 p.

Federal Emergency Management Agency, 1984, National Earthquake Hazards Reduction Program--Fiscal year 1984 activities: Report to the United States Congress, 192 p.

Hays, W.W., and Gori, P.L., editors., 1987, A workshop on "Earthquake hazards along the Wasatch Front, Utah": U.S. Geological Survey Open-File Report 87-154, 146 p.

Jackson, M. E., and Ruzicka, J., 1988, Holocene paleoseismic history of the Levan and Nephi segments, Wasatch fault zone, Utah: Application of the thermoluminescence (TL) method: Geological Society of America Abstracts with Programs, v. 20, no. 5, p. 54.

McCalpin, James, 1987, Recommended setbacks from active normal faults, in McCalpin, James, ed., Proceedings of the 23rd Symposium on Engineering Geology and Soils Engineering: Utah State University Press, Logan, Utah, p. 35-56.

Machette, M. N., 1988, American Fork Canyon, Utah--Holocene faulting, the Bonneville fan-delta complex, and evidence for the Keg Mountain oscillation, in Machette, M. N., ed., In the footsteps of G. K. Gilbert--Lake Bonneville and neotectonics of the eastern Basin and Range province, guidebook for fieldtrip twelve: Utah Geological and Mineral Survey Miscellaneous Publication 88-1, 120 p.

Machette, M.N., and Lund, W.R., 1987, Late Quaternary history of the American Fork segment of the Wasatch fault zone, Utah: Geological Society of America Abstracts with Programs, v. 19, no. 5, p. 317.

Machette, M. N., Personius, S.F., Scott, W.E., and Nelson, A.R., 1987, Quaternary geology along the Wasatch Front: Evidence for ten fault segments and large-scale changes in slip rate along the Wasatch fault zone, in Gori, P.L., and Hays, W.W., eds., Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Open-File Report 87-585, p. A1-A72.

Machette, M.N., 1989, Preliminary surficial geologic map along the Wasatch fault zone in eastern the Utah Valley, Utah County,

and parts of Salt Lake and Juab Counties, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-2109, scale 1:50,000.

Machette, M.N., Personius, S.F., Nelson, A.R., Schwartz, D.P., and Lund, W.R., 1989, Segmentation models and Holocene movement history of the Wasatch fault zone, Utah, in Schwartz, D.P., and Sibson, R., editors, Proceedings of Conference XLV--Fault segmentation and controls on rupture initiation and termination: U.S. Geological Survey Open-File Report 89-315, p. 229-242.

Nelson, A.R., and Personius, S.F., 1987, A nonconservative barrier to Holocene rupture propagation in the northern Wasatch fault zone, Utah: [Abs] Proceedings of XII INQUA Congress, July 31-August 9, 1987, Ottowa, Canada.

Robison, R.M., 1988, Surface fault rupture hazard and tectonic subsidence maps for the Wasatch Front, Utah: Geological Society of America Abstracts with Programs, v. 20, no. 6, p. 465.

Schwartz, D.P., 1988, Geologic characterization of seismic sources--Moving into the 1990s, in Von Thun, J. L., ed., Recent advances in ground-motion evaluation: American Civil Engineers Geotechnical Special Publication No. 20, p. 1-42.

Schwartz, D.P., and Coppersmith, K.J., 1984, Fault behavior and characteristic earthquakes--Examples from the Wasatch and San Andreas fault zones: Journal of Geophysical Research, v. 89, no. B7, p. 5681-5698.

Schwartz, D. P., Swan, F.H., and Cluff, L.S., 1984, Fault behavior and earthquake recurrence along the Wasatch fault zone: U.S. Geological Survey Open-File Report 84-763, p. 113-125.

Smith, R.B., and Richins, W.D., 1984, Seismicity and earthquake hazards of Utah and the Wasatch Front--Paradigm and paradox, in Hays, W. W., and Gori, P. L., eds., Workshop on "Evaluation of regional and urban earthquake hazards and risk in Utah": U.S. Geological Survey Open-File Report 84-763, p. 73-112.

Swan, F.H., II, Hanson, K.L., Schwartz, D.P., and Kneupfer, P.L., 1981, Study of earthquake recurrence intervals on the Wasatch fault at the Little Cottonwood Canyon site, Utah: U.S. Geological Survey, Open-File Report No. 81-450, 30 p.

Utah Section of the Association of Engineering Geologists, 1987, Guidelines for evaluating surface fault rupture hazards in Utah: Utah Geological and Mineral Survey Miscellaneous Publication N, 2 p.

Youd, T.L., 1980, Ground failure displacement and earthquake damage to buildings: American Society of Civil Engineers Conference on Civil Engineering and Nuclear Power, 2d, Knoxville, Tenn., v.2, p. 7-6-2-7-6-26.

LANDSLIDE HAZARDS: A GUIDE FOR LAND-USE PLANNING, DAVIS COUNTY, UTAH

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ABSTRACT

Landslides pose one of the most common geologic hazards in Davis County, Utah, where more than 700 slides have been identified and mapped. Landslides are downslope mass-movements of earth materials under the influence of gravity. Many types of landslides occur in Davis County. This report addresses only translational and rotational landslides. Potential for damage to structures, rupture of underground waterlines and sewers, and damming of streams with resultant catastrophic flooding exists in areas susceptible to landsliding of these types in Davis County.

Two sets of landslide-hazard maps showing where landslides exist or are considered likely to occur in the future have been produced for Davis County. The first set of landslide-hazard maps shows where landslides are likely to occur in the absence of earthquakes. This set of maps was constructed by overlaying geologic maps, slope maps, and landslide-inventory maps and combining areas of known landslides, landslide-prone geologic units, and areas having slope greater than 30 percent into a landslide-hazard special-study zone. The second set of landslide-hazard maps, earthquake-induced landslide-potential maps, delineates areas where landslides are likely to occur in the event of an earthquake. This set of maps was produced by combining data on the strength of earth materials, slope geometry, ground-water conditions, and magnitude of ground shaking to determine the probability of earthquake-induced landslides occurring throughout Davis County. Zones or areas having probabilities of earthquake-induced landslides ranging from high to very low are shown on the earthquake-induced landslide-potential maps.

Site-specific static (non-earthquake) slope-stability studies are recommended prior to planning commission approval of new development within the landslide-hazard special-study zone. It is recommended that site-specific earthquake-induced (dynamic) landslide potential be evaluated prior to planning commission approval of critical facilities, lifelines, and high-occupancy, industrial, and commercial buildings in areas of high or moderate earthquake-induced landslide-potential ratings.

INTRODUCTION

Landsliding historically has been one of the most damaging geologic processes occurring in Davis County, in the unincorporated county and in many cities. All active landslides and most older slides have been mapped at a scale of 1:24,000 scale to produce landslide-inventory maps. These maps serve as an indication of unstable ground. The landslide inventories, along with slope maps and other geologic data, has been used to evaluate slope stability on a broad scale and to prepare landslide-hazard maps. These hazard maps show areas of landslides and slopes which are potentially unstable under static (non-earthquake) conditions. Separate earthquake-induced (dynamic) landslide-hazard maps have been prepared for Davis County by Keaton and others (1987). This report describes landslide hazards and recommends guidelines for use of landslide-hazard and earthquake-induced landslide-potential maps in land-use planning. A major goal is to translate technical information so that government officials and the general public can appreciate the need to reduce landslide hazards.

LANDSLIDE CHARACTERISTICS

Landslides are generally defined as "mass movements of rock or soil downslope under the direct influence of gravitational forces without an aiding transporting medium such as water, air, or ice" (Costa and Baker, 1981, p. 243).

Landslides considered in the landslide-hazard maps include rotational and translational slides and associated earth flows (Varnes, 1978). Rotational slides generally have a curved failure plane. The head of the rotational slide is back-tilted compared to the slope of the original surface. Most rotational slides are termed slumps, and may include an earth flow at the toe where material moves onto the land surface below the slump (fig. 1). Translational slides

Figure 1 next page

generally have a more planar failure surface, and may be broken into several discrete blocks. If rock is involved, the term rock slide may be used. The speed of landslides may vary. Both slide types may occur slowly and progressively over periods of years, or may be extremely rapid and occur in a matter of a few seconds. The landslide-hazard maps do not address rock falls or debris flows, which are other types of failures commonly grouped under the term landslides.

Landslides may be caused by any of several conditions. Oversteepening of slopes, loss of lateral support, weighting of the head, increased pore pressure, and earthquake ground shaking are among the major causes of landslides. Older landslides are particularly susceptible to reactivation due to conditions which exist in a displaced soil mass such as increased permeability and established failure planes.

Landslides are likely to occur in Davis County if a

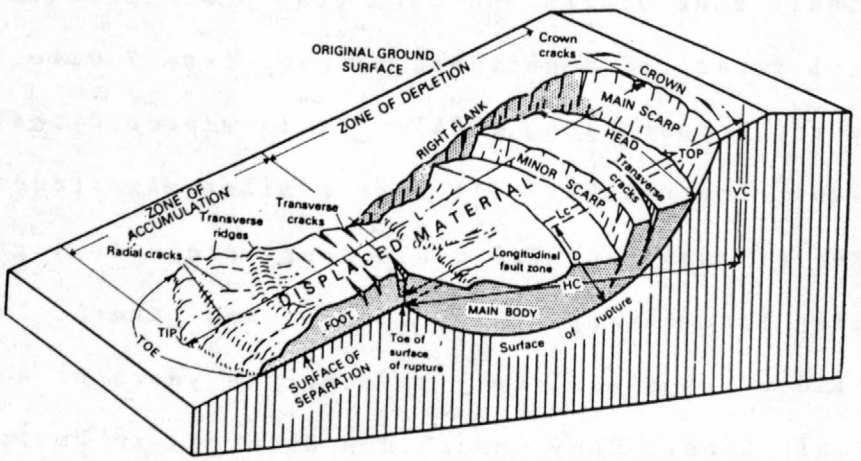

Figure 1. Cross-sectional view of a rotational landslide. Note the back-tilt below the main scarp and material at the zone of accumulation at the toe. If this landslide was translational, then the surface of rupture (failure plane) would be planar like the surface of separation beneath the foot. Adapted from Varnes (1978).

moderate to strong earthquake occurs in northern Utah. Ground failures, including landslides, commonly accompany earthquakes with Richter magnitudes greater than 4.5 (Keefer, 1984). Some form of landslide or ground failure (predominantly rockfall or rockslide) has been noted in the descriptions of 12 earthquakes that occurred in or immediately adjacent to Utah from 1850 to 1986 (magnitudes 4.3 to 6.6) (Keaton and others, 1987). Geologic evidence from trench excavations across Wasatch fault zone scarps indicate that past earthquakes on the Wasatch fault had magnitudes ranging from 7.0 to 7.5 (Schwartz and Coppersmith, 1984). It is expected that future Wasatch fault earthquakes will have similar magnitudes. Earthquakes of magnitude 7.5 could cause slope failures as far as 185 miles from the epicenter (Keaton and others, 1987).

Landslides are also likely to occur in years of abnormally high precipitation. Many landslides occurred in Davis County during the recent wet cycle (1982-1985), causing significant damage to homes and property. Most of this damage was caused by the Memorial Day 1983 Rudd Canyon debris flow which damaged 35 houses, 15 severely. The 1983 Rudd Canyon debris flow, which resulted in deposition of more than 100,000 yd3 (80,000 M3) of earth material at the canyon mouth, was initiated by landsliding (less than 20,000 yd3, 15,000 m3) in the Wasatch Mountains (Wieczorek and others, 1983).

CONSEQUENCES

Damage from a landslide can occur at any point on the slide mass and above or below the landslide. The tops of most landslides are characterized by an arcuate downhill-facing scarp (main scarp) created by the downward displacement of the ground surface (fig. 1). The effect on a building straddling the main scarp is partial loss of foundation support and potential building collapse. Structures upslope from the head of a landslide are endangered because the newly formed main scarp is commonly unstable and may fail causing new scarps to form upslope. Buildings constructed within the central mass of the landslide may be subjected to differential displacement on minor scarps and movement in both vertical and horizontal directions. Table 1 shows the relationship between ground displacement and expected levels of damage to structures. The

Table 1 next page

toe of a landslide will normally move horizontally and upward and may proceed downslope causing extensive damage to structures. Cracks at the head and a bulge at the toe may precede the principal landslide movement. Landslides can damage roads, railroads, and powerlines. Furthermore, landslides may rupture canals, aqueducts, sewers, and water mains, and thereby add water to the slide plane and promote further movement. In addition to ground movement, flooding

Table 1. Relationship between ground displacement and damage to structures from Youd (1980).

Ground Displacement	Level Of Expected Damage
Less than 4 in.	Little damage, repairable
4 in. to 1 ft	Severe damage, repairable
1 ft to 2 ft	Severe damage, non-repairable
More than 2 ft	Collapse, non-repairable

may be caused by landslides. Flooding may occur due to discharge from springs along the basal slide plane (example, 1500 East landslide, Provo, Utah), usually in the toe area, or damming of streams causing upstream flooding as water is ponded and possible flooding downstream if the impounded water overtops or breaches the landslide dam. Spring discharge from landslides is a minor problem and can generally be mitigated by diverting drainage. Damming of streams is a major problem (Schuster, 1987), and was a principal hazard associated with the Thistle landslide in 1983 in Utah County. Lake Thistle formed behind the landslide mass and flooded the town of Thistle to a depth of about 250 ft. A much larger and more populated area downstream was at risk from flooding had the landslide failed or been overtopped and washed-out prior to draining of the lake. Another landslide that caused similar problems is the Gros Ventre landslide in Wyoming where 6 or 7 people were killed in the ensuing flood two years after the landslide event (Costa and Baker, 1981)

LANDSLIDE SUSCEPTIBILITY

Several geologic units in Davis County are susceptible to landslides. Landslide-prone geologic units were identified by overlaying landslide-inventory and geologic maps and tabulating the number of landslides occurring in each geologic unit. The Precambrian Farmington Canyon Complex in the mountains in eastern Davis County weathers in a manner which

provides much unstable hillside debris (colluvium), and debris slides are common. Debris slides in colluvium derived from the Farmington Canyon Complex were responsible for initiating many of the debris flows which occurred in 1983 and 1984. Landslides are also common in areas underlain by the sediments of Pleistocene Lake Bonneville. Rotational landslides (slumps) are particularly common in northern Davis County where stream incision into the Weber River Delta has created high bluffs and exposed silts and clays deposited during the high stand of Lake Bonneville. Many springs occur along these bluffs increasing landslide susceptibility.

Existing landslides pose a particular problem for development because of their tendency to reactivate. Many landslides in the mountains and along the bluff above the City of South Weber are re-activated old landslides or have developed on portions of larger older landslides.

Slope steepness is another important factor in determining slope stability. Almost any material will fail if the slope is steep enough.

Landslides may be triggered by earthquake activity. Although the same slopes which are considered unstable under static conditions will be even less stable during an earthquake, some slopes that are stable under static conditions may fail as a result of earthquake ground shaking, particularly if the earthquake occurs when slopes are wet.

REDUCING LANDSLIDE HAZARDS

Many methods have been developed for reducing landslide hazards. Proper planning and avoidance is the least expensive measure, if landslide-prone areas are identified early in the planning and development process. Care in site grading with proper compaction of fills and engineering of cut slopes is a necessary follow-up to good land-use planning. Where avoidance is not feasible, various engineering techniques are available to stabilize slopes. De-watering (draining) can have a major impact on stabilizing slopes and existing landslides. Retaining structures built at the toe of a landslide may help stabilize the slide and reduce the possibility of smaller landslides. In some cases, piles may be driven through the landslide mass into stable material beneath the slide. If the dimensions of the landslide are known, and the landslide is not excessively large, removing the landslide may be effective. Some other techniques which may be used to reduce landslide hazards include bridging, weighting or buttressing slopes with compacted earth fills, and drainage diversion. A more complete list of landslide-hazard reduction techniques may be found in Costa and Baker (1981), Kockelman (1986), and other engineering geology publications. Every landslide and potentially unstable slope will probably have differing characteristics and will need to be evaluated for an appropriate hazard reduction technique.

SUMMARY OF METHODS USED IN MAP PREPARATION

Landslide-inventory maps (figures 2 and 3) showing existing landslides in Davis County have been compiled at 1:24,000 scale using U. S. Geological Survey topographic quadrangles as base maps (Lowe, unpublished Davis County Planning Commission maps). The following parameters were

Figures 2 and 3 next page

evaluated while preparing the landslide-inventory maps: 1) landslide type, compiled from existing data and air photo interpretation using a classification scheme developed by Varnes (1978); 2) age class of landslides, using a classification scheme developed by McCalpin (1984); 3) elevation of the toe and crown of the landslide; 4) average pre-landslide slope; 5) failed geologic unit, as determined from existing geologic mapping; 6) other geologic units involved; 7) slope aspect; 8) landslide complexity (multiple landslides); and 9) the role of man in causing the failure. If the same landslide was mapped by more than one investigator, and discrepancies were found in the mapping of the perimeter of the landslide, the two maps were overlain and the outermost margin of the landslide on the combined maps was used.

The landslide-inventory maps and slope maps were then used to assess the susceptibility for slope failure on natural

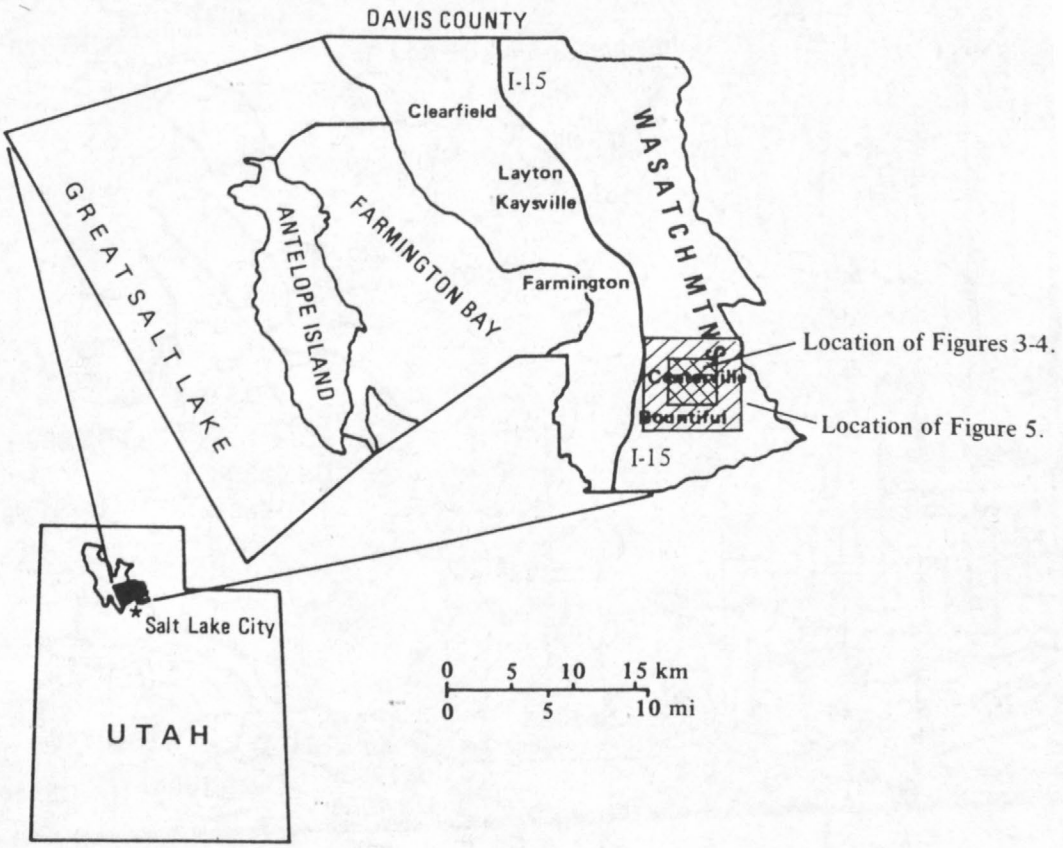

Figure 2. Location map for figures 3, 4, and 5.

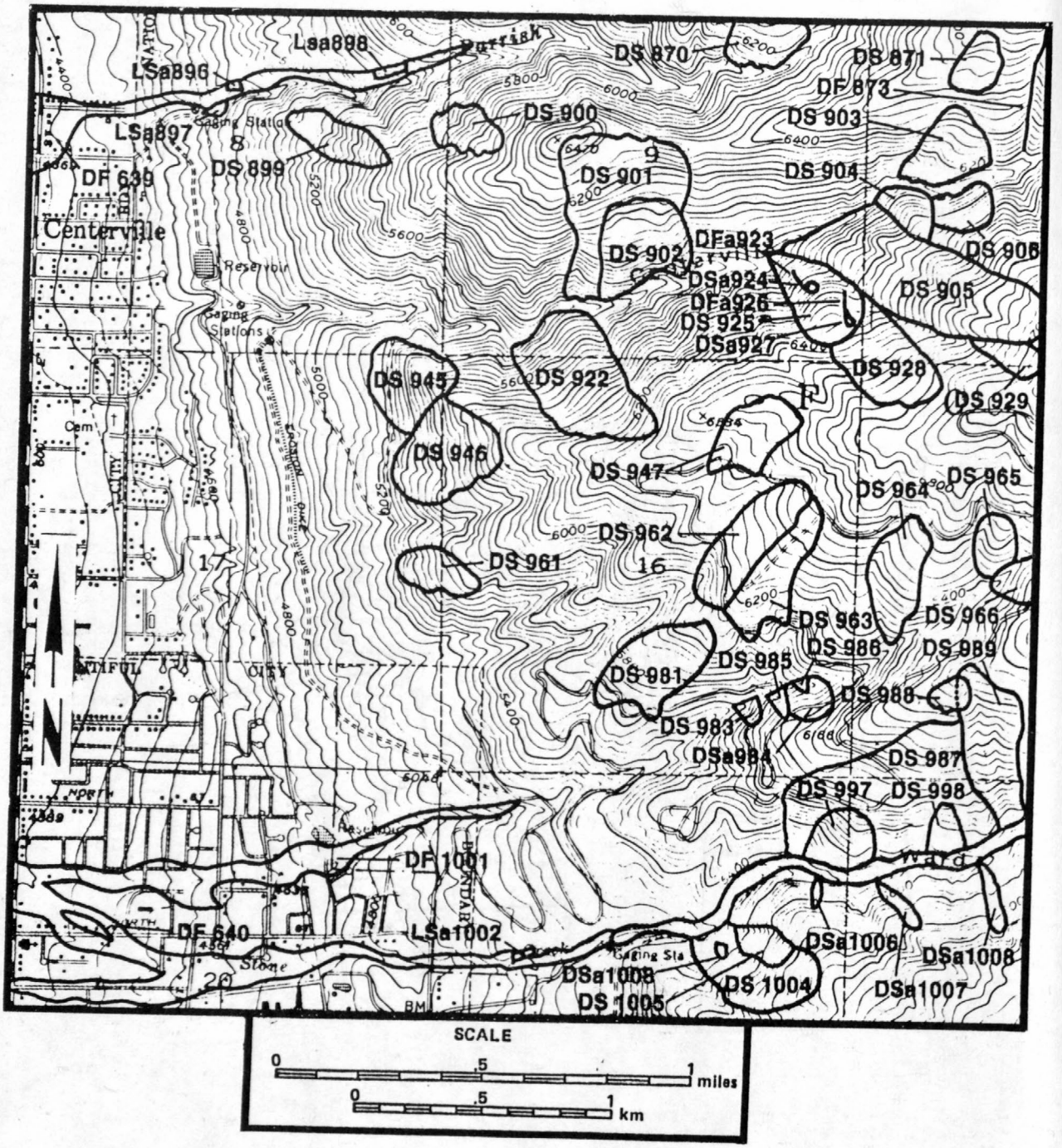

Figure 3. Landslide-Inventory Map for the Centerville and northern Bountiful area of southern Davis County, Utah. DS = shallow failure, chiefly debris slides. DF = debris flow. LS = deep failure, chiefly slumps and earthflows. a = active (historic) slope failure. 123 = inventory number for slope failure. Reproduced from a portion of the Slope-Failure Inventory Map, Bountiful Peak Quadrangle. Original mapping by Keaton (1986), Nelson and Personius (1988), Olson (1981), and Lowe (unpublished Davis County Planning Commission maps).

slopes under static (non-earthquake) conditions and to help construct 1:24,000 scale landslide-hazard maps (figures 2 and 4). Slopes steeper than 30 percent have a relatively high

Figure 4 next page

potential for failure and are generally already subject to land-use restrictions for reasons other than slope stability, so these are included in the recommended study area on the landslide-hazard maps. In certain failure-prone materials such as fine-grained Lake Bonneville deposits, failures have occurred at slopes less than 30 percent. These flatter areas with existing landslides have also been included in the recommended study area on the landslide-hazards maps.

In those areas where unstable slopes occur surrounded by flatter, more stable slopes, it is necessary to extend landslide-hazard study boundaries beyond the base and top of the unstable slope. This situation occurs along the bluff above South Weber, and along incised drainages in Layton and Kaysville, where the potential instability in the steeper slope (bluff face) may affect areas both above and below. The width of the landslide-hazard study area in this situation depends on the height, steepness, ground-water conditions, and strength of the material making up the slope. In these areas of flat land above and below landslide-prone slopes, a conservative stable slope angle through the center of the steep slope was taken to determine where slope-stability

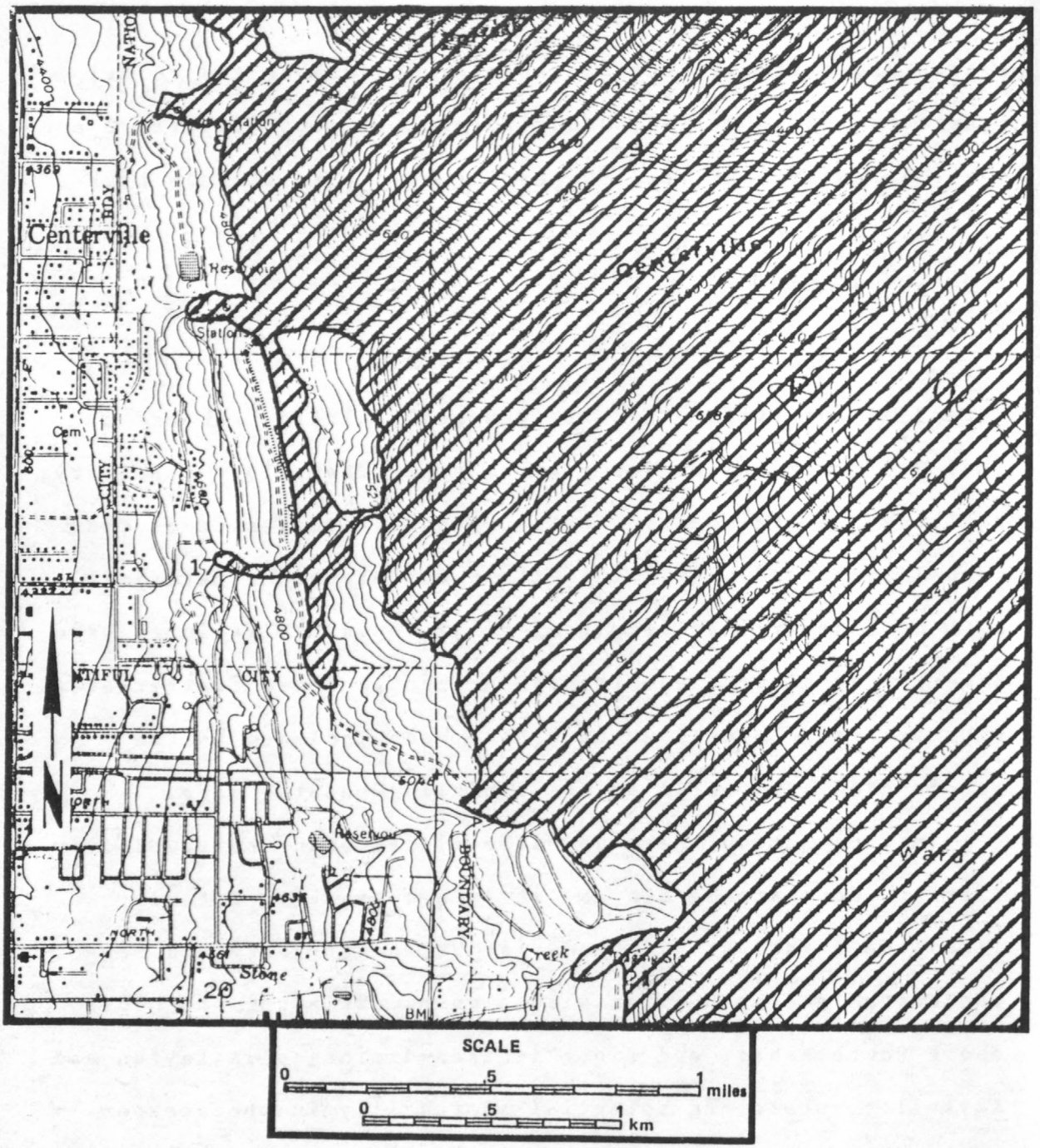

Figure 4. Landslide-Hazard Map for the Centerville and northern Bountiful area of southern Davis County, Utah. Cross-hatching indicates areas where slope-stability studies are recommended prior to planning commission approval of proposed development. This figure was reproduced from a portion of the Landslide-Hazard Map, Bountiful Peak Quadrangle, Davis County, Utah, by Lowe (unpublished Davis County Planning Commission maps).

studies are needed for the flatter land. Rollins, Brown, and Gunnel (1977) determined that this conservative slope angle should be 2 horizontal to 1 vertical (2:1) (50 percent) for dry granular soils, and 2.5:1 (40 percent) for moist fine-grained material.

Earthquake-induced landslide-potential maps (1:48,000 scale) for Davis County (figures 2 and 5) have been prepared

Figure 5 next page

by Keaton and others (1987) using 50-percent reductions of U. S. Geological Survey topographic quadrangles as base maps. In evaluating seismic slope stability Keaton and others (1987) considered: 1) the strength of slope materials, 2) slope geometry, 3) ground-water conditions, and 4) the strength or intensity of earthquake ground shaking. These parameters were evaluated to determine the level (magnitude) of ground shaking necessary to cause slope instability in each type of earth material found in Davis County, for various slopes and slope geometries, and for dry and saturated ground-water conditions. The probability of this level of ground shaking occurring during a 100-year time period was then determined and used to define geographic areas of high, moderate, low, and very low potential for seismic slope failure (Keaton and others, 1987). Table 2 summarizes each category of earthquake-induced landslide potential with respect to the probabilities of the

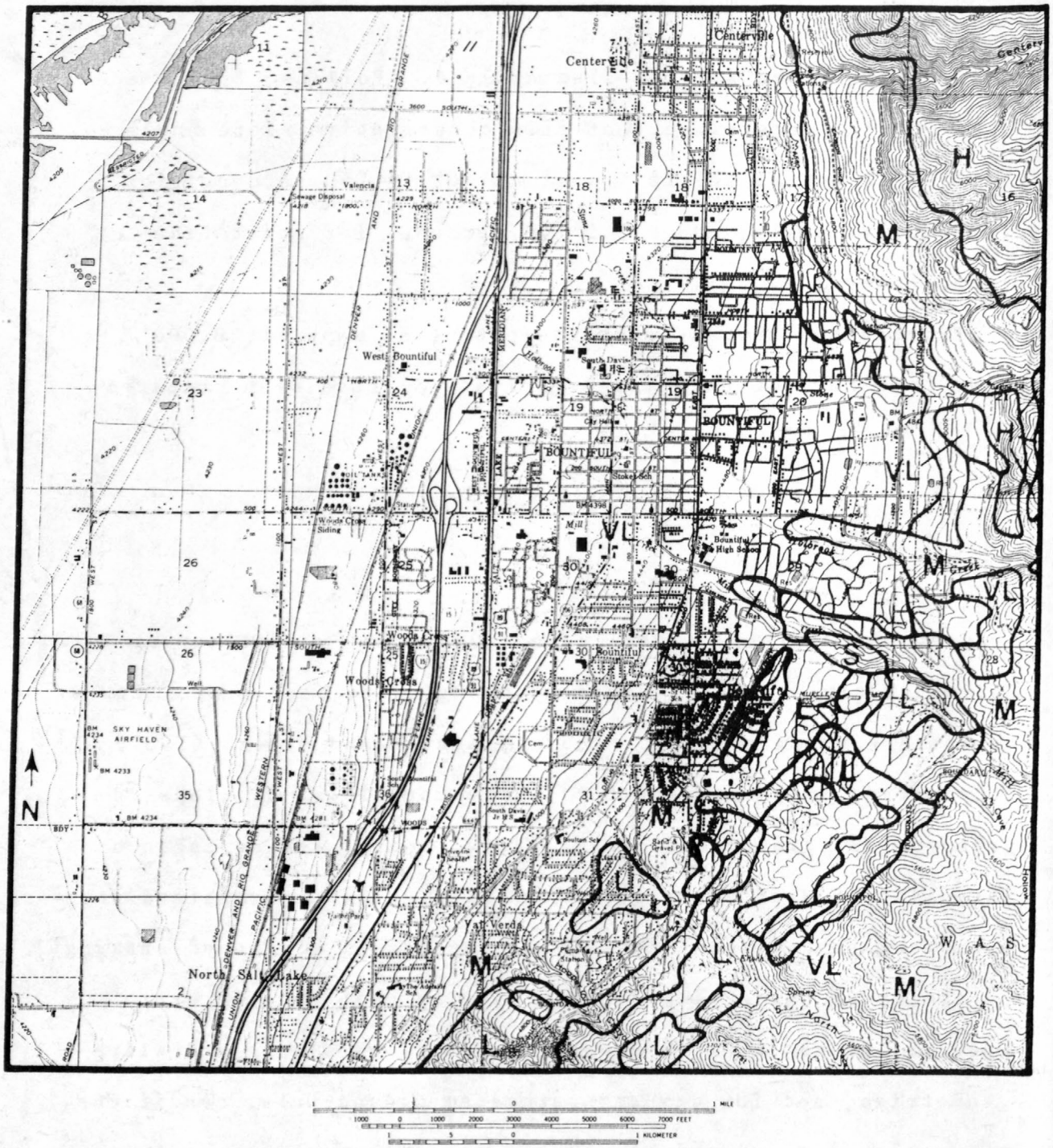

Figure 5. Earthquake-Induced Landslide-Potential Map for the Centerville and northern Bountiful area of southern Davis County, Utah. Earthquake-induced landslide-potential ratings are represented by the following abbreviations: S = landslide, VL = very low, L = low, M = moderate, and H = high. This figure was reproduced from a portion of the Earthquake-Induced Landslide-Potential Map (South Half) for Davis County, Utah, by Keaton and others (1987).

critical accelerations needed to induce failure in each category being exceeded in a 100-year time period and the possible levels of displacement associated with that failure.

Table 2 next page

RECOMMENDED USE OF MAPS FOR LAND-USE PLANNING AND DEVELOPMENT

The landslide-hazard maps that accompany this report show areas of existing landslides and potential landslide hazard at 1:24,000 scale using U.S. Geological Survey 7 1/2 minute (topographic) quadrangles as base maps. These maps are chiefly intended for use by planners to identify areas where site-specific investigations addressing slope stability should be performed prior to development. It is recommended that slope-failure potential be evaluated and, if necessary, mitigative measures recommended in site-specific engineering geologic reports submitted by the developer prior to planning commission approval as outlined in table 3.

Table 3 next page

The results of the earthquake-induced landslide-potential study are presented on a 1:48,000 scale map consisting of two parts (A & B) separating Davis County into a south half and a north half. The earthquake-induced landslide-potential rating

Table 2. Earthquake-induced landslide potential categories, soil moisture levels considered, probability of exceedence of critical acceleration needed to cause failure during 100-year period, and possible magnitudes of displacement from Keaton and others (1987).

Seismic Slope-Failure Potential	Soil Moisture Conditions	Probability Of Critical Acceleration Necessary To Cause Slope Failure Being Exceeded In A 100-Year Time Period	Possible Levels of Displacement
High	Dry and wet	50 percent or greater	4 in. or more
Moderate	Dry	10 to 50 percent	1 to 4 in.
	Wet	50 percent or greater	4 in. or more
Low	Dry	Less than 10 percent	Less than 1 in.
	Wet	10 to 50 percent	Up to 4 in.
Very Low	Dry and wet	10 percent or less	Less than 1 in.

Table 3. Recommended requirement for site-specific slope-stability investigations for various classes of facilities proposed within Davis County, Utah.

Facility Class	Areas Within Landslide-Hazard Area	Areas Outside Landslide-Hazard Area
Critical facilities, including lifelines and high-occupancy buildings	Yes	Yes
Industrial and commercial buildings (other than high-occupancy)	Yes	No
Residential subdivisions	Yes	No
Residential - single lots	Yes	No

for a given location can be determined by locating the site on the Earthquake-Induced Landslide-Potential Map. The approximate probability of ground shaking sufficient to induce slope failure, for both dry and wet soil conditions, occurring during a 100-year period for the landslide-potential rating given on the map may then be determined by referring to the proper category in table 2. It is recommended that earthquake-induced landslide potential be evaluated and, if necessary, mitigative measures recommended in site-specific engineering geologic reports submitted by the developer to the planning commission prior to approval of the development as outlined in table 4.

Table 4 next page

Both the landslide-hazard and the earthquake-induced landslide-potential maps provide a general indication of where slope-failure hazards may exist, and serve as a means for evaluating the need for site-specific studies. These maps are at a regional scale and, although they can be used to gain an understanding of the potential for landslides occurring in a given area, they are not designed to replace site-specific evaluations. Mapped areas rated as having landslide hazards or having a high potential for earthquake-induced landsliding may contain isolated areas which are not prone to landsliding, even during earthquake ground shaking. Also, areas outside the landslide-hazard study boundary, or rated as having a low

Table 4. Recommended requirement for site-specific seismic slope-stability investigations for various classes of facilities in different earthquake-induced landslide-potential zones.

Facility Class	Zones of High-Moderate Potential for Earthquake-Induced Landslides	Zones of Low-Very Low Potential for Earthquake-Induced Landslides
Critical facilities, including lifelines and high-occupancy buildings	Yes	Yes
Industrial and commercial buildings (other than high occupancy)	Yes	No
Residential subdivisions	No*	No
Residential - single lots	No*	No

* Appropriate disclosure should be required

earthquake-induced landslide potential, may contain isolated areas which are highly susceptible to landsliding.

SCOPE OF SITE INVESTIGATIONS

Site evaluations for landslides and potentially unstable slopes, including earthquake-induced landslides, should be performed prior to construction of any structures for human occupancy as outline in tables 3 and 4. The investigation should include accurate maps of the area showing the proposed development, existing landslides and steep slopes, and the site geology. Where necessary, a factor of safety should be computed by a competent geotechnical engineer or engineering geologist to determine the stability of natural or proposed cut slopes. Slope-stability analyses should include potential for movement under static, development-induced, and earthquake-induced conditions. Site grading, including design of cuts and fills, should comply with Chapter 70 of the 1988 Uniform Building Code. A useful guide for preparing site-investigation reports is found in Utah Geological and Mineral Survey Miscellaneous Publication M, Guidelines for Preparing Engineering Geological Reports in Utah, by the Utah Section of the Association of Engineering Geologists (1986). Site-investigation reports should be reviewed by the County Geologist and other appropriate officials. This review will determine if the submitted report is adequate and complete. As new and more accurate information becomes available, the landslide-hazard maps will be amended.

ACKNOWLEDGMENTS

Gary E. Christenson, Utah Geological and Mineral Survey; William J. Kockelman, U. S. Geological Survey; Rex Baum, U. S. Geological Survey; and Wilf Sommerkorn, Davis County Planning Department, kindly reviewed this paper and provided valuable suggestions. Bill Black, Utah Geological and Mineral Survey, drafted the figures.

REFERENCES CITED

Costa, J. E., and Baker, V. R., 1981, Surficial geology, building with the earth: John Wiley and Sons, New York, 498 p.

Keaton, J. R., 1986, Landslide inventory and preliminary hazards assessment, southeast Davis County, Utah: Association of Engineering Geologists 29th Annual Meeting Program with Abstracts, San Francisco, CA, p. 53.

Keaton, J. R., Anderson, L. R., Topham, D. E., and Rathbun, D. J., 1987, Earthquake-induced landslide potential in and development of a seismic slope stability map of the urban corridor of Davis and Salt Lake Counties, Utah: Dames & Moore Consulting Engineers, Salt Lake City, Utah, and Department of Civil and Environmental Engineering, Utah State University, Logan, Utah, 47 p.

Keefer, D. K., 1984, Landslides caused by earthquakes: Geological Society of America Bulletin, v. 95, p. 406-421.

Kockelman, W. J., 1980, Some techniques for reducing landslide hazards: Association of Engineering Geologists bulletin, v. 23, no. 1, p. 29-52.

McCalpin, J. P., 1984, Preliminary age classification of landslides for inventory mapping: Twenty-First Annual Symposium on Engineering Geology and Soils Engineering, April 5 - 6, 1984.

Nelson, A. R., and Personius, S. F., 1988, Surficial geologic map of the Weber segment of the Wasatch fault, Weber and Davis Counties, Utah: U. S. Geological Survey Miscellaneous Field Investigations Map, 1:50,000 scale, in prep.

Olson, E. P., 1981, Geologic hazards of the Wasatch Range, Part 1, Ward Canyon to south side Ogden Canyon: U. S. Department of Agriculture, Forest Service, R-4 Intermountain Region, unpublished 1:24,000 scale maps of selected quadrangles within U. S. Forest Service boundaries.

Rollins, Brown, and Gunnel, Inc., 1977, Provo City hazards study: unpublished consultant's report, 28 p.

Schuster, R. L., 1987, Landslide damming of mountain streams; Geological Society of America, Abstracts with Programs, v. 19, no. 5, p. 332.

Schwartz, D. P., and Coppersmith, K. J., 1984, Fault behavior and characteristic earthquakes - examples from the Wasatch and San Andreas fault zones: Journal of Geophysical Research, v. 89, no. B7, p. 5681-5698.

Utah Section of the Association of Engineering Geologists, 1986, Guidelines for preparing engineering geologic reports in Utah: Utah Geological and Mineral Survey, Miscellaneous Publication M, 2 p.

Varnes, D. J., 1978, Slope movement and types and processes, in Landslides: Analysis and control: Transportation Research Board, National Academy of Sciences, Washington D. C., Special Report 176, Chapter 2, p. 11-33.

Wieczorek, G. F., Ellen, Stephen, Lips, E. W., Cannon, S. H., and Short, D. N., 1983, Potential for debris flow and debris flood along the Wasatch Front between Salt Lake City and Willard, Utah, and measures for their mitigation: U. S. Geological Survey Open-File Report 83-635, 45 p.

Youd, T. L., 1980, Ground failure displacement and earthquake damage to buildings: American Society of Civil Engineers Conference on Civil Engineering and Nuclear Power, 2d, Knoxville, Tenn., 1980, v. 2, p. 7-6-2 - 7-6-26.

Rock-Fall Hazards, A Guide To Land-Use Planning: Salt Lake County, Utah

By

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ABSTRACT

Rock falls along the Wasatch Front are common natural events that pose a threat to development. Rock-Fall Hazard Special Study Area maps have been prepared for Salt Lake County by identifying source areas and computer-simulating rock fall runout distances along the Wasatch Front. An existing Salt Lake County ordinance prohibits building on slopes above 30 percent, and computer models indicate that rocks typically do not runout onto slopes less than 30 percent. Where models suggest runout onto slopes below 30 percent, the longest computed runout distance is used to define a conservative special study area boundary. Due to the general nature and small scale of the hazard map, new developments proposing to place structures in a Rock-Fall Hazard Special Study Area must conduct site-specific rock-fall hazard investigations to define hazard areas and, if found, either avoid or reduce the hazard.

INTRODUCTION

Rock falls are a naturally occurring erosional process in mountain areas along the Wasatch Front. For the purposes of land-use planning the definition of rock fall used in this study has been broadened to include both rock falls (newly detached rocks from a bedrock source) and debris falls (rock clasts originating from coarse-grained unconsolidated deposits such as glacial till and colluvium). As urban development advances higher onto the bench areas and into the canyons, the risk from falling rocks becomes greater. The purpose of this report is to explain how the Rock-Fall Hazards Special Study Area maps were made and how they should be used. This information can benefit land-use planners, developers, real-estate agents, and the general public by informing them of potential hazards and ultimately helping avoid casualties and damage.

CHARACTERISTICS OF ROCK FALLS

Rock falls originate when erosional processes and the pull from gravity dislodge rocks from slopes. The most susceptible slopes are those with outcrops broken by bedding surfaces, joints, or other discontinuities into abundant loose individual fragments called clasts. Boulders in alluvium and glacial till on hillsides also contain clasts which may dislodge and fall. When the clast falls or rolls from the slope, it may travel great distances by rolling, bouncing, and sliding.

A primary mechanism responsible for triggering rock falls is from water freezing in outcrop discontinuities. When this confined water freezes and exerts pressure that exceeds the force keeping the discontinuity closed, frost shattering may occur. In Norway, for example, 60 percent of all rock falls occur in April and May during maximum snowmelt and October and November during

periods of heavy rainfall (Costa and Baker, 1981). In both cases there is water seeping into the rocks with the temperature fluctuating around the freezing point.

In mountainous areas rock falls are probably the most common form of slope instability initiated by the ground shaking from earthquakes (Keefer, 1984). Case (1987a) estimates that a major Wasatch Front earthquake (magnitude 7-7.5) could produce thousands of rock falls along the Wasatch Front. Keefer (1984) indicates that rock falls may occur in earthquakes as small as magnitude 4.0. In the August 1988 San Rafael Swell, M_L (local magnitude) 5.3, earthquake in central Utah, hundreds of rock falls occurred, temporarily obscuring the surrounding cliffs in clouds of dust (fig. 1).

Figure 1 next page

EFFECTS OF ROCK FALL

Rock falls present a hazard because of the potential damage that a large rock impact could cause to structures and personal safety. Rock falls that occur in remote or uninhabited regions go largely unnoticed. It is only when falling rocks pose a threat to man that rock falls must be considered in land-use planning and development regulations.

Figure 2 next page

A 1987 rock fall event near Dead Horse Point, Utah, was large enough to register on seismographs over 60 miles away (fig. 2). Locally, rock falls have historically caused problems along canyon roads by blocking traffic or occasionally striking vehicles. The structures most often affected by rock falls in canyons are exposed aqueducts. Water service from Wasatch Front

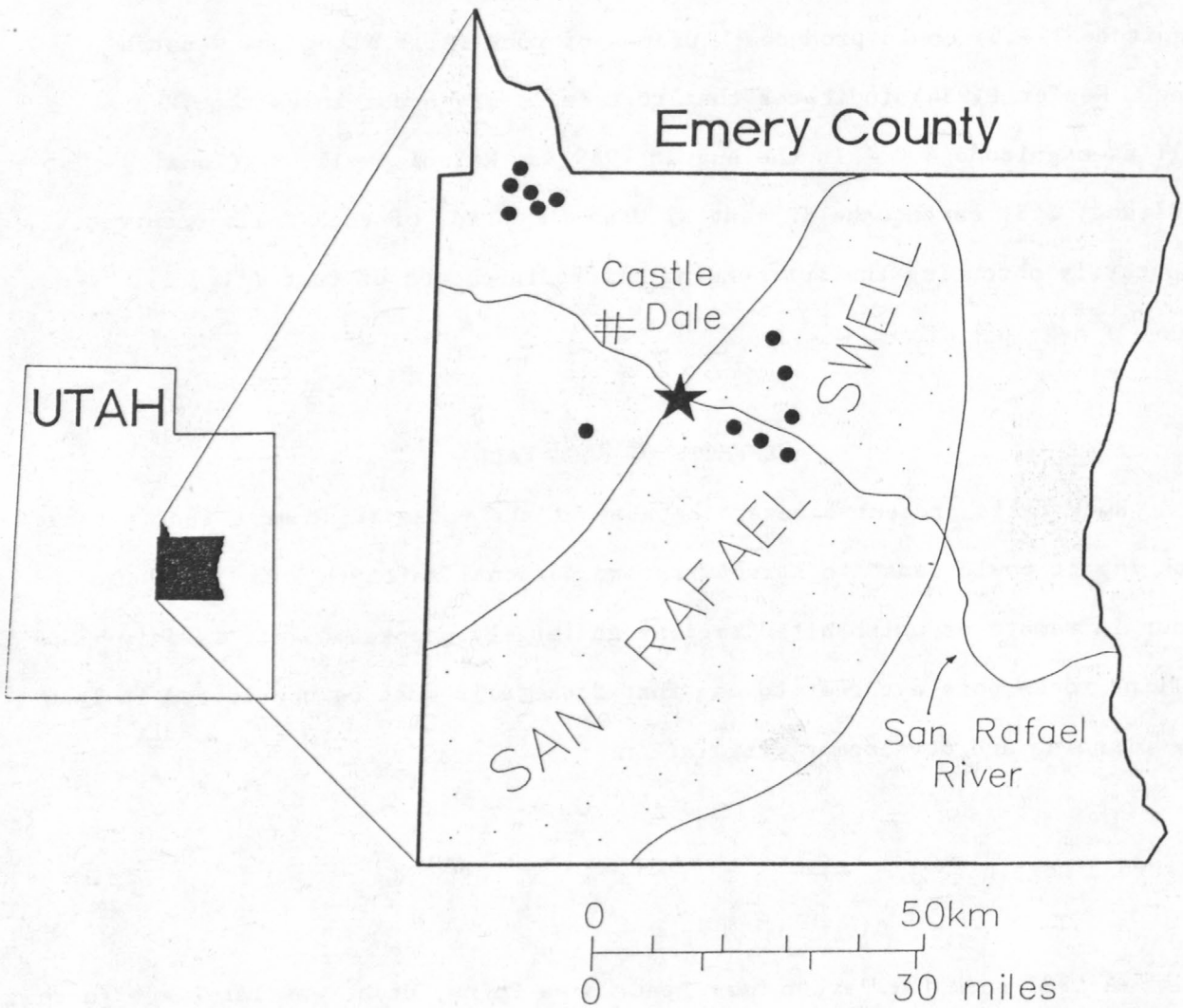

FIGURE 1. -- Location map of the August 14, 1988 San Rafael Swell, Utah earthquake, M_L 5.3, which triggered rock falls up to 30 miles from the epicenter. The star represents the location of the main shock, the solid dots represent individual rock-fall locations. (Modified from Case, 1988, and Nava and others, 1988).

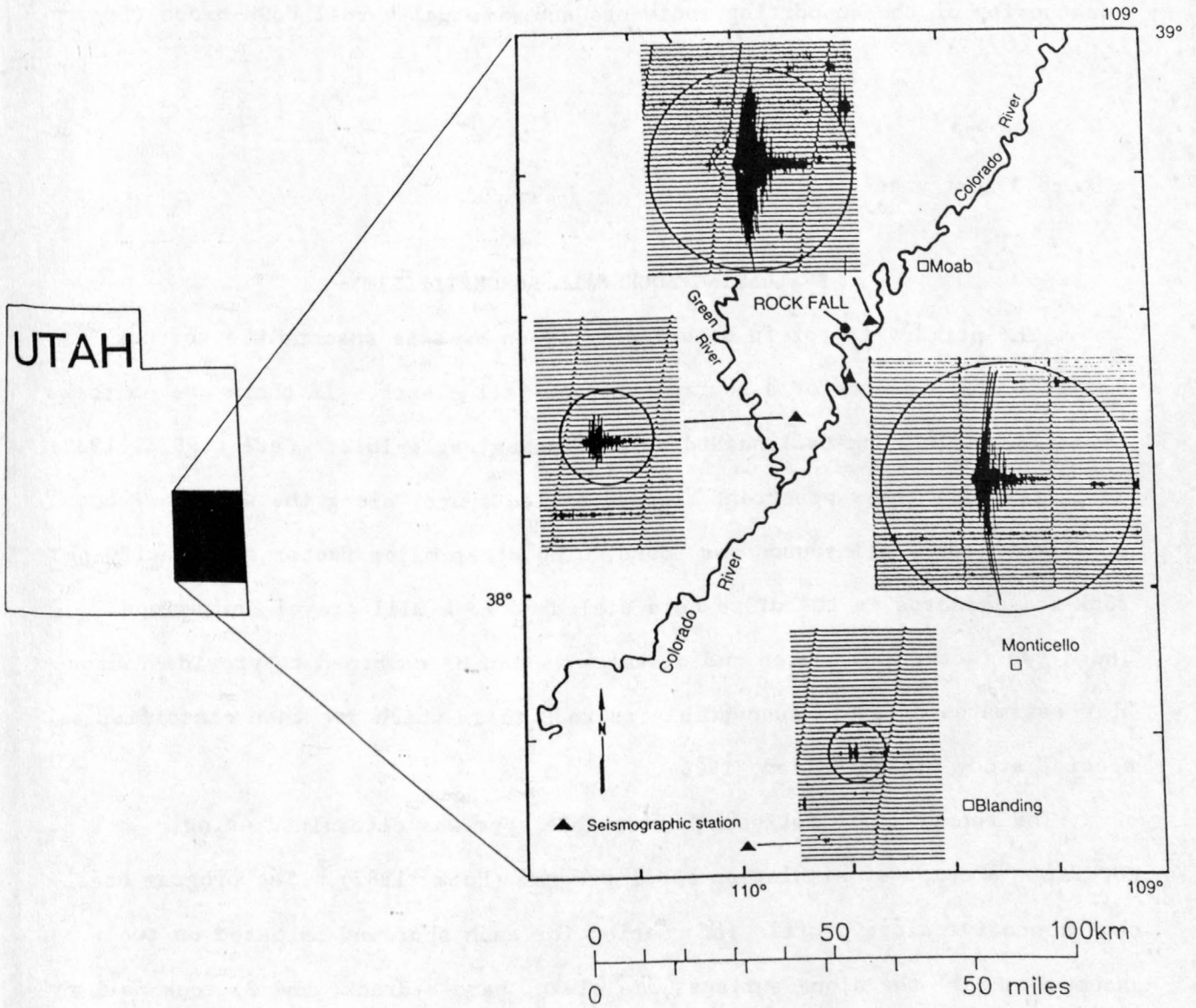

FIGURE 2. -- Location map of the July 3, 1984 Dead Horse Point rock fall which registered on seismographs over 60 miles away (Modified from Case, 1987b).

canyons has been periodically suspended due to damage to aqueducts from falling rocks. Homes built along the mountain front are also subject to rock falls. Development in some high foothill subdivisions in northeastern Salt Lake City has exposed boulders that gradually become unstable through weathering of the supporting sediments and eventually roll down-slope (fig. 3).

Figure 3 next page

EVALUATING ROCK FALL SUSCEPTIBILITY

The primary factor in determining if an area is susceptible to rock falls is the presence of a source for rock-fall clasts. If there are no rocks on a slope, the rock-fall hazard below becomes negligible. Case (1987c, 1989) identified all the range-front slopes, called spurs, along the Wasatch Front on which a rock-fall source was found. The other major factor in identifying rock-fall hazards is the distance a dislodged rock will travel down-slope. These two factors -- source and distance -- can be combined to provide reasonable estimates of areas susceptible to rock falls which are then classified as special study areas (Nelson, 1988).

The runout limit for each susceptible spur was determined using ROCKFALL, a computer simulation model program (Hoek, 1987). The program uses representative slope profile information for each spur and is based on two assumptions: 1) the slope surfaces are clean, hard bedrock, and 2) rock fall is initiated from a 20-ft high outcrop. Rock-fall events were simulated originating both at the top of each spur, and at the steepest point on the spur. Rocks were started 1) with no initial velocity (simple gravity fall), and 2) given an initial velocity (throw)(fig. 4). The combination of these

CRASS CLAST CRASHES CLAMBAKE!

A barbeque party was rudely interrupted when a boulder two feet in diameter made a social comment by landing on the grill. The incident occurred the evening of 5 July, 1987, in the backyard of a house in the high avenues of Salt Lake City on North Cliff Drive. The rockfall clast originated from a back yard on North View Drive which is perched on a sand and gravel slope deposited by Ice-Age Lake Bonneville when it was at the Bonneville Level (5090 feet).

Craig V. Nelson, Salt Lake County Geologist, reported that the county was first notified when the owner of the barbeque grill asked about possible legal retribution. Craig, and Salt Lake City Environmental Planner Robert H. Buchanan, visited the scene of the crime on the 10th of July but missed seeing the culprit rock, presumably because it was retrieved by its previous owner.

Other boulders, partially hidden in weeds, appeared to be ready to follow their sibling and crash a party of their own. Slopes in the area were oversteepened when toes were removed during home construction. Erosion of the slope is gradually exposing large boulders which eventually must live down to their potential energy. Craig recommended a taller railroad tie retaining wall to prevent other social interruptions.

Interesting legal precedents, albeit small scale, may be set by the incident. Should the upslope owner be responsible for "acts of God" and replace the barbeque grill? Who owned the recalcitrant intruder, the source person or the receivership plaintiff?

There are copious boulders on retreating, oversteepened, slopes in the neighborhood to cause a recurrence of the problem. ■

FIGURE 3. -- Article from UGMS Survey Notes, Spring 1987.

factors (origination point and initial velocity) that yielded the longest runout distance was used as the lower limit of the special study area. It is believed that this represents a worst-case rock-fall event and provides some margin of safety.

Figure 4 next page

The Salt Lake County Hillside Protection Zone ordinance prohibits building on slopes over 30 percent; therefore all slopes over 30 percent automatically fall into the special study area. The rock-fall analyses suggest that, in general, most rocks would stop above the 30 percent slope break, making this slope the lower boundary of the study area. The runout continued below the 30 percent slope break onto gentler slopes on only 19 percent of the spurs. The special study area boundary between spurs follows the 30 percent slope break and includes all canyon areas. No studies have been performed in canyons, and there all slopes are considered susceptible.

REDUCING ROCK FALL HAZARDS

When faced with any geologic hazard the best alternative, where feasible, is avoidance. Therefore, it is best for developers to first try to locate buildings so that structures are not positioned in an area susceptible to rock falls. Often, however, new developments cannot be designed around a rock-fall path or the rock-fall paths cannot be accurately predicted, so hazard-reduction measures must be considered. When faced with land-use decisions, the costs of hazard reduction should be carefully compared to the costs of avoidance.

Techniques for reducing rock-fall hazards may include mitigation of the

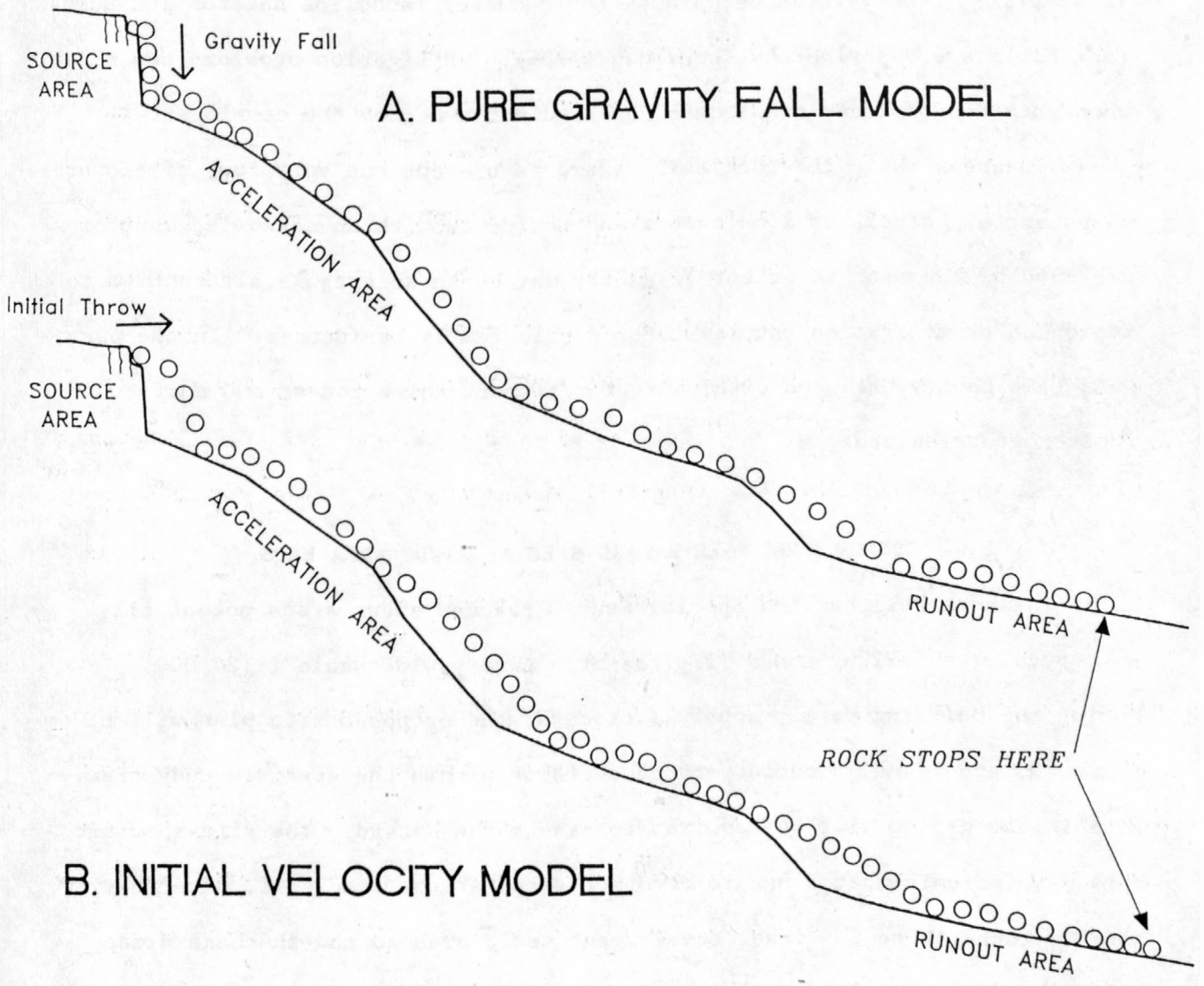

FIGURE 4. -- Example of the output model generated by the computer program ROCKFALL (Hoek, 1987) for a rock-fall event on a generalized slope. The total rock runout distance is estimated in A given no initial velocity (pure gravity fall), and in B given an initial velocity (throw).

actual hazard or modifying the exposed structure or facility. Rock stabilization techniques such as bolting, cable lashing, burying, and grouting discontinuities; and removal or break-up of potential rock-fall clasts are all physical methods of mitigating the hazard. Deflection berms, slope benches, and rock-catch fences may all stop or at least slow down falling rocks. Strengthening a structure to withstand impact is an example of modifying what is at risk. Twenty-seven techniques for reducing landslide hazards including rock falls are described by Kockelman (1986). Mitigation problems can arise when rock source areas are located on land not owned by the developer.

In areas where the rock-fall hazard is present but very low, disclosure of potential hazards to land owners and residents with an acknowledgment of risk and willingness to accept liability may be an acceptable alternative to avoidance or mitigation, at least for single family residences. In the past, Salt Lake County has used disclosure for airport noise zones, and surface fault rupture hazards.

USE OF ROCK-FALL HAZARD SPECIAL STUDY AREA MAPS

The Rock-Fall Hazards Special Study Area map shows areas potentially susceptible to falling rocks (fig. 5) at a county-wide scale (1:24,000). During the building permit approval process, the proposed site plan will be reviewed, and if any proposed structure falls within the special study area, a site investigation will be required to assess the hazard. The site-specific data may indicate that a hazard does not exist at the site. If, after review, this is found to be the case, development would proceed and the hazard map will be amended. Should the site-specific data indicate that a rock-fall hazard exists, the consultant should give recommendations for avoiding or reducing the hazard, and include these considerations in the site plan.

Regardless of the conclusions, results of the site-specific study should be submitted to the county geologist for review. A report discussing this review process has been prepared (Nelson and others, 1987), and is available from the county geologist. The Salt Lake County Planning Commission considers the recommendations of planning staff and consultants and makes the final decision for approval of developments.

It is important that geological input be used early in the development process. In the past, developers have faced considerable expense in redesigning subdivisions around geologic problems. The astute real-estate purchaser often seeks geological counsel prior to making an offer, or makes a favorable geologic report a contingency of purchase. The hazard maps may also prove useful to private citizens and real-estate agents by providing information needed to make an informed decision in the purchase of property.

Figure 5 next page

SCOPE OF SITE INVESTIGATIONS

When development is proposed within the Rock-Fall Hazard Special Study Area, a qualified engineering geologist or licensed geotechnical engineer must be employed to assess the site-specific rock-fall hazard. Site investigations must define rock fall sources and estimate runout paths and runout distances from each source. Rock-fall sources may be outcrops or individual clasts on a slope. Size, shape, depth of burial, and slope geometry are all factors to be considered in defining sources as well as runout path and distance. Computer models are available to simulate runout (Hoek, 1987; Pfeiffer and Bowen, 1989), but physical evidence such as extent of clast accumulations below sources, topographic configuration, damaged vegetation, and natural barriers

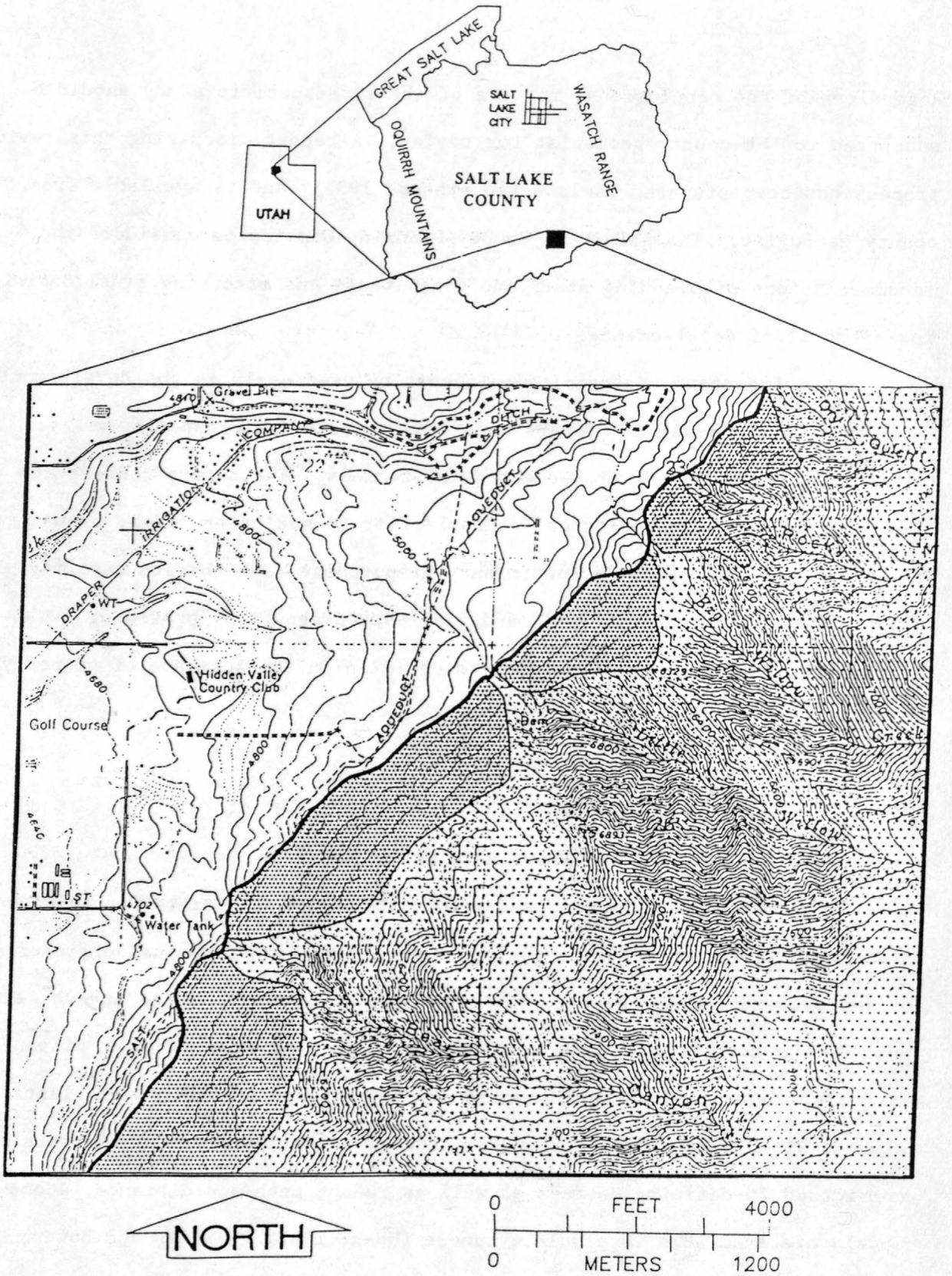

FIGURE 5. -- Portion of the Rock-Fall Hazards Special Study Area map in the Draper Quadrangle, southeast of Salt Lake City, Utah. Areas requiring site-specific investigations are stippled. Range-front source areas (spurs) are the darker shaded regions.

are also important to consider.

SUMMARY

The objective of special study area hazard maps, and regulation during permit approval is not to restrict development, but to help ensure that when development does occur in geologically sensitive areas, the safety and property of citizens and their community is protected.

It must be realized that rock falls are a natural phenomena and not every rock-fall event can be accurately modelled. Therefore, the rock-fall special study areas are a best estimate of the probable hazard area. The hazard map is a regional, small scale map suitable for indicating potential hazard areas. The map is not intended to substitute for site-specific data. As improved analytical tools become available, and the results of site-specific studies are completed, the hazard map will be updated.

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REFERENCES

Case, W. F., 1987a, Rock fall hazards in Utah's urban corridor: Geological Society of America Abstracts with Programs, v. 19, no. 7, p. 614.

Case, W. F., 1987b, Dead Horse Point rock fall recorded on seismograph: Utah Geological and Mineral Survey - Survey Notes, v. 21, no. 4, p .5.

Case, W. F., 1987c, Rock fall hazard susceptibility due to earthquakes, central Wasatch Front, Utah: U.S. Geological Survey Open-File Report 87-585, p. V1-V36.

Case, W. F., 1988a, Geology effects of the 14 and 18 August, 1988 earthquakes in Emery County, Utah: Utah Geological and Mineral Survey - Survey Notes, v. 22, no. 1-2, p. 8-15.

Case, W. F., 1989, Rock-fall hazards in Cache, Salt Lake, and Tooele valleys, Wasatch Front, Utah: Utah Geological and Mineral Survey, in preparation, scale 1:24,000.

Costa, J. E., and Baker, V. R., 1981, Surficial Geology - Building With The Earth: John Wiley and Sons, New York, New York, 498 p.

Hoek, E., 1987, ROCKFALL - A program in BASIC for the analysis of rockfalls from slopes: Unpublished NSERC Industrial Research Professor report July 1, 1987, Toronto, Ontario, 10 p.

Keefer, D. K., 1984, Landslides caused by earthquakes: Geological Society of America Bulletin, v. 95, p. 402-421.

Kockelman, W. J., 1986, Some techniques for reducing landslide hazards: Bulletin of the Association of Engineering Geologists, v. 23, no. 1, p. 29-52.

Nava, S.J., Pechman, J.C., and Arabasz, W.J., 1988, The magnitude 5.3 San Rafael Swell, Utah earthquake of August 14, 1988: Utah Geological and Mineral Survey - Survey Notes, v. 22, no. 1-2, p. 16-19.

Nelson, C. V., Christenson, G. E., Lowe, Mike, and Robison, R. M., 1987, The review process and adequacy of engineering geologic reports Wasatch Front, Utah, in McCalpin, James, ed., Proceedings of the 23rd Annual Symposium on Engineering Geology and Soils Engineering: Utah State University, April 6-8, 1987, p. 83-85.

Nelson, C. V., 1988 Preparation and use of earthquake groundshaking and rock-fall hazard maps, Wasatch Front, Utah: Geological Society of America Abstracts with Programs, v. 20, no. 6, p. 459.

Pfeiffer, T.J., and Bowen, T.D., 1989. Computer simulation of rockfalls: Bulletin of the Association of Engineering Geologists, v. 26, no. 1, p. 135-146.

DEBRIS-FLOW HAZARDS: A GUIDE FOR LAND-USE PLANNING, DAVIS COUNTY, UTAH

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ABSTRACT

Debris flows, debris floods (hyperconcentrated streamflows), and clear-water flooding form a continuum of sediment and water mixtures which may be hazardous to development on alluvial fans. Debris flows can be generated either by scouring soil materials from the ground surface and stream channels during rainstorms, or by adding water to debris slides until they are fluid enough to reach a flowing stream. In Davis County, debris flows and debris floods have occurred often historically and have caused loss of life and significant damage to property.

Debris-flow hazards (including hyperconcentrated-streamflow hazards) in Davis County are mapped at a scale of 1:24,000 using U. S. Geological Survey 7 1/2 minute (topographic) quadrangles as base maps. It is recommended that debris-flow hazards be evaluated, and if necessary hazard-reduction measures required, prior to planning commission approval of new development proposed within the debris-flow hazard area depicted on these maps.

INTRODUCTION

Debris flows are mixtures of water, rock, soil, and organic material (70-90 percent solids by weight) that form a muddy slurry much like wet concrete, and flow downslope, commonly in surges or pulses, due to gravity. They generally remain confined to stream channels in mountainous areas, but may reach and deposit debris over large areas on alluvial fans at and beyond canyon mouths. The eastern portion of Davis County is particularly susceptible to debris-flow hazards because of the steep mountains and the weathering characteristics of the bedrock (the Precambrian Farmington Canyon Complex) which provides much unstable hillside debris (Wieczorek and others, 1983; Pack, 1985). Debris flows have occurred often in Davis County during historical time and have caused damage to property and loss of life (table 1). It is the purpose of this report to discuss: 1) the nature of

Table 1 next page

debris-flow hazards in Davis County; 2) the potential consequences; 3) Davis County Debris-Flow Hazard Special Study Zone Maps; and 4) recommendations regarding use of the maps for land-use planning. A major goal is to translate technical information so that government officials and the general public can appreciate the need to reduce debris-flow hazards. The Debris-Flow Hazard Special Study Zone Maps, which were

Table 1. Historical Davis County debris flows (from Marsell, 1972; Wieczorek and others, 1983; and U.S. Army Corps of Engineers, 1984).

DRAINAGE	YEARS	REPORTED DAMAGE OR LOSS OF LIFE
Dry Fork, Kays Creek	1984	house damaged.
Middle Fork, Kays Creek	1947, 1953	
South Fork, Kays Creek	1912, 1923, 1927, 1945, 1947	
North Fork, Holmes Creek	1983	
South Fork, Holmes Creek	1917	
Baer Creek	1983	
Shepard Creek	1923, 1930, 1983	
Farmington Creek	1878, 1923, 1926, 1930, 1947, 1983	1923 - 7 deaths, several houses damaged.
Rudd Creek	1983, 1984	1983 - 35 houses damaged, 15 severely.
Steed Creek	1923	
Davis Creek	1878, 1901, 1923	
Ricks Creek	1923, 1929, 1930	1923 - 1 house damaged, 1930 - 1 house damaged.
Parrish Creek	1930 (several events)	several houses destroyed, school damaged.
Stone Creek	1983	houses damaged.
Mill Creek	1983	

constructed from the boundaries of active alluvial fans and areas with slopes steeper than 30 percent, identify areas where debris-flow hazards should be evaluated prior to approval of proposed development.

NATURE AND CAUSES OF DEBRIS FLOWS

Although this report chiefly addresses debris flows, other forms of flow are also considered because debris flow, debris flood (hyperconcentrated streamflow), and normal streamflow form a continuum of sediment/water mixtures that grade into each other as the relative proportion of sediment to water changes and as stream gradient changes (Pierson and Costa, 1987). Deposition of sediment transported by these types of flows ultimately takes place on alluvial fans at and beyond canyon mouths. Deposition on alluvial fans is caused by the decrease in channel gradient and increase in channel area, resulting in a decrease in depth and velocity of flow and an increase in internal friction of the flowing debris as the stream leaves its constricted channel and enters the main valley floor (Jochim, 1986).

Debris flows can form in at least two different ways. In mountainous eastern Davis County, where cloudburst rainstorms are common, overland flow and flood waters can scour materials from the ground surface and stream channels, thereby increasing the proportion of soil materials to water until the mixture becomes a debris flow (Wieczorek and others, 1983). The size and frequency of debris-flow events generated by

rainfall are dependent upon several factors including the amount of loose material available for transport, the magnitude and frequency of the storms, the density and type of vegetative cover, and the moisture content of the soil (Campbell, R. H., 1975; Pack, 1985; Wieczorek, 1987). Debris flows during the 1920s and 1930s in Davis County were generated by overland erosion during summer cloudburst storms which fell on watersheds depleted of vegetative cover by overgrazing and burning (Copeland, 1960).

Debris flows can also mobilize directly from debris slides. A debris slide is a type of landslide in which the material involved is predominantly coarse-grained debris, chiefly colluvium, and the form of movement is mainly translational (Varnes, 1978). A debris flow may be generated when the debris slide reaches a stream, or when the water content is increased in the debris slide by some other means until sufficient to permit flow. Debris flows during the springs of 1983 and 1984 in Davis County were mobilized from debris slides caused by rapid melting of an unusually thick snowpack (Wieczorek and others, 1983).

As the relative proportion of water to sediment increases with either the addition of more water or removal of sediment by deposition, debris flows become hyperconcentrated streamflows. Hyperconcentrated streamflows are often referred to as debris floods or mud floods. In hyperconcentrated streamflow, soil materials are transported by fast-moving flood waters (Wieczorek and others, 1983). Solids account for

40% to 70% of the material by weight. These flows can originate either by progressive incorporation of materials by flood waters or by dilution of debris flows (Waitt and others, 1983; Wieczorek and others, 1983). Because of difficulties in distinguishing hyperconcentrated streamflow from flood stages of normal streamflow, there is no adequate record of historical hyperconcentrated-streamflow events in Davis County.

In normal streamflow, solids account for less than 40% of the water/sediment mixture by weight. Snowmelt flooding in Davis County is a nearly annual event and abnormally high snowmelt floods occurred in Davis County in 1922, 1952, 1983, and 1984. Snowmelt-induced flood magnitudes are somewhat predictable and depend on the volume of snow in the mountains and the rate of temperature increase in the spring. Summer cloudburst floods account for more localized but often very destructive flooding and can occur with little warning. Davis County experienced 39 cloudburst floods between 1850 and 1969 (Butler and Marsell, 1972). The clear-water flooding hazard has been significantly reduced in recent years by the construction of flood detention structures and improvements in storm-sewer systems and stream channels.

EFFECTS OF DEBRIS FLOWS

Loss of life during debris-flow, hyperconcentrated-streamflow, and normal-streamflow events may result from

drowning, high-velocity impact, or burial. Figure 1 indicates the areas on alluvial fans most likely to be affected and the types of hazards associated with each type of flow. Damages associated with debris flows have been described by Campbell (1975). The effects on residential structures range from simple inundation to complete destruction by high-velocity impact. The velocity of a debris flow is an important consideration in determining the level of damage to structures. Many debris flows move with speeds on the order of 27 mi/h (40 ft/sec, 12 m/sec), but others move as slowly as 1 ft/sec (.305 m/sec) as they flow down relatively gentle slopes. Debris flows of sufficient volume and momentum have destroyed residential structures and moved the remains off their foundations. Debris flows of relatively small volume but high momentum have broken through outside walls and even completely through structures. Low-velocity debris flows may enter dwellings through open doors or push laterally through windows and doorways and flood interiors. All three types of flows may fill basements with mud, water, and debris, or pile debris around structures. Debris may also bury yards, streets, parks, driveways, parking lots, and any ground-level structure. In the distal portions of the alluvial fans, damage is usually comparatively minor, consisting primarily of mud and water damage to outer walls of buildings, basements, and yards. Keaton and others (1988) have devised an intensity scale, generally related to thickness of deposition, for damages associated with debris-flow events (table 2). This

table gives a good indication of the types and severity of potential damage.

Table 2 next page

DEBRIS-FLOW HAZARD REDUCTION

Methods for reducing debris-flow hazards include: 1) avoidance; 2) source-area stabilization; 3) transportation-zone (debris-flow track between the source area and the depositional zone) modification; and 4) defense measures in the depositional zone (Hungr and others, 1987). Different methods or combinations of methods may be appropriate for different drainages or types of development.

Debris-flow hazards may be reduced by avoiding, either permanently or at the time of imminent danger, areas at risk from debris flows (source areas, transportation zone, and depositional zones). Permanent avoidance is not possible in some areas because many Davis County cities have large numbers of existing structures on active alluvial fans (potential depositional zones) where damage due to debris flows may occur. Permanent avoidance of debris-flow hazards could be required for proposed new development in most Davis County cities through enforcement of existing foothill-development (zoning) ordinances, but this is generally not politically acceptable unless other mitigation techniques are not

Table 2. Proposed alluvial-fan sedimentation intensity scale, from Keaton and others (1988).

Intensity	Damage	Description
0	None	No damage.
1	Negligible	Damage to landscape and access; no damage to structures; minor scour and/or sediment deposition.
2	Slight	Sediment generally less than 3.3 ft (1 m) thick deposited against buildings without structural damage; sediment flooded around parked vehicles.
3	Moderate	Sediment generally greater than 3.3 ft (1 m) thick deposited against buildings with easily repairable structural damage; basements partially filled with with sediment; parked vehicles shoved by sediment with repairable damage.
4	Severe	Sediment greater than 3.3 ft (1 m) thick deposited against buildings with repairable structural damage; basements completely filled with sediment; wood structures detached from foundations; parked vehicles shoved by sediment with nonrepairable damage (e.g., distorted frames).
5	Extreme	Sediment greater than 3.3 ft (1 m) thick deposited against buildings with nonrepairable damage; structures collapsed by force (drag or impact) of flow; wood structures shoved from foundations; parked vehicles so badly damaged that they have small salvage value.

feasible.

Warning systems may be used to avoid debris-flow hazards at the time of imminent danger, generally through evacuation of threatened areas. Hungr and others (1987) identify three categories of debris-flow warning systems: pre-event, event, and post-event. Pre-event warning systems are designed to identify periods of time when climatic conditions have increased the potential for debris-flow occurrence. Davis County has established a computer-linked remote weather station ALERT system which allows real-time evaluation of rainfall, wind, soil-moisture, streamflow, and landslide-movement data. Although this ALERT system has not yet been used to predict debris-flow events, this may be possible in the future as the relationship between between climatic conditions and the initiation of debris flows in Davis County becomes better understood. The purpose of an event warning system is to provide an alarm when a debris-flow event is occurring (Hungr and others, 1987). Two types of event warning systems are being implemented in Davis County. Computer-linked remote extensometers have been used to monitor real-time movement of detached landslides in Rudd and Baer Canyons. Computer-linked remote streamflow gages, which have been placed on most Davis County streams, can sound alarms if streamflow drops below or rises above preset levels. In both cases, the event warnings are designed to alert Davis County Flood Control and Davis County Sheriff Department personnel of potential debris-flow events. Post-event warning systems,

such as slide-warning fences, are usually designed to warn of disruption of transportation routes (Hungr and others, 1987). This type of warning system has not been used in Davis County where most transportation routes are in urban areas, and where mass-media warnings, barricades, and detours have been sufficient in the past.

Source-area stabilization consists of reducing the amount of hillside material available for incorporation into debris-flow or hyperconcentrated-streamflow events. Improving drainage-basin vegetation is one method of source-area stabilization. The prevention of wildfires and forest fires combined with protection against overlogging and overgrazing will protect existing vegetation. Terracing of mountain slopes, such as was done in the 1930s in Davis County by the Civilian Conservation Corps under the supervision of the U. S. Forest Service (Bailey and Croft, 1937), is useful in preventing debris flows caused by erosion during cloudburst storms. Landslide events on oversteepened slopes comprising the source-area scars of former debris flows may be the source of additional hillside material during future landslide-initiated debris-flow events (Baldwin and others, 1987). Landslide-mitigation techniques have been used in California to reduce debris-flow hazards. These techniques include: 1) control of subsurface drainage; 2) diversion of surface drainage, 3) grading of source-area scars to a uniform slope, 4) riprap repair of the source-area scar, and 5) retaining walls (Baldwin and others, 1987). Stabilization of source areas for landslide-initiated debris flows has not been

attempted in Davis County.

Transportation-zone modifications are generally designed to reduce the incorporation of channel material into debris flows and improve the ability of the channel to pass debris surges downstream. Scour of loose material in stream beds and undercutting of unstable stream banks are two of the most important processes of debris-flow-surge growth (Hungr and others, 1987). Check dams (small debris-retention structures placed in unstable channel areas to prevent incorporation of material from that part of the channel into debris flows) are used extensively in Europe and Japan to arrest or reduce debris-flow surges (Hungr and others, 1987). Stabilization of the stream bed may also be achieved by lining the channel. The ability of stream channels to pass debris surges downstream may be improved through: 1) removal of channel irregularities; 2) enlargement of culverts combined with installation of upstream removable grates to prevent blockage; and 3) construction of flumes, baffles, deflection walls, and dikes (Jochim, 1986; Baldwin and others, 1987). Structures crossing potential debris-flow channels may be protected by: 1) bridging the channels with sufficient clearance to allow debris surges to pass under structures; 2) construction of debris sheds designed to allow debris flows to pass over structures; and 3) designing structures to withstand debris-flow impact, burial, and reexcavation (Hungr and others, 1987). Transportation-zone modifications in Davis County have been restricted to some stream channels below canyon mouths

and consist mainly of dikes and deflection walls constructed in the 1920s and 1930s, and removal of channel irregularities and lining of channels in the 1980s. Stream channels above canyon mouths have generally not been modified.

The purpose of defense measures in the deposition zone is to control the areal extent of deposition and to design any structures located there so that damage is controlled when deposition takes place (Hungr and others, 1987). Defense measures include deflection devices, impact walls, and debris basins. Deflection devices are used to control the direction and reduce the velocity of debris flows. Types of deflection devices include: 1) pier-supported deflection walls; 2) debris fences (a series of steel bars or cables placed horizontally at increasing elevations above the stream channel); 3) berms; 4) splitting-wedge walls (reinforced concrete wall in the shape of a "V" with the point facing uphill); and 5) gravity structures like gabions (hollow wicker-works or iron cylinders filled with earth) (Baldwin and others, 1987; Jochim, 1986). Impact walls are designed to sustain the instantaneous force of impact from debris flows while containing the soil and vegetation debris until it can be removed (Baldwin and others, 1987). This impact force may be as high as 125 lb/ft3 (19,640 N/m3) (Hollingsworth and Kovacs, 1981). Types of impact walls employed in the United States include concrete walls, soldier pile walls, and soil and/or rock gravity walls (including gabions) (Baldwin and others, 1987). Two types of debris basins, open and closed, are commonly employed to reduce debris-flow hazards. Both types are designed to constrain the

natural deposition area of a debris flow to predetermined limits laterally, upstream, or downstream (Hungr and others, 1987). Open debris basins commonly have a basin-overflow spillway designed to direct excess material to an insensitive area or back into the stream channel, but straining outlets to remove water from entrapped debris are not generally provided. Closed debris barriers and basins need not be located in the deposition zone or on the debris fan (Hungr and others, 1987). A suitable location is chosen along the lower part of the debris-flow path, a barrier erected across it, and a basin created behind. The barrier is provided with both a straining outlet to pass water discharges and a spillway to handle emergency debris overflow (Hungr and others, 1987). Both types of debris basins require access for removal of entrapped debris and maintenance. Debris basins, both open (constructed in the 1930s) and closed (constructed in the 1980s), are the primary debris-flow hazard-reduction technique employed in Davis County. Figure 1 shows the location of these debris basins. The Davis County debris basins vary greatly in storage capacity and their adequacy to contain various magnitude debris-flow events has generally not been evaluated.

Figure 1 next page

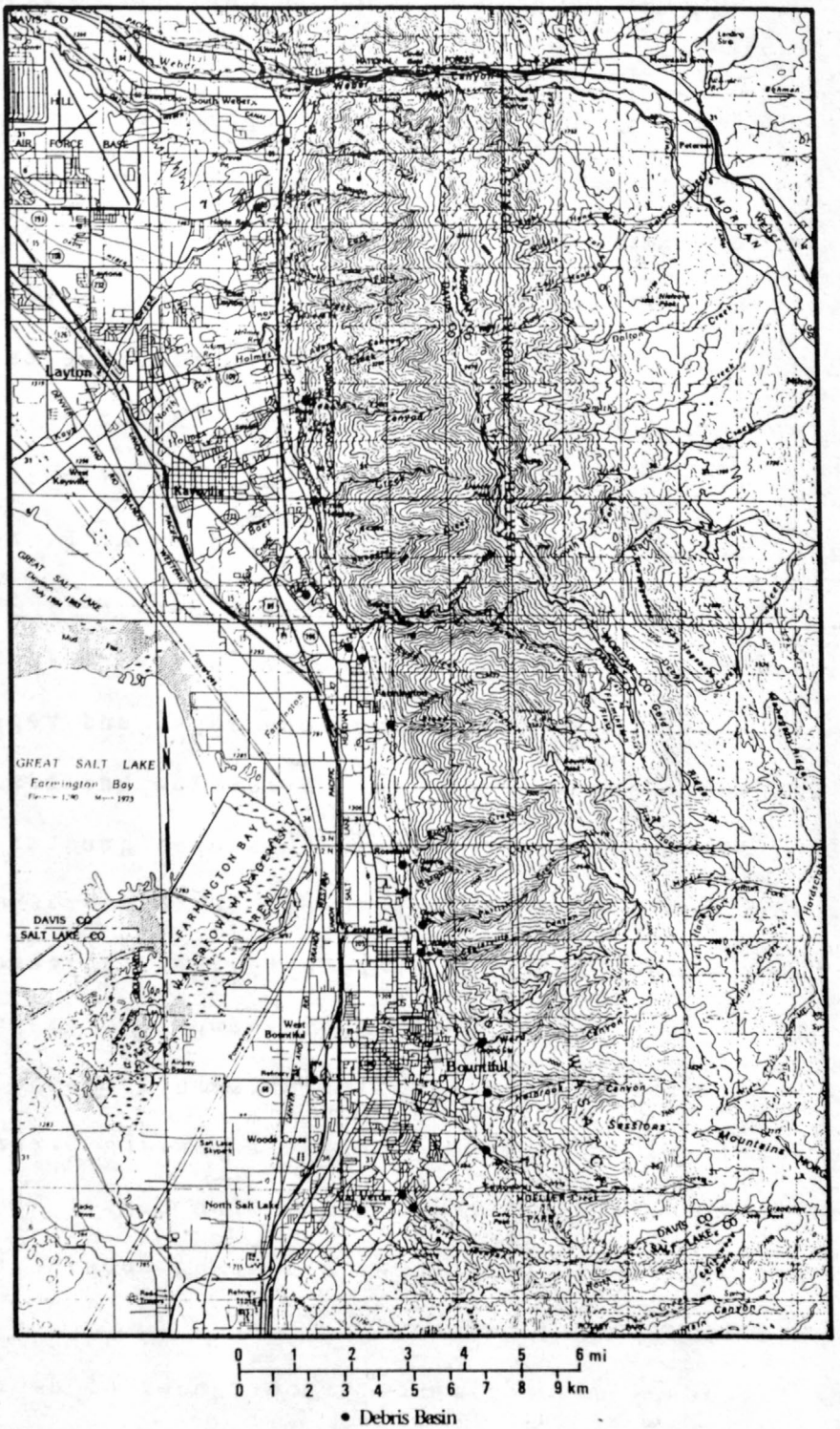

Figure 1. Location map for Davis County debris basins.

SUMMARY OF METHODS USED IN MAP PREPARATION

Preliminary surficial geologic mapping by A. R. Nelson and S. F. Personius (unpublished mapping, 1987) was used to define debris-flow hazard areas at the mountain front. These maps differentiate active alluvial fans, where deposition during debris-flow and hyperconcentrated-streamflow events may occur, from areas not subject to debris flows, including older fans which are no longer active. Upper Holocene alluvial fans and undivided young alluvial fans, as mapped by A. R. Nelson and S. F. Personius (unpublished mapping, 1987), were combined and redesignated younger Holocene (active) alluvial fans on the Debris-Flow Hazard Special Study Zone maps, and represent areas considered susceptible to debris-flow hazards. In addition, all mountainous areas with slopes greater than 30 percent are considered to be susceptible to debris-flow initiation. Mountain front spurs are likely to generate debris flows only during periods of snowmelt or rainfall. The adequacy of existing debris basins or structures built to divert debris flows were not considered during preparation of the Debris-Flow Hazard Special Study Zone Maps. The existence and adequacy of these structures should be considered for site-specific studies, however.

The frequency of occurrence (recurrence) of debris-flow events in a drainage basin depends upon climatic factors as well as the availability of debris. Recurrence intervals vary among drainage basins and depend on the magnitude of the event (volume of sediment transported). For example, the recurrence

interval for sedimentation events exceeding 40,000 yd3 (30,600 m3) of material deposited at the Ricks Creek debris basin has been calculated to range between 55 and 1,590 years, but the recurrence interval for sedimentation events exceeding 65,000 yd3 (49,700 m3) of material deposited at the Rudd Creek debris basin has been calculated to range between 155 and 5,845 years (Keaton and others, 1988). These numbers are significant because the volumes given represent the capacity of debris basins constructed at the mouths of Ford (Ricks Creek) and Rudd Canyons, respectively (Keaton and others, 1988). Recurrence intervals for different magnitude debris-flow events are not currently available for the other Davis County drainages.

RECOMMENDED USE OF MAPS IN LAND-USE PLANNING

The Debris-Flow Hazard Special Study Zone maps (figures 2 and 3) show areas where site-specific studies addressing debris-flow hazards are recommended prior to development.

Figure 2 and 3 next page

These maps are at a scale of 1:24,000 and are designed to show potential hazard areas for planning purposes only. It is recommended that debris-flow hazards be evaluated and, if necessary, hazard reduction measures recommended in site-

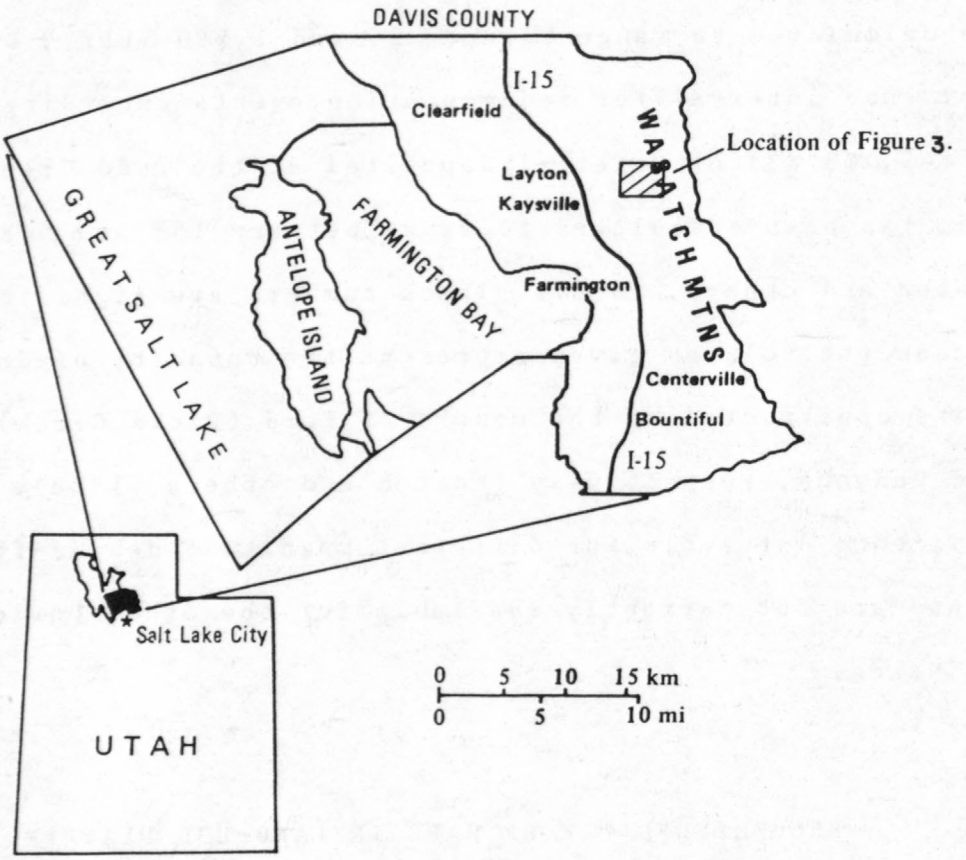

Figure 2. Location map for figure 3.

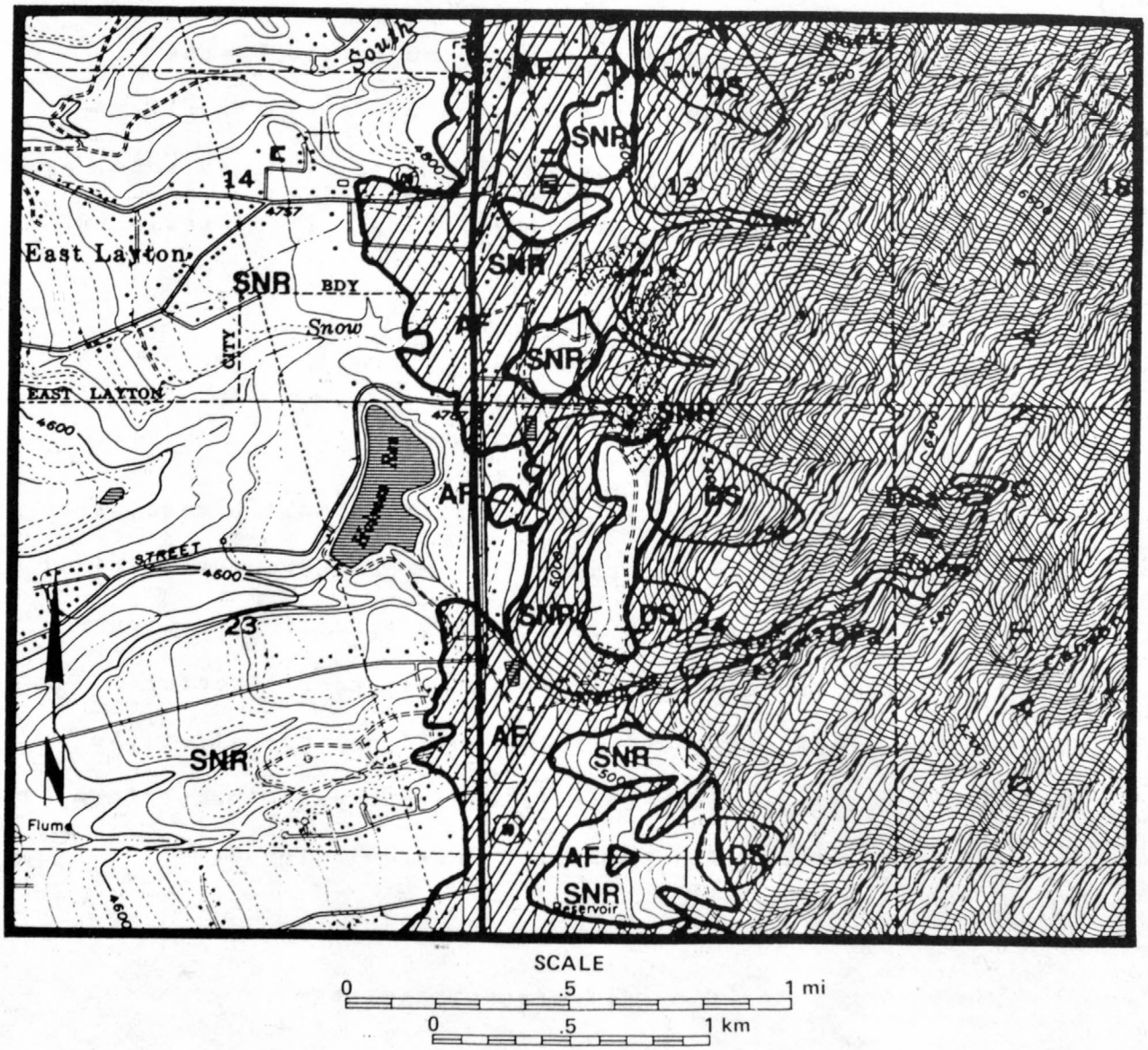

Figure 3. Example of a Debris-Flow Hazard Special Study Zone Map. Area shown is the east Layton area of northern Davis County, Utah. Cross-hatching indicates areas where debris-flow hazards studies are recommended prior to planning commission approval of proposed development. SNR = area where debris-flow studies should not be required, DS = debris slide, DF = debris flow, a = active (historic) slope failure, AF = younger Holocene (active) alluvial fan. This figure was reproduced from a portion of the Debris-Flow Hazard Special Study Zone Map, Kaysville Quadrangle, Davis County, Utah, and is based on information from the following sources: A. R. Nelson and S. F. Personius (unpub. mapping, 1987); G. Kappeser, written commun., 1986; Bryant, 1984; Olson, 1981; and M. Lowe (unpub. mapping, 1987).

specific engineering geologic reports submitted by the developer prior to planning commission approval for all construction in the debris-flow hazard special study zone, as shown in table 3. Because of the relatively small scale of

Table 3 next page

the maps, the possibility exists that some small hazard areas are not shown; studies are therefore recommended for critical facilities even outside the debris-flow special study zones. The importance in terms of life-safety of such structures merits this precaution, and studies need only consider the hazard and either confirm that it does not exist or perform the necessary study if a potential hazard is found.

SCOPE OF SITE INVESTIGATIONS

The scope of investigation for site-specific reports evaluating debris-flow hazards for proposed development should include: 1) an analysis of the drainage basin's potential to produce debris flows based on the presence of debris slides and colluvium-filled slope concavities, and an estimate of the largest probable volumes likely to be produced during a single event; 2) an analysis of the stream channel to determine if the channel will supply additional debris, impede flow, or contain debris flows in the area of the proposed development;

Table 3. Matrix indicating recommended report requirements for debris-flow hazards, Davis County, Utah.

Type Of Development	Debris-Flow Hazard Special Study Zone	
	Inside	Outside
Critical facilities, such as lifelines and high-occupancy buildings	Yes*	Yes*
Industrial & commercial buildings (other than high-occupancy)	Yes+	No
Residential subdivisions	Yes+	No
Residential - single lots	Yes+	No

*If a debris basin is present above site, debris-flow special study must address adequacy of debris basin, both in terms of design and maintenance.

+If a debris basin is present above the site, debris-flow special studies are not required.

3) an analysis of man-made structures upstream that may divert or deflect debris flows; and 4) recommendations concerning any channel improvements, flow modification and catchment structures, direct protection structures, or floodproofing measures, if necessary, to help protect the proposed development.

For critical facilities within the debris-flow hazard special study zone, the storage capacity of any debris basins upstream from the site to reduce the debris-flow hazard must be evaluated. The quality of debris-basin maintenance should also be addressed. The U. S. Army Corps of Engineers (1988) has evaluated the adequacy of many of the central Davis County basins to contain the 100-year debris-flow event volumes, but Davis County is challenging the methodology used in determining what those 100-year event volumes should be (Williams and others, 1988). Wieczorek and others (1983), Pack (1985), and Keaton and others (1988) identified factors to be considered when evaluating debris-flow hazards, and these references should be consulted when conducting site investigations. When site-specific reports are submitted, they should be reviewed by the county geologist and engineer and, once approved, forwarded to the planning commission along with review comments so that the planning commission has sufficient information to make decisions regarding the proposed development.

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REFERENCES CITED

Bailey, R. W., and Croft, A. R., 1937, Contour trenches control floods and erosion on range lands: Emergency Conservation Work Forestry Publication No. 4, U. S. Government Printing Office, Washington, D. C., 22 p.

Baldwin, J. E., II, Donley, H. F., and Howard, T. R., 1987, On debris flow/avalanche mitigation and control, San Francisco Bay area, California, in Costa, J. E., and Wieczorek, G. F., eds., Debris flows/avalanches: process, recognition, and mitigation: Geological Society of America Reviews in Engineering Geology, v. 7, p. 223-236.

Bryant, Bruce, 1984, Reconnaissance geologic map of the Precambrian Farmington Canyon Complex and surrounding rocks in the Wasatch Mountains between Ogden and Bountiful, Utah: U. S. Geological Survey Miscellaneous Investigation Series Map I-1447, 1:50,000 scale.

Butler, Elmer, and Marsell, R. E., 1972, Cloudburst floods in Utah, 1939-69: Utah Department of Natural Resources, Division of Water Resources, Cooperative Investigations Report No. 11, 103 p.

Campbell, R. H., 1975, Soil slips, debris flows, and rainstorms in the Santa Monica Mountains and vicinity, southern California: U. S. Geological Survey Professional Paper 851, 51 p.

Copeland, O. L., 1960, Watershed restoration: a photo-record of conservation practices applied in the Wasatch Mountains of Utah: Journal of Soil and Water Conservation, v. 15, no. 3, p. 105-120.

Hollingsworth, Robert, and Kovacs, G. S., 1981, Soil slips and debris flows; prediction and protection: Association of Engineering Geologists Bulletin, v. 18, no. 1, p. 17-28.

Hungr, Oldrich, VanDine, D. F., and Lister, D. R., 1987, Debris flow defenses in British Columbia, in Costa, J. E., and Wieczorek, G. F., eds., Debris flows/avalanches: process, recognition, and mitigation: Geological Society of America Reviews in Engineering Geology, v. 7, p. 201-222.

Jochim, C. L., 1986, Debris-flow hazard in the immediate vicinity of Ouray, Colorado: Colorado Geological Survey Special Publication 30, 63 p.

Keaton, J. R., Anderson, L. R., and Mathewson, C. C., 1988, Assessing debris flow hazards on alluvial fans in Davis County, Utah: Proceedings of the 24th Symposium on Engineering Geology and Soils Engineering, p. 89-108.

Marsell, R. E., 1972, Cloudburst and snowmelt floods, in, Hilpert, L. S., ed., Environmental geology of the Wasatch Front, 1971: Utah Geological Association Publication 1, p. N1-N18.

Olson, E. P., 1981, Geologic hazards of the Wasatch Range, Part 1, Ward Canyon to south side Ogden Canyon: U. S. Department of Agriculture, Forest Service, R-4 Intermountain Region, unpublished 1:24,000 scale maps of selected quadrangles within U. S. Forest Service boundaries.

Pack, R. T., 1985, Multivariate analysis of relative landslide susceptibility in Davis County, Utah (Ph. D. dissertation): Utah State University, Logan, Utah, 233 p.

Pierson, T. C., and Costa, J. E., 1987, A rheologic classification of subaerial sediment-water flows, in Costa, J. E., and Wieczorek, G. F., eds., Debris flows/avalanches: process, recognition, and mitigation: Geological Society of America Reviews in Engineering Geology, v. 7, p. 1-12.

U. S. Army Corps of Engineers, 1984, Wasatch Front and central Utah flood control study, Utah: Sacramento District, U. S. Army Corps of Engineers, 180 p.

U. S. Army Corps of Engineers, 1988, Mudflow modeling, one- and two-dimensional, Davis County, Utah: Omaha District, U. S. Army Corps of Engineers, 53 p.

Varnes, D. J., 1978, Slope movement types and processes, in Schuster, R. L., and Krizek, R. S., eds., Landslides; analysis and control: Washington D. C., National Academy of Sciences, Transportation Research Board, Special Report 176, p. 12-33.

Waitt, R. B., Pierson, T. C., Maclead, N. S., Janda, R. J., Voight, B., and Holcomb, R. T., 1983, Eruption-triggered avalanche, flood, and lahar at Mount St. Helens - effects of winter snowpack: Science, v. 221, no. 4618, p. 1394-1397.

Wieczorek, G. F., 1987, Effect of rainfall intensity and duration on debris flows in central Santa Cruz Mountains, California, in Costa, J. E., and Wieczorek, G. F., eds., Debris flows/avalanches: process, recognition, and mitigation: Geological Society of America Reviews in Engineering Geology, v. 7, p. 93-104.

Wieczorek, G. F., Ellen, Stephen, Lips, E. W., Cannon, S. H., and Short, D. N., 1983, Potential for debris flow and debris flood along the Wasatch Front between Salt Lake City and Willard, Utah, and measures for their mitigation: U. S. Geological Survey Open-File Report 83-635, 45 p.

Williams. S. R., Lowe, Mike, and Smith, S. W., 1988, The discrete debris-mud flow risk analysis method: Proceedings of the 1988 Conference of the Arid West Committee of the Association of State Floodplain Managers, Las Vegas, Nevada, October 19-21, 1988, 14 p.

LIQUEFACTION HAZARDS: A GUIDE FOR LAND-USE PLANNING, DAVIS COUNTY, UTAH

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ABSTRACT

Earthquake ground shaking may cause saturated sandy soils to "liquefy" as a result of increased pore-water pressures, resulting in bearing capacity failure, ground oscillation, lateral spreading, or flow landsliding. The potential for liquefaction is dependent both on soil and ground-water conditions, and on the severity and duration of ground shaking. In general, an earthquake of Richter magnitude 5 or greater is needed to induce soil liquefaction.

Five lateral spread landslides which are believed to have resulted from liquefaction during prehistoric earthquakes have been mapped in Davis County. Also, generalized maps depicting liquefaction potential in Davis County are available and can be used to indicate hazard areas where site-specific studies should be required prior to development. The purpose of this report is to make recommendations concerning how these maps should be used as part of the development approval process.

It is recommended that planning commissions require site-specific liquefaction-hazard evaluations for all critical facilities such as lifelines and high-occupancy buildings. For industrial and commercial building sites, it is recommended that liquefaction-hazard evaluations be required only in areas with high- or moderated-susceptibility ratings on the liquefaction potential maps. It is recommended that site-specific studies generally not be required for residential subdivisions or single lots because of the lower risk in terms of life loss and property damage in such structures, and the relatively high costs of study and mitigation.

INTRODUCTION

Earthquake ground shaking causes a variety of phenomena which can damage structures and threaten lives. One of these is termed soil liquefaction. Ground shaking tends to increase the pressure in the pore water between soil grains, which decreases the stresses between the grains. The loss of intergranular stress can cause the strength of some soils to decrease nearly to zero. When this happens, the soil behaves like a liquid, and therefore is said to have liquefied. When liquefaction occurs, foundations may crack, buildings may tip, buoyant buried structures, such as septic tanks and storage tanks, may float to the surface, and even gentle slopes may fail as liquefied soils and overlying materials move downslope.

The potential for liquefaction depends both on soil and ground-water conditions, and on the severity and duration of ground shaking. Soil liquefaction most commonly occurs in areas of shallow ground water (less than 30 feet) and loose sandy soils such as are found in western Davis County. In general, an earthquake of Richter magnitude 5 or greater is needed to induce liquefaction (Kuribayashi and Tatsuoka, 1975, 1977; Youd, 1977). For larger earthquakes, liquefaction has a greater likelihood of occurrence and will occur at greater distances from the epicenter (the point on the earth's surface directly above the focus of the earthquake). Earthquakes of Richter magnitude 7.0-7.5 are the largest expected along the Wasatch front (Schwartz and Coppersmith, 1984), and during such earthquakes liquefaction has occurred up to 170 miles (1977 Romanian earthquake, magnitude 7.2) from the epicenter (Youd and Perkins, 1987).

Anderson and others (1982) have produced maps depicting liquefaction potential for Davis County. It is the purpose of this report to discuss the nature of the hazard, its potential consequences, commonly used techniques to reduce the hazard, and to give recommendations regarding how these maps should be used by Davis County and its cities for land-use planning. A major goal is to translate technical information so that government officials and the general public can appreciate the need to reduce liquefaction hazards.

NATURE OF THE LIQUEFACTION HAZARD

Liquefaction itself does not necessarily cause damage, but it may induce ground failure of various types which can be very damaging. Four types of ground failure commonly result from liquefaction: 1) loss of bearing strength, 2) ground oscillation, 3) lateral spread landslides, and 4) flow landslides (Youd, 1978a, b; Tinsley and others, 1985). Youd and others (1975) relate these types of ground failure to the slope of the ground surface (table 1). Tinsley and others (1985), and National Research Council (1985), describe and give examples of these ground failure types.

Table 1 next page

Loss of bearing strength can occur under a structure during earthquake ground shaking when the soil loses strength and liquefies in areas where slopes are generally less than about 0.5 percent (figure 1). Large deformations can then

Figure 1 next page

occur within the soil mass and allow buildings to settle and/or tilt. Buoyant buried structures such as gasoline storage or septic tanks, may float upward in liquefied soils. Among the more spectacular examples of a bearing capacity

Table 1. Ground slope and expected failure mode resulting from liquefaction (modified from Youd, 1978a; Anderson and others, 1982).

Ground Surface Slope	Failure Mode
Less than 0.5 percent	Bearing Capacity
Less than 0.5 percent, liquefaction at depth	Ground Oscillation
0.5 to 5.0 percent	Lateral Spread Landslide
Greater than 5.0 percent	Flow Landslide

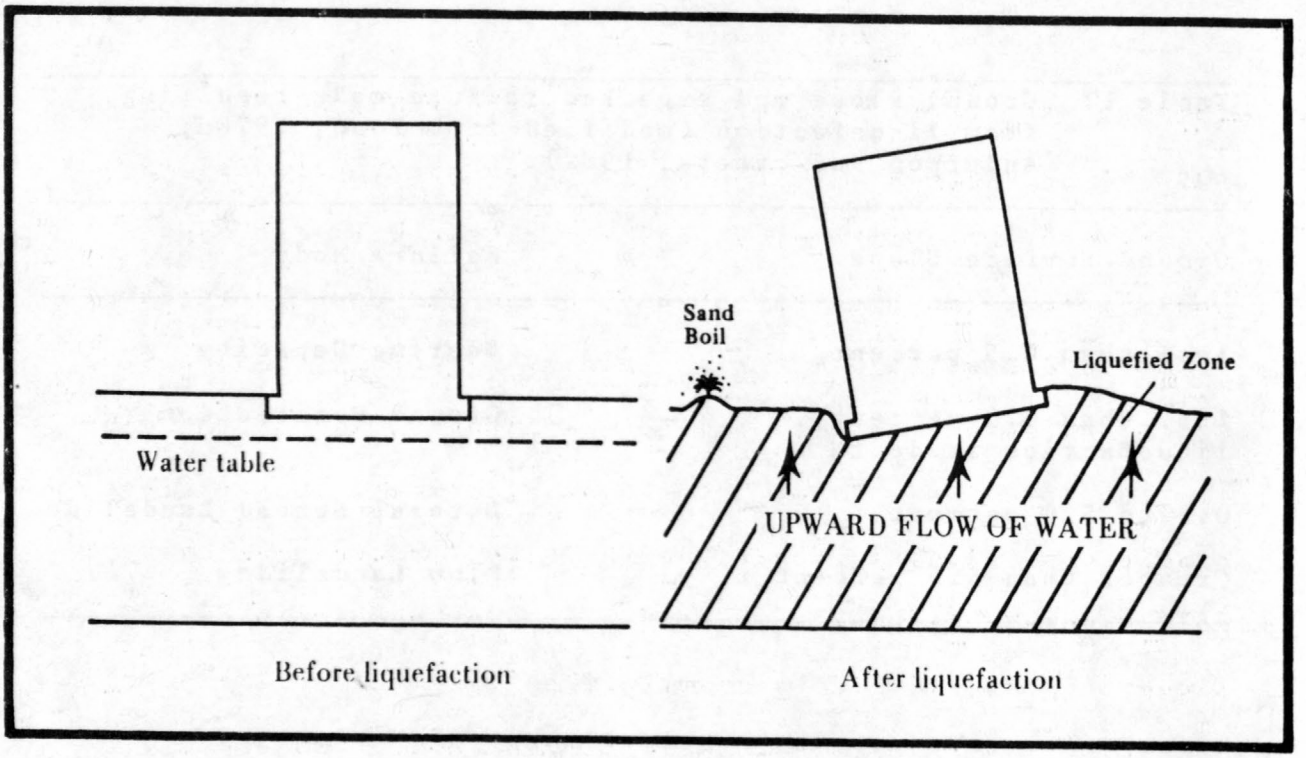


Figure 1. Tilting of a building from liquefaction and loss of bearing strength in soil. Liquefaction weakens the soil, reducing the foundation support and causing the building to settle and tilt, from Youd (1984) and National Research Council (1985).

failure was the tilting of four four-story buildings, some as much as 60 degrees, in the Kwangishicho apartment complex during the 1964 Niigata, Japan, earthquake. Buried septic tanks rose as much as three feet during the same earthquake.

Ground oscillation takes place if liquefaction occurs at depth below soil layers that do not liquefy, and if the slopes are too gentle to permit lateral displacement. Under these conditions, liquefaction at depth commonly decouples overlying soil blocks, allowing them to jostle back and forth on the liquefied layer during an earthquake (figure 2). The decoupled layer vibrates in a different mode than the

Figure 2 next page

underlying and surrounding firm ground, causing fissures to form and impacts to occur between oscillating blocks and adjacent firm ground. Ground settlement, the opening and closing of fissures, and sand boils may accompany the oscillations, and overlying structures and subgrade facilities commonly sustain damage through this mode of ground failure.

Where the ground surface slope ranges between 0.5 and 5.0 percent, failure by lateral spreading may occur. Lateral spreads occur as surficial blocks of sediment are displaced laterally downslope as a result of liquefaction in a subsurface layer (figure 3). The surface layer commonly

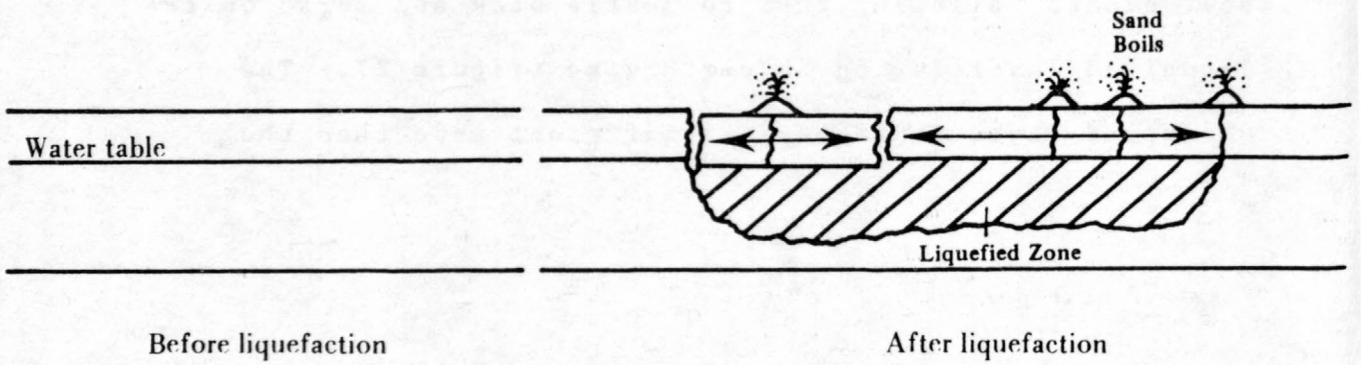


Figure 2. The mechanism of ground oscillation. Liquefaction occurs in the cross-hatched zone, decoupling the surface layer from the underlying firm ground, from Youd (1984) and National Research Council (1985).

Figure 3 next page

breaks up into blocks bounded by fissures which may tilt and settle differentially with respect to one another. Lateral displacements commonly amount to several feet, perhaps tens of feet if soil conditions are especially favorable for liquefaction and if earthquake shaking is of sufficient duration. As shown in table 2, significant damage to structures may result from lateral spreading.

Table 2 next page

Lateral spread landsliding is especially destructive to pipelines, utilities, bridge piers, and other structures having shallow foundations. Lateral spreads resulting in ground displacements of only a few feet were responsible for every major pipeline break in San Francisco during the 1906 earthquake (Youd, 1978a). Hence, liquefaction was responsible for the severely compromised ability to fight the fires that caused 85 percent of the damage to that city.

Where ground surface slopes are steeper than about 5.0 percent, slope failure may occur in the form of flow landslides (figure 4). Flow failure constitutes the most

Figure 4 next page

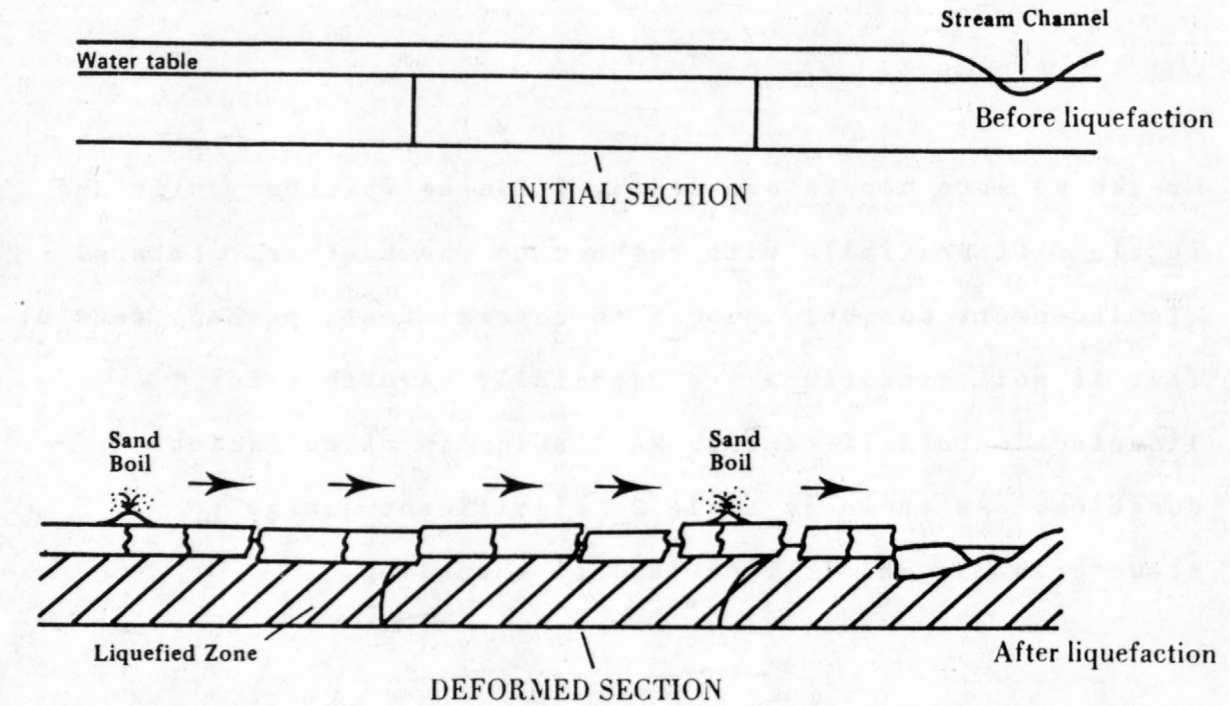


Figure 3. Diagram of a lateral spread, from Youd (1984) and National Research Council (1985). Liquefaction occurs in the cross-hatched zone. The ground surface slopes slightly to the right.

Table 2. Relationship between ground displacement and damage to structures (from Youd, 1980).

Ground Displacement	Level Of Expected Damage
Less than 4 in.	Little damage, repairable
4 in. to 1 ft	Severe damage, repairable
1 ft to 2 ft	Severe damage, non-repairable
More than 2 ft	Collapse, non-repairable

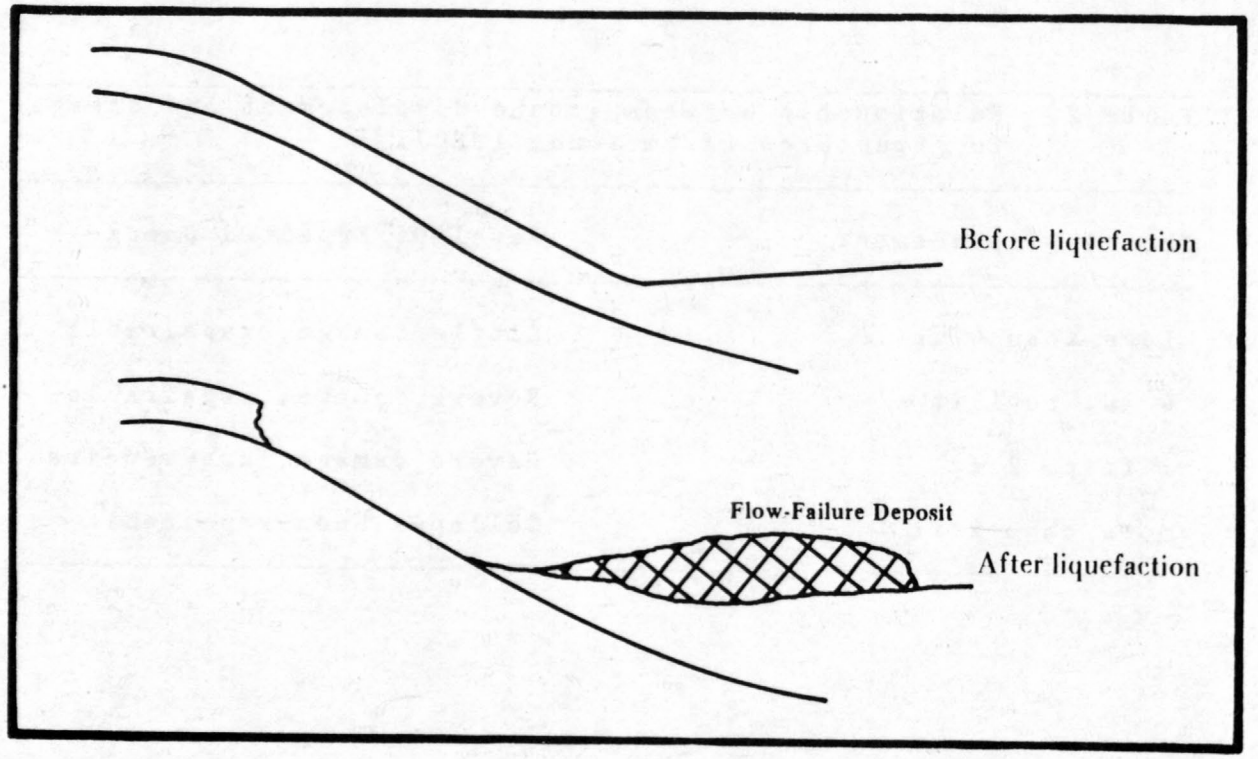


Figure 4. Diagram of a flow failure. Liquefaction develops beneath the ground surface, causing the soil to lose strength and flow down the steep slope, from Youd (1984) and National Research Council (1985).

catastrophic mode of ground failure caused by liquefaction. Flow landslides are comprised chiefly of liquefied soil or blocks of intact material riding on a liquefied layer. Flow failures commonly displace soil masses by tens of yards. In favorable circumstances, flow failure has displaced materials by more than 30,000 feet at velocities of more than 500 feet per minute. Extensive damage due to flow landslides occurred in the cities of Seward and Valdez, Alaska, during the 1964 Alaska Earthquake. A flow landslide during the 1906 San Francisco earthquake knocked a power-house near the Mount Olivet Cemetery from its foundation (Youd, 1973).

HOW THE LIQUEFACTION HAZARD CAN BE REDUCED

Earthquake-induced soil liquefaction or liquefaction-induced ground failures have the potential to cause damage to most types of structures. Structures that are particularly sensitive to liquefaction are: buildings with shallow foundations, railway lines, highways and bridges, buried structures, dams, canals, retaining walls, port structures, utility poles, and towers (National Research Council, 1985). The National Research Council (1985) identifies several alternative approaches that can be taken if earthquake-induced liquefaction is determined to be a threat to existing or proposed structures. For an existing structure the choices include: 1) retrofitting the structure and/or site to reduce the potential for liquefaction-induced damage, 2) abandoning

the structure if the retrofit costs exceed the potential benefits derived from maintaining the structure, or 3) accepting the risk.

Possible actions which may be taken if a liquefaction hazard exists at the site for a proposed structure include: 1) improving site conditions to lower the potential for liquefaction, 2) designing the structure to withstand the effects of liquefaction, 3) avoid the risk by moving the proposed development to a less hazardous site, 4) insure the development so that if liquefaction-induced damage occurs, funds will be available to repair the damage, or 5) accept the risk if the potential for and consequences of liquefaction are clearly understood.

Structural solutions to reduce the effects of liquefied soils can take several forms. For buildings, the questionable foundation support offered by liquefiable soils may be avoided by the use of end-bearing piles, caissons, or fully compensated mat foundations designed for the predicted liquefaction phenomena at the site. Methods of improving liquefiable soil foundation conditions are: 1) densification of soils through vibration or compaction, 2) grouting, 3) dewatering with drains or wells, and 4) loading or buttressing to increase confining pressures. Costs of site improvement techniques range from less than $0.50 to more than $500.00 per cubic yard of soil foundation material treated.

LIQUEFACTION POTENTIAL INFORMATION FOR DAVIS COUNTY

The results of the liquefaction study are summarized in four maps. Each map consists of two parts (A & B) separating Davis County into a south half and a north half (Anderson and others, 1982). The base maps are 50 percent reductions of U. S. Geological Survey 7 1/2-minute (topographic) quadrangles and have a scale of one in. equals 4,000 ft (scale 1:48,000). The four maps are: 1) Selected Geologic Data Map, 2) Soils and Ground Water Data Map, 3) Ground Slope and Critical Acceleration Map, and 4) Liquefaction Potential Map. Figure 5 shows the location of figure 6 which is a reproduction of a portion of Anderson and others (1982) Liquefaction Potential Map (South Half) for Davis County.

Figures 5 and 6 next page

A summary of the methods used in preparing the maps follows; for a detailed discussion of the technical aspects of map preparation, refer to Anderson and others (1982). Maps prepared by Anderson and others (1982) take into consideration soil and ground-water conditions and earthquake probability in determining liquefaction potential in Davis County. Soil and ground-water conditions were evaluated on the basis of subsurface data, chiefly boreholes and cone penetrometer tests, obtained from private engineering consultants, state and local government agencies, and tests run as part of the

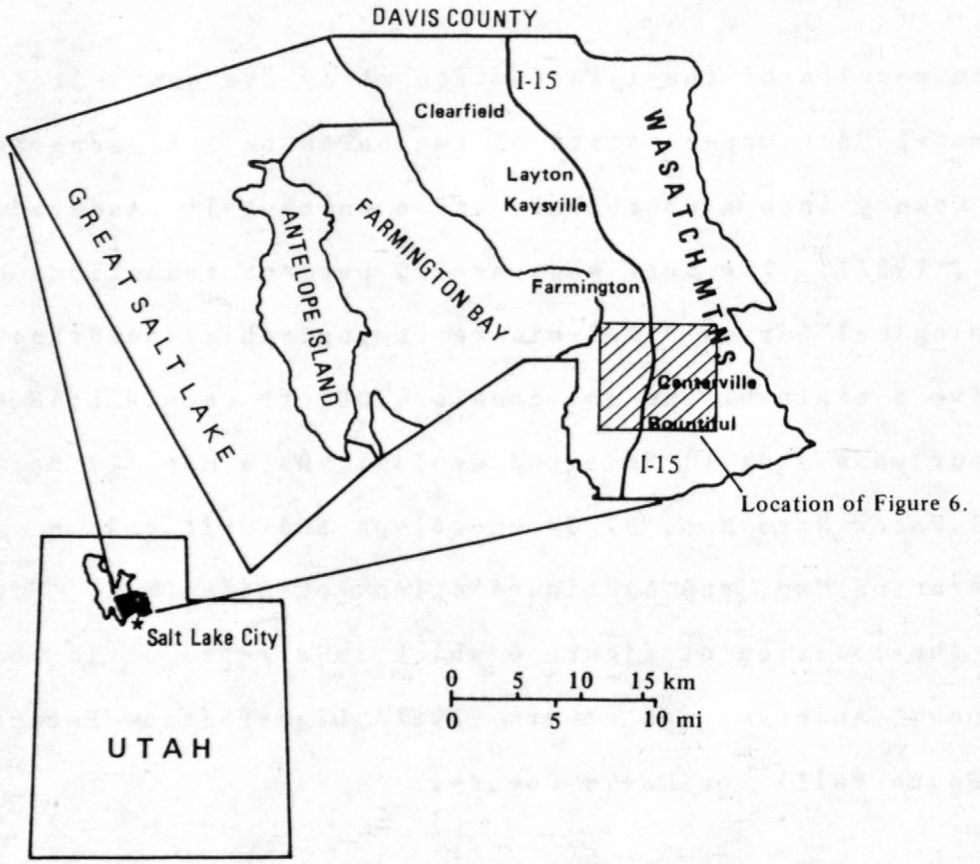
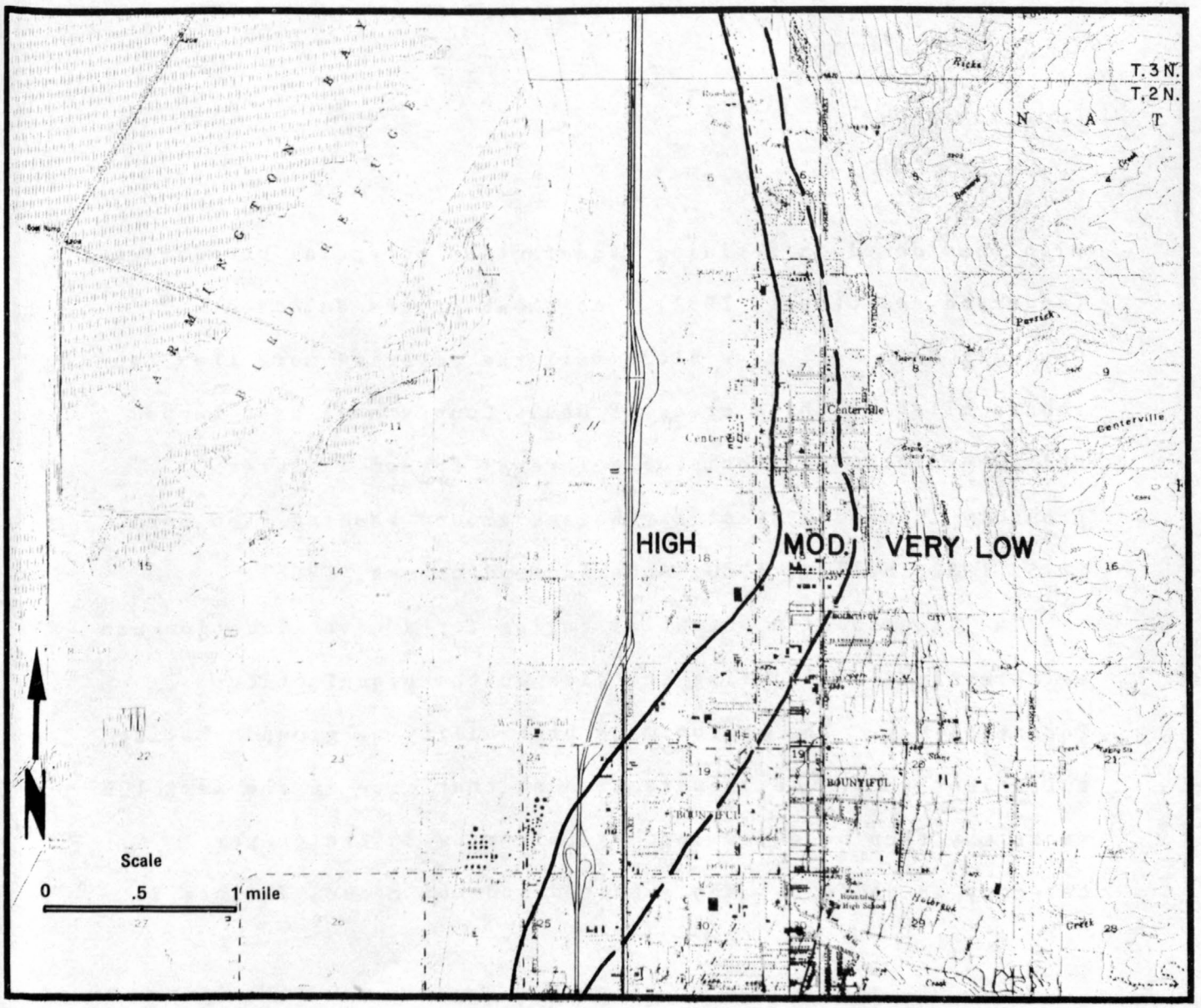


Figure 5. Location map for figure 6.

Figure 6. Liquefaction Potential Map for the Centerville and northern Bountiful area of southern Davis County, Utah. High, Mod. (moderate), and Very Low refer to liquefaction potential ratings determined by Anderson and others (1982). This figure was reproduced from a portion of the Liquefaction Potential Map (South Half) for Davis County, Utah, by Anderson and others, (1982).



liquefaction potential investigation. A calculation of the level of ground shaking needed to induce liquefaction was then made at each data point. Peak horizontal ground acceleration was used as the measure of ground shaking, and that needed to induce liquefaction under a particular set of soil and groundwater conditions was termed the critical acceleration. The liquefaction potential in Davis County has been rated based on the probability that the critical acceleration needed to induce soil liquefaction will be exceeded during a 100-year return period (table 3). Local geological conditions were

Table 3 next page

also considered in refining liquefaction potential boundaries (Anderson and others, 1982). As shown on the Selected Geologic Data Map, five slope failures covering more than ten square miles in three areas of Davis County have been mapped and interpreted as prehistoric lateral spread failures probably induced by past earthquake ground shaking (Van Horn, 1975, 1982; Miller, 1980; Anderson and others, 1982).

The liquefaction potential rating for a given location can be determined by locating the site on the Liquefaction Potential Map. The approximate probability of ground shaking sufficient to induce liquefaction at that site in the next 100 years may then be determined by referring to the proper category in table 3. The expected mode of ground failure if

Table 3. Criteria used to evaluate liquefaction potential (Anderson and others, 1982).

Liquefaction Potential	Critical Acceleration Needed To Induce Liquefaction (g = force of gravity)	Approximate Probability That The Critical Acceleration Needed To Induce Liquefaction Will Be Exceeded During The Next 100 Years
High	less than 0.12 g	greater than 50%
Moderate	between 0.12 & 0.20 g	between 10% & 50%
Low	between 0.20 & 0.30 g	between 5% & 10%
Very Low	more than 0.30 g	less than 5%

liquefaction occurs at a given location may be evaluated by determining the approximate ground surface slope at the site on the Ground Slope and Critical Acceleration Map and referring to table 1. Contours depicting areas of less than 0.5 percent, 0.5 to 5.0 percent, and greater than 5.0 percent slope are included in this map. To differentiate between bearing capacity and soil oscillation failure modes in areas of less than 0.5 percent slope, the depth of the liquefiable layer must be known. This can be determined for specific sites by using the Soils and Ground Water Data Map to determine the depth to liquefiable soils and the nature of overlying and underlying units. However the map does not interpret depths to liquefiable layers between data points, so the two failure modes can only be differentiated at specific sites where data were collected.

RECOMMENDED USE OF MAPS IN LAND-USE PLANNING

These maps are at a regional scale and, although they can be used to gain an understanding of probable potential of a given area for liquefaction during earthquake ground shaking, they are not designed to replace site-specific evaluations. Mapped areas rated as having a low liquefaction potential may contain isolated areas with a high liquefaction potential and areas rated as having a high liquefaction potential may contain isolated areas which are not prone to liquefaction. Site-specific liquefaction potential studies should be conducted where this information is needed.

Large areas of Davis County have moderate to high potential for liquefaction during earthquake ground shaking, including most of the area west of State Highway 89. The liquefaction potential maps provide a general indication of where the hazard may exist, and serve as a means of evaluating the need for site-specific studies. Because of the distribution of data points and the relatively small scale of the maps, it does not preclude the necessity for site-specific evaluations. Where a use is planned at a site where data used in preparing the maps were collected, the point data may be useful in a site evaluation, depending on its quality. It is recommended that liquefaction potential be evaluated and, if necessary, mitigative measures recommended in site investigation reports submitted by the developer prior to planning commission approval as outlined in table 4. Areas of

Table 4 next page

moderate to high liquefaction potential need not be avoided, because structural measures and site modification techniques are available to reduce hazards. Reports addressing liquefaction potential in such areas are recommended for large structures, but not for single-family dwellings, as has been recommended by the engineers and geologists who conducted the liquefaction potential study (Anderson and others, 1987). This is because the cost of reducing liquefaction hazards

Table 4. Matrix indicating recommended report requirements for liquefaction hazards, Davis County, Utah.

Type Of Development	Liquefaction Potential Rating	
	High/Moderate	Low/Very Low
Critical Facilities, including lifelines and high-occupancy buildings	Yes	Yes
Industrial & commercial buildings (other than high occupancy)	Yes	No
Residential subdivisions	No*	No
Residential-single lots	No*	No

*Appropriate disclosure should be required.

commonly exceeds the value of single-family dwellings (L. R. Anderson, personal commun., August 31, 1987), and because liquefaction is generally not a life-threatening hazard.

SCOPE OF SITE INVESTIGATIONS

A liquefaction potential evaluation should be part of a standard soil foundation investigation for the proposed development. Initial evaluations for liquefaction potential should be based on depth to ground water and soil types. If soil and ground-water conditions indicate that liquefiable soils may be present, standard penetration tests and/or cone penetration tests should be conducted to determine critical accelerations needed to induce liquefaction. All site evaluations for liquefaction should contain certain information. A site-specific liquefaction potential report should include accurate maps of the area showing any proposed development, the location of bore holes and/or test pits, and the site geology. Logs of bore holes and test pits should be included in the report and any ground water encountered should be noted on the logs. The location of and depths to liquefiable soils should be noted and the probability of critical accelerations needed to induce liquefaction in these soils being exceeded for appropriate time periods should be determined. Recommendations for hazard reduction techniques should be included. A meeting with the county geologist and engineer should occur prior to conducting site-specific liquefaction studies to discuss the scope of work and types of

information that should be obtained from such a study.

A useful guide for use in preparing reports is found in Utah Geological and Mineral Survey Publication M, Guidelines For Preparing Engineering Geological Reports In Utah, by the Utah Section of the Association of Engineering Geologists (1986). When site-specific reports are received addressing liquefaction hazards, they should be reviewed by the county geologist and engineer and, once approved, submitted to the planning commission along with review comments so that the planning commission has sufficient information available to make decisions regarding the proposed development.

ACKNOWLEDGMENTS

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REFERENCES CITED

Anderson, L. R., Keaton, J. R., Aubry, Kevin, and Ellis, S. J., 1982, Liquefaction potential map for Davis County, Utah: Department of Civil and Environmental Engineering, Utah State University, Logan, Utah, and Dames & Moore Consulting Engineers, Salt Lake City, Utah, 50 p.

Anderson, L. R., Keaton, J. R., Bay, J. A., and Rice, J. D., 1987, Liquefaction potential mapping, Wasatch Front, Utah, in McCalpin, James, ed., Proceedings of the 23rd Annual Symposium on Engineering Geology and Soils Engineering: Utah State University, Logan, Utah, p. 1-17.

Kuribayashi, Eiichi, and Tatsuoka, Fumio, 1975, Brief review of liquefaction during earthquakes in Japan: Soils and Foundations, v. 15, no. 4, p. 81-92.

----1977, History of earthquake-induced liquefaction in Japan: Japan Ministry of Construction, Public Works Research Institute Bulletin, v. 31, p. 26.

Miller, R. D., 1980, Surficial geologic map along part of the Wasatch Front, Great Salt Lake Valley, Utah: U. S. Geological Survey Miscellaneous Field Studies Map MF-1198, 1:100,000 scale.

National Research Council, 1985, Liquefaction of soils during earthquakes: National Academy Press, Washington D. C., 240 p.

Tinsley, J. C., Youd, T. L., Perkins, D. M., and Chen, A. T. F., 1985, Evaluating liquefaction potential, in Ziony, J. I., ed., Evaluating earthquake hazards in the Los Angeles region- an earth science perspective: U. S. Geological Survey Professional Paper 1360, p. 263-315.

Van Horn, Richard, 1975, Largest known landslide of its type in the United States- a failure by lateral spreading in Davis County, Utah: Utah Geology, v. 2, no. 1, p. 83-87.

----1982, Surficial geologic map of the Salt Lake City North Quadrangle, Davis and Salt Lake Counties, Utah: U. S. Geological Survey Miscellaneous Investigation Series Map I-1404, 1:24,000 scale.

Youd, T. L., 1973, Liquefaction, flow, and associated ground failure: U. S. Geological Survey Circular 688, 12 p.

----1977, Discussion of " Brief review of liquefaction during earthquakes in Japan" by Kuribayashi, Eiichi, and Tatsuoka, Fumio, 1975: Soils and Foundations, v. 17, no. 1, p. 82-85.

----1978a, Major cause of earthquake damage is ground failure: Civil Engineering, v. 48, no. 4, p. 47-51.

----1978b, Mapping liquefaction-induced ground failure potential: Proceedings of the American Society of Civil Engineers Journal of Geotechnical Engineering Division, v. 4 no. 674, p. 433-446.

----1980, Ground failure displacement and earthquake damage to buildings: American Society of Civil Engineers Conference on Civil Engineering and Nuclear Power, 2d, Knoxville, Tenn., 1980,v. 2, p. 7-6-2 - 7-6-26.

----1984, Geologic effects - liquefaction and associated ground failure: U. S Geological Survey Open-File Report 84-760, p. 210-232.

Youd, T. L., Nichols, D. R., Helley, E. J., and Lajoie, K. R., 1975, Liquefaction potential, in, Studies for seismic zonation the San Francisco Bay region: U. S. Geological Survey Professional Paper 941-A, p. A68-A74.

Youd, T. L., and Perkins, D. M., 1987, Mapping of liquefaction severity index: Journal of Geotechnical Engineering, v. 113, p. 1374-1392.

TECTONIC SUBSIDENCE HAZARD: A GUIDE FOR LAND-USE PLANNING, UTAH AND JUAB COUNTIES, UTAH

by

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ABSTRACT

Tectonic subsidence (seismic tilting) is the downwarping and tilting of the valley floor relative to the mountains during a surface-faulting earthquake (> M 6.5). The maximum vertical subsidence occurs at the base of the fault and decreases toward the valley. Two historic earthquakes in the Intermountain Seismic Belt (ISB) are used as models for the Wasatch fault zone (WFZ), the 1959 Hebgen Lake, Montana, and the 1983 Borah Peak, Idaho, earthquakes. Although the maximum subsidence was 20 ft (6 m) at Hebgen Lake, the average offset of the WFZ is expected to produce surface offset of about 6 to 9 ft (2 to 3 m) with less tectonic subsidence. The affected area could extend for about 10 mi (16 km) basinward from the fault with maximum tilt within about 3 mi (5 km). The lateral extent of subsidence is controlled by the length of fault rupture, which is expected to coincide with segment lengths which are generally 15 to 20 mi (24 to 32 km). The recurrence interval for tectonic subsidence along a particular fault segment is the same as that of surface-faulting earthquakes, ranging from hundreds to several thousands of years.

Hazards associated with tectonic subsidence in Utah and Juab counties include shoreline flooding along Utah Lake and other bodies of water tilted by faulting, inundation from shallow groundwater, and damage to facilities that

cannot tolerate small changes in gradient, such as wastewater-treatment facilities. Tectonic subsidence maps for the WFZ which show areas of potential flooding and tilting have been prepared for Utah and Juab counties. However, they are based on theoretical models and are approximations of what may actually occur. Site-specific studies are recommended for certain vulnerable facilities within zones of flooding and maximum tilting such as electricity-generating plants, wastewater-treatment facilities, and other structures which, if tilted or inundated, could cause public health and safety problems as well as economic losses. The site-specific report should determine the depth to ground water and the site elevation with respect to projected lake and ground-water levels, and recommend hazard-reduction techniques. Mitigation could include provisions to relevel after subsidence occurred, or building more freeboard or tolerance for containers which hold toxic or other dangerous materials. Reports would be reviewed by the County Geologist and County Engineer.

INTRODUCTION

Tectonic subsidence is the warping, lowering and tilting of a valley floor that accompanies surface-rupturing earthquakes on normal (dip slip) faults such as the Wasatch fault zone. Subsidence occurred during the 1959 Hebgen Lake, Montana, earthquake and the 1983 Borah Peak, Idaho, earthquake, and geologic evidence for tectonic subsidence, such as backtilting adjacent to the fault zone, during prehistoric earthquakes along the Wasatch Front is present (Keaton, 1987). Inundation along the shores of lakes and reservoirs and the ponding of water in areas with a shallow water table may be caused by tectonic subsidence. Also, tectonic subsidence may adversely affect certain structures which require gentle gradients or horizontal floors, particularly wastewater-treatment facilities and sewer lines (Keaton, 1987). In this

report I discuss the consequences of possible tectonic subsidence in Utah and eastern Juab counties (fig. 1) and make recommendations concerning the use of hazard maps for mitigation of subsidence hazards in land-use planning.

Figure 1 next page

CHARACTERISTICS OF TECTONIC SUBSIDENCE

Tectonic subsidence, also termed seismic tilting, occurs during large magnitude earthquakes (> M 6.5) generated along normal faults which have accompanying deformation or displacement at the ground surface. The extent of seismic tilting is controlled chiefly by the amount and length of surface displacement, and normally occurs only along the portion of the fault that experienced surface deformation. The area of subsidence is controlled by the length of the fault rupture and subsidence should extend only a short distance beyond the ends of the fault rupture.

The Wasatch fault zone (WFZ) consists of 10 to 11 distinct segments which probably break independently and average about 20.6 to 22.7 mi (33.3 to 36.6 km) in length (Machette and others, 1989). The WFZ segments in Utah and eastern Juab counties are the Provo (unrestricted) and Nephi which are 43 mi (69.5 km) and 26.4 mi (42.5 km) long respectively (Machette and others, 1989), and are discussed further by me in this volume.

The probability of tectonic subsidence occurring is the same as a large earthquake (> M 6.5). The average composite recurrence interval for large earthquakes on the WFZ is 340 to 415 years, however, for any given individual segment, the average recurrence interval is 2035 to 2070 years (Machette and others, 1989). Due to the dispersion in the timing of events and the catastrophic losses which will occur during a large magnitude earthquake, the most conservative estimate, 340 to 415 years, should be used. This figure becomes even more significant when the timing of the most recent event, about 400 years ago (Machette and others, 1989), is considered.

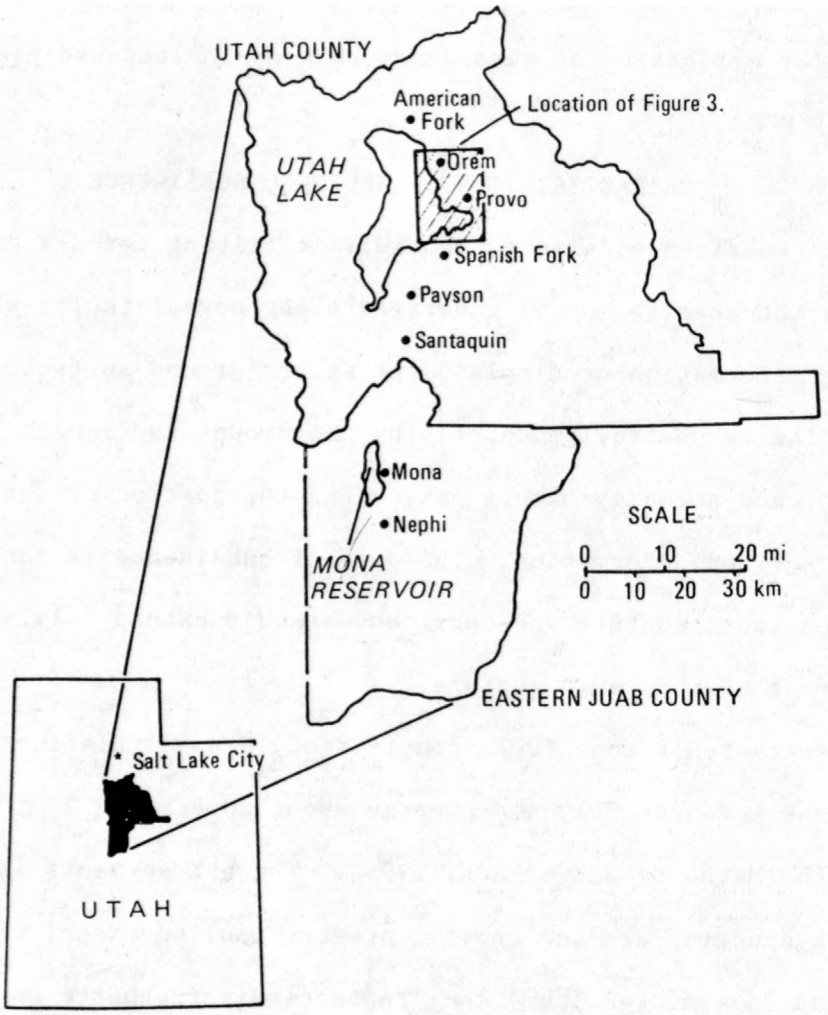

Figure 1. Map showing the location of Utah and northeastern Juab Counties.

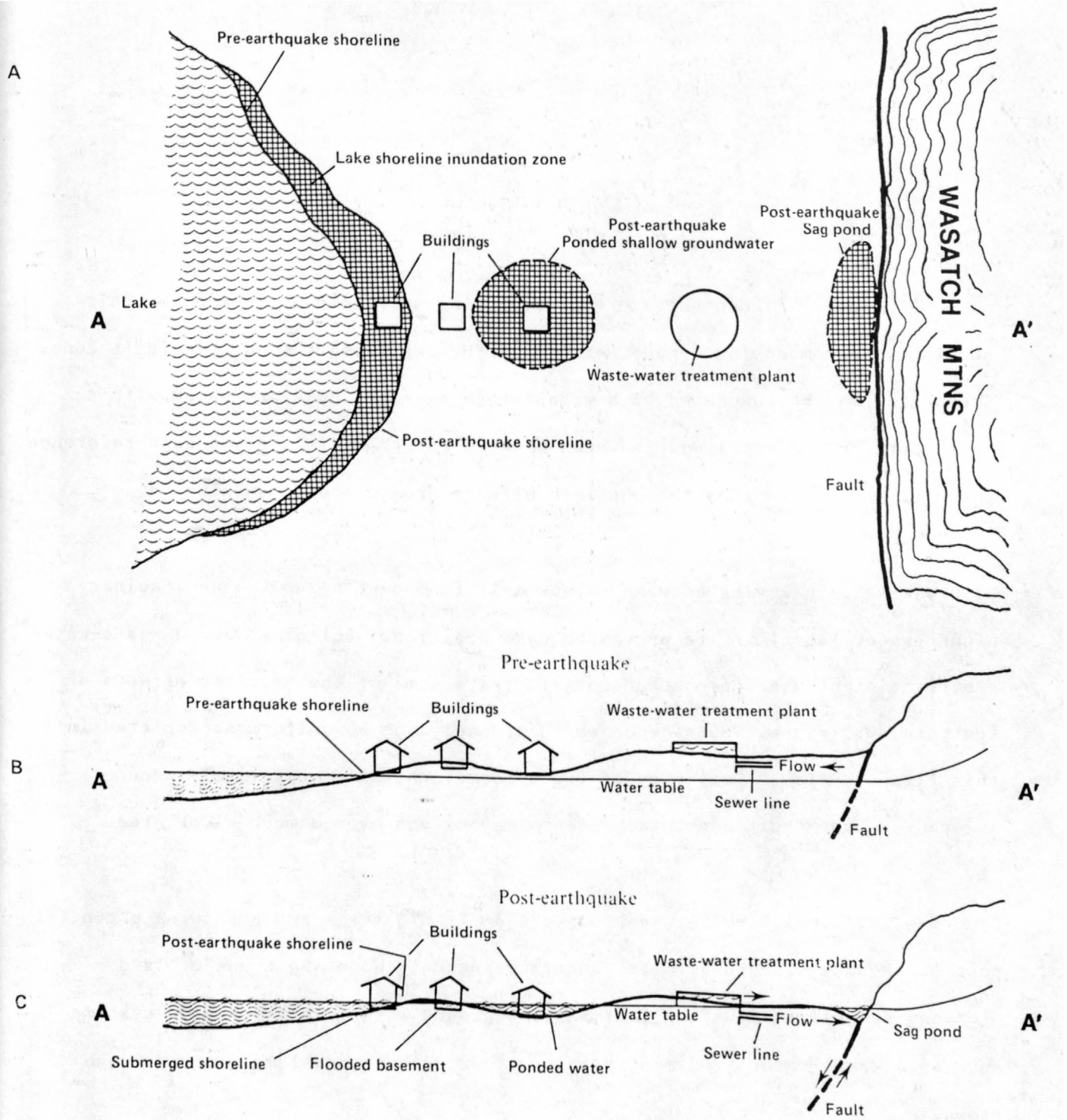
A
Pre-earthquake shoreline
Lake shoreline inundation zone
Buildings
Post-earthquake
Ponded shallow groundwater
Post-earthquake
Sag pond
WASATCH MTNS
Lake
A
A'
Waste-water treatment plant
Post-earthquake shoreline
Fault
Pre-earthquake
B
Pre-earthquake shoreline
Buildings
Waste-water treatment plant
Flow
A
Water table
Sewer line
A'
Fault
Post-earthquake
C
Post-earthquake shoreline
Buildings
Waste-water treatment plant
A
Water table
Flow
Sag pond
A'
Sewer line
Submerged shoreline
Flooded basement
Ponded water
Fault

Figure 2. A) Map (not to scale) showing surface rupture and tectonic subsidence accompanying a hypothetical earthquake along the Wasatch fault zone. Areas that may be indunated with water after an earthquake are shown with a boxed pattern. A cross-section view between points A-A' is given as a reference in parts B and C to show the possible effects from tectonic subsidence.

B) Cross sectional view between points A-A' from part A showing an imaginary plane (water table) at its pre-earthquake position. Buildings and a waste-water treatment plant are represented to illustrate some of the possible effects of tectonic subsidence. Subsidence would probably not be uniform as depicted in this figure. Also, a majority of the deformation would most likely occur adjacent to the fault and total effects may extend over a much wider area.

C) Cross sectional view between points A-A' from parts A and B showing potential post-earthquake effects from tectonic subsidence. Note the areas of lake flooding as well as flooding from shallow ground water. Gravity flow systems such as a waste-water treatment plants may experience problems from reversed flows.

Two earthquakes have occurred in the northern Basin and Range which are models for the WFZ; the largest is the 1959 M_s 7.5 Hebgen Lake, Montana, earthquake (Doser, 1985). The area of tilting, measured perpendicular to the fault, extended up to 10 mi (16 km) from the fault at Hebgen Lake (Meyers and Hamilton, 1964). The amount of subsidence at Hebgen Lake is larger than that expected for the `characteristic earthquake' (Schwartz and Coppersmith, 1984) of the Wasatch front and was not used as a direct analog for the Utah and Juab Counties area. The maximum subsidence at Hebgen Lake was 20 ft (6 m), whereas the WFZ has an expected offset of 6 to 9 ft (2 to 3 m) (Schwartz and Coppersmith, 1984). Also, the hazard maps for Utah and Juab counties will show average expected offset for the WFZ, not the largest displacement which has occurred locally. The second earthquake model, the 1984 Borah Peak event, also formed subsidence but lack of pre-earthquake survey and profile control eliminated evaluation of tectonic subsidence adjacent to the fault (Keaton, 1987).

The expected area of subsidence for the WFZ extends for about 10 mi (16 km) west of the fault zone with the majority of the deformation within about 3 mi (5 km) (Keaton, 1986). The maximum amount of subsidence should occur at the fault and decrease gradually away on the downdropped valley block (Keaton, 1986).

Tectonic subsidence may cause flooding (Smith and Richins, 1984; fig. 2). The amount of inundation along shorelines will depend upon lake levels at the time of the event. Several zones of flooding have been delineated by Keaton (1986) for Utah Lake which correlate to lake elevations of 4485, 4490, and 4495 ft (1368, 1370, and 1371 m). These levels cover the range of lake fluctuations since 1935, when the lake reached its historical low of 4478 ft (1365 m). The normal-operating or "compromise" level of the lake is about

4490 ft (1370 m). Also plotted on the maps prepared for the counties are areas where the ground water may pond in the event of seismic tilting. Ground water was considered to be three feet from the ground surface prior to subsidence. A portion of the tectonic subsidence maps prepared by Keaton (1986) was adapted and presented in figure 3. Also, the east shore of Mona Reservoir in Juab County may experience flooding due to tectonic subsidence similar to the shoreline of Utah Lake.

Figure 2 previous page
Figure 3 next page

MITIGATION

The two major types of hazards associated with tectonic subsidence are tilting of the ground surface, and flooding from lakes, reservoirs, or shallow ground water (fig. 2). Because subsidence may occur over large areas (tens of square miles), it is generally not practical to avoid the use of potentially affected land except in narrow areas of hazard due to lake shoreline flooding. For gravity-flow structures such as wastewater-treatment plants that are within areas of possible subsidence, it is advisable to consider the tolerance of such structures to slight changes in gradient. Some structures may have to be releveled after a large-magnitude earthquake. Critical facilities which contain dangerous substances should have safety features to protect the structure, its occupants, and the environment, from both tilting and flooding.

Flooding problems along lakes from tectonic subsidence can be reduced using standard techniques. Structures can be raised above expected flood levels and dikes can be built. Land use regulations around lakes or reservoirs can prohibit or restrict development in a zone along the shoreline that may be inundated. A buffer or safety zone of several feet of elevation above projected lake levels could be adopted to protect against natural rises from wet periods, storm waves, and earthquake-induced seiching, as well as hazards associated with tectonic subsidence.

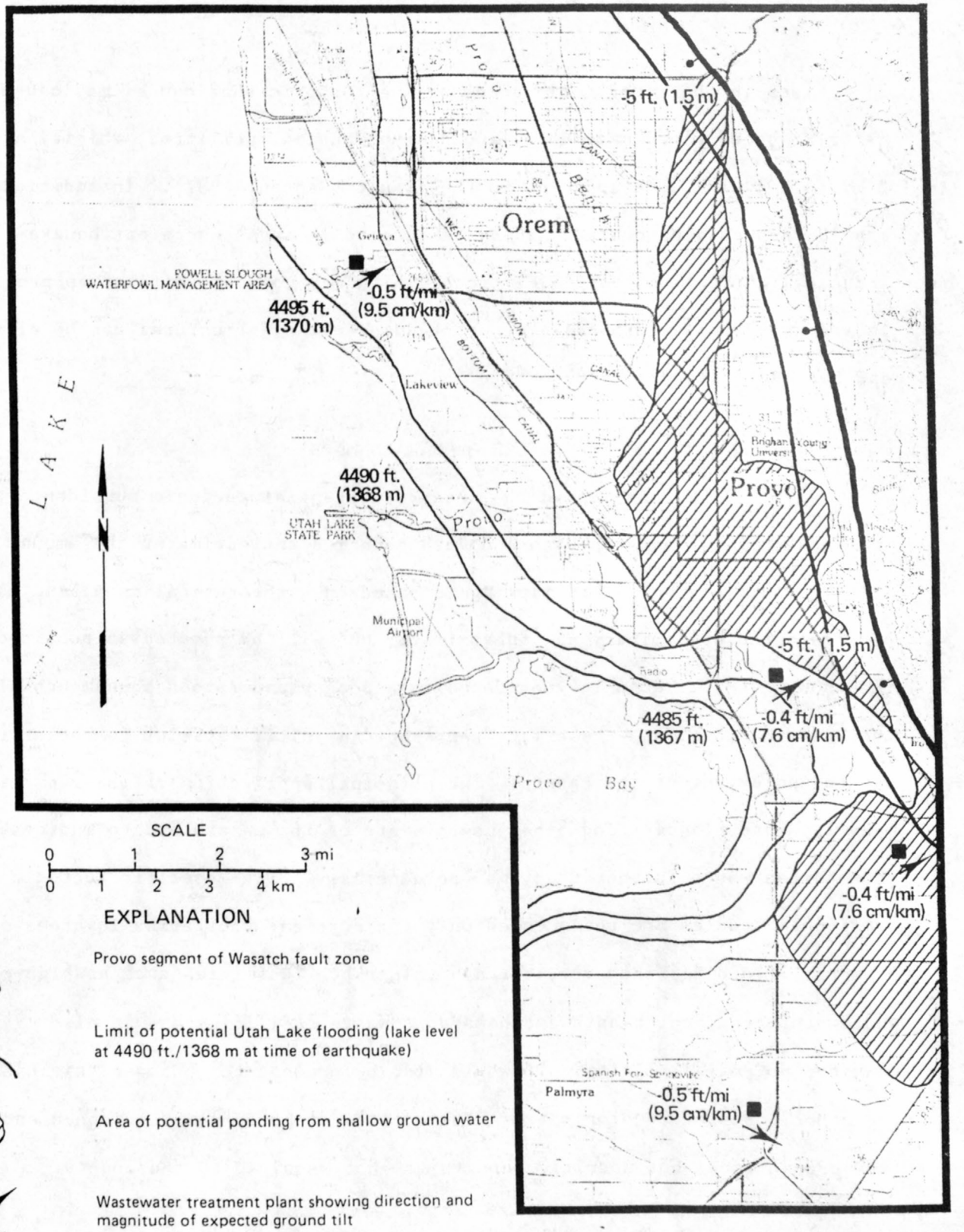

Figure 3. Map showing area of potential tectonic subsidence in part of Utah Valley, based on a M 7-7.5 earthquake with about 6-9 ft (2-3 m) of surface rupture. Heavy (numbered) lines around Utah Lake indicate potential post-earthquake shorelines at three possible elevations of the lake at the time of the event. Modified from Keaton (1986).

Rises in the water table accompanying tectonic subsidence may cause water to pond, flood basements, and disrupt buried facilities, chiefly along a 3 mi (5 km) wide zone adjacent to the fault (Keaton, 1987). In addition, shallow groundwater conditions may be located in areas where earthquake-induced liquefaction could also occur, which may compound mitigation problems. In areas of shallow ground water or standing water, structures can be elevated and basements floodproofed.

USE OF HAZARD MAPS

Keaton (1986) has mapped the areas of potential tectonic subsidence along the Wasatch fault zone in Utah and Juab counties and estimated the amount of tilting and flooding. This mapping is based on a theoretical model and must be considered preliminary and approximate, but will be adopted as published (Robison, 1988). Tectonic subsidence is a poorly understood phenomenon along the Wasatch Front, and these maps represent an initial attempt to depict the nature and extent of the hazard. The principal application of the maps is to make land-use planners and other users aware of the hazard and to indicate those areas where further study may be necessary. Site-specific tectonic subsidence studies are recommended only for critical facilities in areas of potential flooding. However, certain vulnerable facilities such as high-cost wastewater-treatment plants and hazardous-waste facilities should also consider potential tilting. It would also be prudent to consider this hazard for other types of development within the area of potential subsidence and take precautions, but specific reports are not required by the county.

SCOPE OF SITE INVESTIGATIONS

Site-specific studies of tectonic subsidence hazard should determine the depth to ground water and site elevation with respect to projected lake and

ground water levels. These results would then be compared to expected amounts of subsidence shown on the map by Keaton (1986). Recommendations regarding hazard reduction should be based on the extent of flooding or ground tilt indicated. These reports will be reviewed by the County Surveyor and County Geologist. The hazard maps of Keaton (1986) will be amended as new and more accurate information becomes available.

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REFERENCES

Doser, D.I., 1985, Source parameters and faulting processes of the 1959 Hebgen Lake, Montana, earthquake sequence: Journal of Geophysical Research, v. 91, no. B12, p. 4537-4555.

Keaton, J.R., 1986, Potential consequences of tectonic deformation along the Wasatch fault: Utah State University, Final report to the U.S. Geological Survey for Earthquake Hazards Reduction Program Grant 14-08-0001-G1174.

_____, 1987, Potential consequences of earthquake-induced regional tectonic deformation along the Wasatch Front, north-central Utah, in McCalpin,

James, ed., Proceedings of the 23rd symposium on Engineering Geology and Soils Engineering: Boise, Idaho Department of Transportation, p. 19-34.

Machette, M.N., Personius, S.F., Nelson, A.R., Schwartz, D.P., and Lund, W.R., 1989, Segmentation models and Holocene movement history of the Wasatch fault zone, Utah, in Schwartz, D.P., and Sibson, R.H., eds., Proceedings of Conference XLV--Fault segmentation and controls on rupture initiation and termination: U.S. Geological Survey Open-File Report 89-314, p. 229-242, in press.

Meyers, W.B., and Hamilton, W., 1964, Deformation accompanying the Hebgen Lake earthquake of August 17, 1959: U.S. Geological Survey Professional Paper 435-I, p. 55-98.

Robison, R. M., 1988, Surface fault rupture hazard and tectonic subsidence maps for the Wasatch Front, Utah: Geological Society of America Abstracts with Programs, v. 20, no. 6, p. 465.

Schwartz, D.P., and Coppersmith, K.J., 1984, Fault behavior and characteristic earthquakes -- Examples from the Wasatch and San Andreas fault zones: Journal of Geophysical Research, v. 89, no. B7, p. 5681-5698.

Smith, R.B., and Richins, W.D., 1984, Seismicity and earthquake hazards of Utah and the Wasatch Front -- Paradigm and paradox, in Hays, W.W., and Gori, P.L., eds., Proceedings of Conference XXVI, Workshop on "Evaluation of regional and urban earthquake hazards and risk in Utah": U.S. Geological Survey Open-File Report 84-763, p. 73-112.

EARTHQUAKE-INDUCED GROUND FAILURE IN SENSITIVE CLAYS, VIBRATORY SETTLEMENT, SEICHES, SURFACE-DRAINAGE DISRUPTIONS, AND INCREASED GROUND-WATER DISCHARGE, DAVIS COUNTY, UTAH

by

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ABSTRACT

A number of potential hazards associated with earthquakes exist along the Wasatch Front that have not been sufficiently studied to determine probability of occurrence for various exposure periods or to produce maps showing areas at risk. These potentially damaging but poorly understood hazards include ground failure in sensitive clays, vibratory settlement in granular materials, and flooding due to seiches, surface-drainage disruptions, and increased ground-water discharge. Many of the consequences of these hazards are identified in this report. Additional study is required before these hazards can be considered in city and county planning. Some of these hazards, however, can be evaluated at the site-specific level and should be considered for major construction projects and, in particular, for critical facilities.

INTRODUCTION

A variety of phenomena that can cause damage to property and/or threaten lives may accompany earthquakes. The principal hazards are addressed in other reports in this Professional Paper covering surface-fault rupture, ground shaking, liquefaction, tectonic subsidence, landslide, and rockfall hazards. It is the purpose of this report to discuss other potentially damaging but less well-understood phenomena associated with earthquakes, including: 1) ground failure due to loss of strength in sensitive clays; 2) subsidence caused by vibratory settlement in granular materials; 3) flooding caused by seiches in Great Salt Lake; 4) flooding due to surface drainage disruptions; and 5) increased ground-water discharge. A major goal is to translate technical information so that government officials and the general public can appreciate the need to reduce earthquake hazards.

GROUND FAILURE DUE TO LOSS OF STRENGTH IN SENSITIVE CLAYS

Nature And Causes

Fine-grained lake deposits underlie much of western Davis County. Near Farmington these deposits are about 810 feet thick (Feth and others, 1966), and some areas of Davis County may be underlain by as much as 1,000 feet of sediments (Parry, 974) deposited by lakes occupying the Great Salt Lake Basin during the last 15 million years (Currey and others, 1984).

Much of these lake sediments are silicate clays, some of which are classified as sensitive (Parry, 1974).

Most clays lose strength when disturbed; sensitive clays are those which experience a particularly large loss of strength. The sensitivity of clays is defined as the ratio of shear strength in an undisturbed condition to shear strength after being remolded (severely disturbed)(Costa and Baker, 1981). One proposed origin for these clays holds that the platy clay particles were deposited in an edge-to-edge "house of cards" (flocculated) structure in saline (generally marine) environments in which the sodium and other cations in the water provided bonding strength (Rosenqvist, 1953, 1968). Later, when this saline water is leached out by fresh ground water, the clays are left in an unstable arrangement subject to collapse and liquefication when disturbed or shaken. After disturbance, the clays may revert from a flocculated soil structure in which ground water fills the interstitial pore spaces, to a dispersed soil structure in which the interstitial water is expelled, often liquefying the clay (Costa and Baker, 1981).

Effects

The principal effect of disturbance of sensitive clays is ground failure. The kinds of ground failures associated with sensitive clays are similar to those accompanying liquefaction, including flow failures, slump-type landslides,

and lateral spreads or translational landslides (Earthquake Engineering Research Institute, 1986; Costa and Baker, 1981). Liquefied sensitive clays may flow downhill on slopes of one degree or less (Costa and Baker, 1981). One triggering mechanism for ground failure in sensitive clays is intense ground vibration generated by earthquakes. The most devastating damage resulting from the 1964 Anchorage, Alaska, magnitude-8.6 earthquake was the result of translational landslides accompanying failure in sensitive clays. The largest of these landslides, located in the Turnagain Heights residential area, damaged 75 homes (Hansen, 1966).

The potential for ground failure in sensitive clays is related to the intensity and duration of ground shaking, and the sensitivity of the clays. Clays with sensitivities of 10 or more may be prone to failure during seismic ground shaking (Earthquake Engineering Research Institute, 1986). Clays exceeding sensitivities of 10 have been identified in Davis County along the Weber River and at the Interstate 15 Parrish Lane overpass (Parry, 1974), indicating that sensitive clays are present and may be widely distributed in Davis County. The intensity and duration of ground shaking needed to induce failure in these sensitive clays have not been investigated and, therefore, the probability of this type of ground failure occurring in Davis County cannot be currently determined.

Hazard Reduction

Earthquake-induced ground failure due to sensitive clays

has the potential to cause damage to most types of structures. Possible actions which may be taken if sensitive clays are present include: 1) improving site conditions by converting the clays from a flocculated soil structure to a dispersed soil structure (preconstruction vibration techniques, etc.) and/or dewatering the site; 2) designing the structure to withstand the effects of the potential ground failure using structural solutions such as end-bearing piles (placed below the sensitive clay), caissons, or fully compensated mat foundations designed for the anticipated failure type; and 3) avoid the risk by moving the proposed development to a less hazardous site.

Land-Use Planning

Maps have not been produced which show the extent of sensitive clay deposits in Davis County, but assessment of this hazard can be undertaken at site-specific level as part of standard foundation investigations. This involves laboratory tests (unconfined compression tests) in which axial loads are applied to unconfined cylindrical samples, first in an undisturbed state and then in a remolded state (Spangler and Handy, 1973). The ratio of the strength of the soil under undisturbed versus disturbed conditions is then determined. Additional study is needed to determine the levels of ground shaking necessary to cause ground failure in sensitive clays before this hazard can be considered in regional land-use

planning. Sensitive clays are, a factor that should be considered in site-specific studies for all major construction, however, including critical facilities.

SUBSIDENCE CAUSED BY VIBRATORY SETTLEMENT IN GRANULAR MATERIALS

Nature And Causes

Loose granular materials such as some sands and gravels can be effectively compacted by vibration. The material assumes a more dense arrangement by particles moving closer together and decreasing the volume. Earthquake-induced ground shaking is one source of vibrations that may cause this type of subsidence. During the 1964 Alaska earthquake, vibratory settlement caused the ground to subside at some locations as much as 5.9 ft (Costa and Baker, 1981). Materials that may be susceptible to vibratory settlement are relatively common in Davis County. Large areas of western Davis County are underlain by clean sand and gravel deposited in Pleistocene Lake Bonneville where the potential for settlement may be high. Also, many areas of fill exist in the county which may be susceptible to vibration-induced settlement. No studies to determine levels of ground shaking necessary to induce vibratory settlement in susceptible soils have been conducted in Davis County and, therefore, probabilities of this hazard occurring are unknown.

Effects

Differential settlement can cause severe damage to structures if foundations are built across deposits with varying physical properties such as sorting and texture, which can cause one part of the foundation to settle more than another (Costa and Baker, 1981). Structural failure of building members (Dunn and others, 1980), and foundation cracking may also be caused by excessive settlement. Earthen fill is commonly used for construction of railway embankments, highway foundations, bridge abutments, and dikes and levees. Even minor differential settlement can cause extensive damage to these structures. If not adequately compacted during placement, these fills may be susceptible to this hazard because of the granular material commonly used (Schmidt, 1986). Utility lines and connections may be severed due to vibratory settlement. Rate of settlement is an important factor that must be considered in evaluating the potential for damage (Dunn and others, 1980). Settlements due to earthquake ground shaking would be nearly instantaneous.

Hazard Reduction

Structural methods to reduce damage due to settlement include supporting structures on piles, piers, caissons, or walls which are founded below the susceptible material (U. S. Department of the Interior, 1985). Where structural measures to reduce vibratory settlement in granular soils are not

possible, actions which may be taken to mitigate the hazard include: 1) improve site conditions by removing or precompacting the in situ granular materials prior to construction; and 2) avoid the risk by moving the proposed development to a less hazardous site.

Land-Use Planning

Maps delineating areas susceptible to vibratory settlement have not been completed for Davis County. Also, studies to determine the levels of ground shaking necessary to induce settlement have not been completed. Vibratory settlement, therefore, may not be properly considered in land-use planning in Davis County. Assessment of this hazard can be undertaken at a site-specific basis, however, as part of a standard foundation evaluation. Standard penetration and Dutch cone penetrometer tests are commonly used to evaluate the potential for vibratory settlement (Dunn and others, 1980). The potential for vibratory settlement should be evaluated for all major construction, especially for critical facilities.

FLOODING CAUSED BY SEICHES IN GREAT SALT LAKE

Nature And Causes

A seiche is the oscillation of the surface of a lake or other landlocked body of water; seiches vary in period from a

few minutes to several hours. Seiches can be likened to the oscillations produced by the sloshing of water in a bowl or a bucket when it is shaken or jarred (Nichols and Buchanan-Banks, 1974). The magnitude of oscillation of the water surface is determined by the degree of resonance between the water body and the periodic driving force such as earthquake ground shaking and wind. When the periodic driving force is oscillating at the same frequency at which the water body tends to oscillate naturally, the magnitude of the oscillation is greatest. The oscillation takes the form of unusually large waves that break at considerable height and with great suddenness along the coastline (Costa and Baker, 1981).

The effects of seiches are in part determined by water depth, the configuration of the local shoreline, and the lake bottom. These parameters determine the lake's natural period of oscillation and inherent system of long waves, much as the natural frequency of a pendulum is determined by its physical characteristics (Lin and Wang, 1978). The system of long waves includes an infinite number of species of waves, usually called the normal modes. The fundamental mode refers to the wave with the longest wavelength (Lin and Wang, 1978). It is the fundamental mode that is generally observed during surging and seiching (Lin and Wang, 1978). The period of the fundamental mode of Great Salt Lake's South Basin is 6 hours (Lin and Wang, 1978). Studies from other areas have shown that seiches may raise and lower a water surface from inches to many yards, causing severe flooding and damage from wave action (Blair and Spangle, 1979).

Seiches may be generated by wind, landslides, and/or earthquakes (ground shaking, surface-fault rupture, and earthquake-induced landslides). The principle area at risk from seiches in Davis County is the shore of Great Salt Lake. Wind seiches in Great Salt Lake have been studied and the maximum wave amplitude generated by this type of seiche is expected to be about 2 ft (Lin and Wang, 1978). No systematic or theoretical studies of landslide or earthquake-induced seiching in Great Salt Lake have been completed. Seiches were reported along the southern shoreline of Great Salt Lake at Saltair and at the trestle at Lucin during the magnitude 6 Hansel Valley earthquake of October 5, 1909 (Williams and Tapper, 1953). The elevation of Great Salt Lake was 4202.0 ft on October 1, 1909 (U.S. Geological Survey lake elevation records). The seiche generated by the 1909 Hansel Valley earthquake overtopped the Lucin cutoff railroad trestle which had an elevation of 4214.85 ft (Southern Pacific Transportation Company records). Assuming that reports of the seiche overtopping the trestle are true, and that lake and trestle elevation records were accurately reported, the seiche wave was more than 12 ft high.

Effects

Damage from seiches is primarily related to flooding, erosion, and forces exerted by waves. Seiches are a potential hazard to shoreline development and in-lake structures, and

are becoming a concern to the proposed inter-island diking project in Great Salt Lake.

Hazard Reduction

Dikes which are protected against erosion on the lakeward side and engineered breakwaters can be used to protect development or dissipate wave energy. Shoreline buildings can also be floodproofed, elevated, and constructed or reinforced to withstand the lateral forces of seiches (Costa and Baker, 1981).

Land-Use Planning

Maps have not been produced that show areas that may be affected by seiches in Davis County. No comprehensive studies of landslide or earthquake-generated seiches have been completed for Great Salt Lake, but eyewitness accounts of the seiche generated by the 1909 Hansel Valley earthquake suggest that maximum wave amplitudes generated by earthquakes may far exceed maximum wave amplitudes associated with wind seiches. Landslide and earthquake-generated seiches are a hazard to shoreline development and in-lake construction and should be taken into consideration during planning phases of development in Great Salt Lake and within the proposed Great Salt Lake Beneficial Development Area (Utah Division of Comprehensive Emergency Management, 1985).

FLOODING DUE TO SURFACE DRAINAGE DISRUPTIONS DURING EARTHQUAKES

Flooding may be caused by earthquake ground shaking, surface-fault rupture, ground tilting, and landsliding during earthquakes if water tanks, reservoirs, pipelines, or aqueducts are ruptured, or if stream courses are blocked or diverted. The areas where such flooding may occur can be predicted to some extent by defining where such structures and streams cross known active faults, active landslides, and potentially unstable slopes. Damming of streams by landslides can cause upstream inundation and, if the landslide dam subsequently fails, cause catastrophic downstream flooding (Schuster, 1987). Maps delineating active faults and landslides are available at the Davis County Planning Department. Site-specific studies addressing earthquake and slope-failure hazards should be completed prior to construction for all major water-retention structures or conveyance systems so that mitigative measures can be recommended. For existing facilities, studies can be done to evaluate the possible extent of flooding and to recommend drainage modifications to prevent damaging floods. Potential flooding from diversion of stream courses is more difficult to evaluate, but should be considered during hazard evaluations for critical facilities.

INCREASED GROUND-WATER DISCHARGE DUE TO EARTHQUAKES

The effects of earthquakes on ground-water systems have not been extensively studied and, consequently, are not well understood. During the 1983 Borah Peak, Idaho, earthquake, local surface flooding and erosion were caused by increases in spring flow and expulsion of water from shallow bedrock aquifers. Resulting increases in stream flow of more than 100 percent occurred following the earthquake, and flow remained high for about 2 weeks before declining to near original levels (Whitehead, 1985). Although this earthquake appeared to be one in which the ground water was more profoundly affected than others, similar effects may occur during large-magnitude earthquakes in the vicinity of Davis County. Increased flow from springs in mountain drainages will be confined to stream channels, and adherence to Federal Emergency Management Agency flood-plain regulations should effectively reduce the risk. Increased flow from springs on the valley floor may result in ponded water and basement flooding. Until further evaluation of this phenomena has been completed and areas at risk are mapped in Davis County, it is not feasible to consider earthquake-induced ground-water discharge on the valley floor in regional land-use planning.

CONCLUSIONS AND RECOMMENDATIONS

This report identifies a variety of phenomena associated with earthquakes which can damage property and threaten lives.

Although many of the consequences of these hazards have been identified, the probability of occurrence has not been evaluated for Davis County, and maps delineating areas in Davis County where hazards associated with these phenomena may occur are not available. Much study is required before these phenomena can be considered in regional planning for Davis County. However, some of these hazards can be evaluated on a site-specific basis; such studies should be considered for major construction projects, particularly critical facilities.

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REFERENCES CITED

Blair, M. L., and Spangle, W. E., 1979, Seismic safety and land-use planning - selected examples from California: U. S. Geological Survey Professional Paper 941-B, 82 p.

Costa, J. E., and Baker, V. R., 1981, Surficial geology, building with the Earth: New York, John Wiley and Sons, Inc., 498 p.

Currey, D. R., Atwood, Genevieve, and Mabey, D. R., 1984, Major levels of Great Salt Lake and Lake Bonneville: Utah Geological and Mineral Survey Map 73, 1:750,000 scale.

Dunn, I. S., Anderson, L. R., and Kiefer, F. W., 1980, Fundamentals of geotechnical analysis: New York, John Wiley and Sons, Inc., 414 p.

Earthquake Engineering Research Institute, 1986, Reducing earthquake hazards: lessons learned from earthquakes: Earthquake Engineering Research Institute Publication No. 86-02, 208 p.

Feth, J. H., Barker, D. A., Moore, L. G., Brown, R. J., and Veirs, C. E., 1966, Lake Bonneville: geology and hydrology of the Weber Delta District, including Ogden, Utah: U. S. Geological Survey Professional Paper 518, 76 p.

Hansen, W. R., 1966, Effects of the earthquake of March 27, 1964, at Anchorage, Alaska: U. S. Geological Survey Professional Paper 542-A, 68 p.

Lin, Anching, and Wang, Po, 1978, Wind Tides of the Great Salt Lake: Utah Geology, v. 5 no. 1, p. 17-25.

Nichols, D. R., and Buchanan-Banks, J. M., 1974, Seismic hazards and land-use planning: U. S. Geological Survey Circular 690, 33 p.

Parry, W. T., 1974, Earthquake hazards in sensitive clays along the Wasatch Front, Utah: Geology, v. 2, no. 11, p. 559-560.

Rosenqvist, I. Th., 1953, Consideration of the sensitivity of Norwegian quick clays: Geotechnique, v. 3, p. 195-200.

----, 1966, Norwegian research into the properties of quick clay - a review: Engineering Geology, v. 1, p. 445-450.

Schmidt, R. G., 1986, Geology, earthquake hazards, and land-use in the Helena area, Montana - a review: U. S. Geological Survey Professional Paper 1316, 64 p.

Schuster, R. L., 1987, Landslide damming of mountain streams: Geological Society of America, Abstracts with Programs, v. 19, no. 5, p. 332.

Spangler, M. G., and Handy, R. L., 1973, Soil Engineering: Intext Educational Publishers, New York, 748 p.

U. S. Bureau of Reclamation, 1985, Earth manual - a water resources technical publication: U. S. Department of Interior, 810 p.

Utah Division of Comprehensive Emergency Management, 1985, State hazard mitigation plan - 1985 - Executive summary, Great Salt Lake Beneficial Development Area: Utah Division of Comprehensive Emergency Management, 21 p.

Whitehead, R. L., 1985, Hydrologic changes following the Idaho Borah Peak earthquake: Proceedings of workshop XXVIII on the Borah Peak, Idaho Earthquake, v. A., U. S. Geological Survey Open-File Report 85-290, p. 556-572.

Williams, J. S., and Tapper, M. L., 1953, Earthquake history of Utah, 1850-1948: Bulletin of the Seismological Society of America, v. 43, no. 3, p. 191-218.

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