PLANNING SCENARIO
for a Major Earthquake

Reno-Carson City Urban Corridor
Western Nevada

PHASE I
The Scenario Earthquake and Associated Hazards

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This information should be considered preliminary. It has not been edited, reviewed, or checked for completeness or accuracy.

These Scenario Maps are for Emergency Planning Purposes Only

TABLE OF CONTENTS

Preface 4

Executive Summary 5

Acknowledgments 6

Introduction 7

Uses and Limitations of Scenario Maps and
Damage Assessments 8

Geology and Seismology 9
The Carson Range fault system 9
Major earthquakes in western Nevada 10

The Scenario Earthquake 16
Rationale for selecting the earthquake 16
Characteristics of the scenario earthquake 17
Estimated seismic intensity distribution 18
Surface faulting hazards 22
Liquefaction hazards 22
Rockfall, landslide, and snow avalanche hazards 25

Geologic Hazards Posed by the Scenario Earthquake 28

References 29

Appendix 31

Plates 33

PREFACE

This open-file report was written as background information for the scenario earthquake. As such, it is geared to several widely diverse audiences, from scientific to the general public. To accommodate this, some discussions get somewhat detailed and use scientific jargon. Our apologies to those who do not understand (or have time to read) these sections; please skip over them. For those whose scientific curiosity is aroused, a geologic dictionary will help with some of the words. Our apologies to the scientists, as well. Although these discussions are detailed enough to understand what we did, they do not offer all the nuances of decisions and technical details, and in some cases are not totally comprehensive discussions. We have tried to generalize as much of the information as we could.

This report is written in the spirit of becoming more prepared for a disastrous earthquake. We cannot stop earthquakes from occurring and there is usually no forewarning that one is about to occur. But, as has been demonstrated in California, we can reduce injuries, damage, and economic disruption by preparing for an earthquake, and knowing what the best way to survive, respond to, and recover from an event is. This report is dedicated to all those engaged in this effort in western Nevada. Together, we can make a difference.

Craig M. dePolo
April 25, 1995

EXECUTIVE SUMMARY

The Western Nevada Earthquake Scenario Project is being produced to assist and improve the planning and response for an earthquake event in this region. Earthquakes are instantaneous events; there is usually no forewarning. If an earthquake is large enough and close enough to a community, an earthquake can be an instantaneous disaster. Therefore planning for earthquakes makes good sense. The recent 1994 magnitude 6 Double Spring Flat earthquake, just south of Carson Valley, emphasizes to us beyond any question that western Nevada is earthquake country.

A magnitude 7.1 earthquake along the northern Carson Range front is used as the scenario earthquake. Earthquake effects from this event that are presented are Modified Mercalli earthquake intensity, surface faulting, liquefaction, and mass wasting (rockfalls, snow avalanches). The preparation of the scenario earthquake and its associated hazards has been the first phase of this project. The second phase is the description of hypothetical, but realistic effects of the scenario earthquake. The third phase of the project is planning to respond to the scenario earthquake.

The Modified Mercalli Intensity map for this event was estimated by: 1) estimating general velocity groups for the local geologic units, 2) using Boore and others' (1993, 1994) relationship to calculate peak bedrock accelerations, and 3) using Krinitzky and Chang's (1988) relationships to convert peak bedrock acceleration into intensity. A zone of normal-slip surface faulting 32 km (20 mi) long and up to 33 m (100 ft) wide extends from Washoe Valley, along the base of the Carson Range and into southwest Reno. The ground is offset 2 m (6 ft) vertically over much of this distance, with a localized maximum of 4 m (13 ft), and the rupture dies down to 0.5 m (1.5 ft) in Reno. High and moderate areas of liquefaction susceptibility were identified by using a detailed study by Wythes (1993) for the Reno area and crossing areas of sandy Holocene alluvium with groundwater tables of less than or equal to 3 m (10 ft) and 10 m (30 ft), respectively. Areas of major rockfall and landslide hazard were delineated by identifying bouldery slopes greater than 33 m (100 ft) high that exceed 50% gradient, and by identifying existing landslides. Localized rockfall potential was delineated as any slopes of greater than 70% gradient. Areas of potential earthquake-induced snow avalanche are also identified.

The scenario earthquake strongly shakes western Nevada and poses many serious geologic hazards. Preparation for an event of this severity would be, in general, adequate for almost any earthquake that could affect this region.

ACKNOWLEDGMENTS

This project was made possible by funding from the Federal Emergency Management Agency, through the National Earthquake Hazards Reduction Program. We sincerely appreciate these resources.

A special thanks goes to our sister agency, the California Division of Mines and Geology (CDMG). The CDMG made available information and examples that provided the nucleus of our scenario. Without their help, the task of creating the scenario project would have been significantly more difficult, and not have benefitted from their experience. In particular, we would like to thank Tousson R. Toppozada and Michael S. Reichle from the Sacramento office.

The U.S. Geological Survey Water Resources Division in Carson City provided well water data for the liquefaction analysis. We would like to thank Karen Mello and Sonya L. Clary for their assistance in obtaining these data.

We also thank WESTEC of Reno for donating Mr. Wythes' time to this project.

INTRODUCTION

An earthquake scenario describes what could happen in an area in response to a specific plausible earthquake. It consists of several phases. The first phase is the identification of the earthquake, and estimation of geological effects of that event. The second phase is to consider the response of various facilities to the event, and the third phase is to determine how to best organize the human response. The purpose is to facilitate earthquake preparedness. Response plans can be developed, tested, and coordinated, and hopefully mitigation will occur to lessen the impacts of the earthquake. Scenarios are becoming widely used in the United States, because they are perhaps the best means for scientists studying earthquake hazards to communicate the hazards effectively to the population that will be affected. They are also an excellent basis for a community to prepare for the many different impacts that occur during an earthquake (and other) disaster.

Western Nevada stands to benefit greatly from a scenario. The population of the Reno-Carson City urban corridor is exposed to a very significant level of seismic hazard and, consequently, risk. In 1994, approximately 320,000 people resided in the western Nevada region. There is also a large tourist population, which may be as large as 100,000 during large and special events. The region is a vital center for the gaming and transportation sectors of the Nevada economy, and home of the State Capital and the one of the State's two universities. All of these factors emphasize the importance to Nevada of planning for, and being able to respond effectively to, a strong earthquake.

Historical earthquakes that have affected the region include several magnitude 6+ events within the urban corridor. Paleoseismic evidence indicates that earthquakes from 6.6 to 7.5 or greater could occur along the active local range front faults. Most of the historical earthquakes occurred in the 1800s or the earliest 1900s. The long period of relative quiescence since then invites complacency, but any sense of security from earthquakes would not find scientific justification.

The earthquake that is described in this scenario is very intentionally chosen to be a large event (magnitude 7.1) that severely taxes local resources and local ability to respond, and creates many geologic hazards. It originates on the northern extension of the Carson Range fault system. This fault system forms the eastern boundary of the Carson Range, a young, linear mountain range with peaks 6000 to 7000 feet (1830-2130 m) above the Reno - Carson City urban corridor. The Carson Range fault system dips east, underneath the Carson Valley, Washoe Valley, and Truckee Meadows. The valleys that form on the hanging wall of the fault are broad, relatively flat, and have shallow water tables. All of these features plus the proximity to the mountains make it a very attractive, even ideal, location for a city to develop. These features also exacerbate the seismic hazards. The earthquake that is described here is believed to be a real event, but one that probably happens only once every 1000 to 2000 years. It can be safely stated that if the community is prepared for this event, it will be well prepared for just about any earthquake.

USES AND LIMITATIONS OF SCENARIO MAPS AND DAMAGE ASSESSMENTS

The general approach in evaluating damage assessments is first to evaluate the potential ground shaking and surface rupture from the scenario event, and second to speculate on the plausible disruption to various major facilities and lifelines. The effects of the scenario earthquake are based mainly on the authors' and their consultants' professional judgements. Users of this scenario must recognize that assessments of the performance of individual structures are hypothetical and are not the result of site-specific evaluations. **It is therefore improper to use this earthquake scenario for any purpose other than emergency response and preparedness planning.**

When the scenario event does occur, the details of effects would likely be different. Some effects would be worse than the scenario suggests, and some not as bad. However, experiences from other earthquakes show that the general kinds of effects that are described would occur. Also, areas of high risk from this earthquake will often correlate with areas of high risk in other earthquakes. Thus, preparing for this earthquake scenario prepares for many other potential earthquakes in the region at the same time.

The predicted seismic intensities from which damage was assessed are based on a specific model. A different model would yield a different intensity pattern. The quality of geological information, on which the seismic intensity distribution map also depends varies throughout the planning area. Only generalized geologic information is available for much of the area.

While no scenario is accurate in detail, it provides planners with a regional pattern of the degree and a representation of the types of multiple hazards and multiple problems that will confront emergency response personnel.

Planning scenarios serve two principal functions: to assist with preparing for emergency response activities, and communicating the threat and potential consequences of an earthquake event to various professionals, politicians, and the public. The following is taken from the California Division of Mines and Geology's San Bernardino earthquake planning scenario, by Toppozada and others (1993).

"This planning scenario is intended to contribute to the efforts of the following types of users:

- Local, state, and federal officials with emergency planning responsibilities.

- Elected officials who need to visualize the threat in order to commit themselves to the leadership roles needed.

- Private sector managers, planners, and professionals who must understand the scope of the hazard in order to prepare for it.

- Educators, journalists, and others who must communicate to the public the character of the threat, and the importance of preparedness in mitigating its effects.

- The general public who need to support public mitigation efforts and develop personal strategies to minimize the effects of the earthquakes on themselves and their families."

This scenario is being produced through joint funding by the Nevada Bureau of Mines and Geology and the Federal Emergency Management Agency. A framework to create the earthquake and its associated hazards (described below) was developed by the Nevada Bureau of Mines and Geology, the University of Nevada Seismological Laboratory, and WESTEC. The scenario was produced on the Nevada Bureau of Mines and Geology's Geographical Information System to facilitate the input and presentation of information and data from many different sources.

The project is divided into two phases. The first phase (Phase I) is the production of the earthquake event, the shaking intensity, the surface rupture, potential areas of liquefaction, and potential areas of rockfall. This report is principally the results of Phase I. The second phase (Phase II) is the solicitation of input from the local industrial and governmental entities on hypothetical, but realistic, effects of the scenario earthquake. Further phases of preparing master plans and exercising plans are hoped to be added.

GEOLOGY AND SEISMOLOGY

The Carson Range Fault System

The eastern Carson Range front is bounded by a prominent fault system, known as the Carson Range fault system (CRFS). The system extends 96 to 102 km (60-63 mi) from near Markleeville in the south to Reno in the north. This fault system can be subdivided into two major fault zones, the Genoa fault in the south and the Mt. Rose fault zone in the north.

Recent studies by Ramelli and others (1994) have divided the CRFS into five geometric or structural segments. Their conclusions are based on geologic mapping and trenching results. The results begin to describe the paleo-earthquake history of the system. They estimate that major earthquakes likely involve multiple segments and occur every few thousand years. Existing geologic information suggests the last time an event occurred along the Mt. Rose fault zone was about 1000 years ago (Schilling and Szecsody, 1982).

Two segments are identified along the northern part of the CRFS, the Mt. Rose and Washoe Valley segments. These two segments are separated from the southern part of the CRFS by a significant discontinuity in the fault system which is taken to control the southern extent of the scenario event. The Mt. Rose segment can be further subdivided by character into the Mt. Rose fan and Reno sections. Failure of these two sections constitutes the first two subevents of the

scenario earthquake. Both sections are thought to have low dips (<50°) and are modeled that way. The Reno section consists of discontinuous faults scarps that leave the range front and enter Reno from the southwest, continuing to near the heart of the city. The Mt. Rose fan section consists of a range front fault, and many other faults distributed over the fan and mountain front. The scenario earthquake's hypocenter is near the junction of the Reno and Mt. Rose sections, at the deepest part of the seismogenic fault. Because the fault dips to the east, the epicenter is in the Virginia Range. The Washoe Valley segment is made up of two principal, subparallel faults, the Washoe Valley fault and the Little Valley fault; failure of these two faults make up the second pair of subevents for the scenario earthquake. These two sections are thought to have dips of about 60°. Figure 1 shows a simplified map of the portion of the Carson Range fault system that is involved in the scenario earthquake, the epicenter of the scenario earthquake, and a cross section showing the hypocenter.

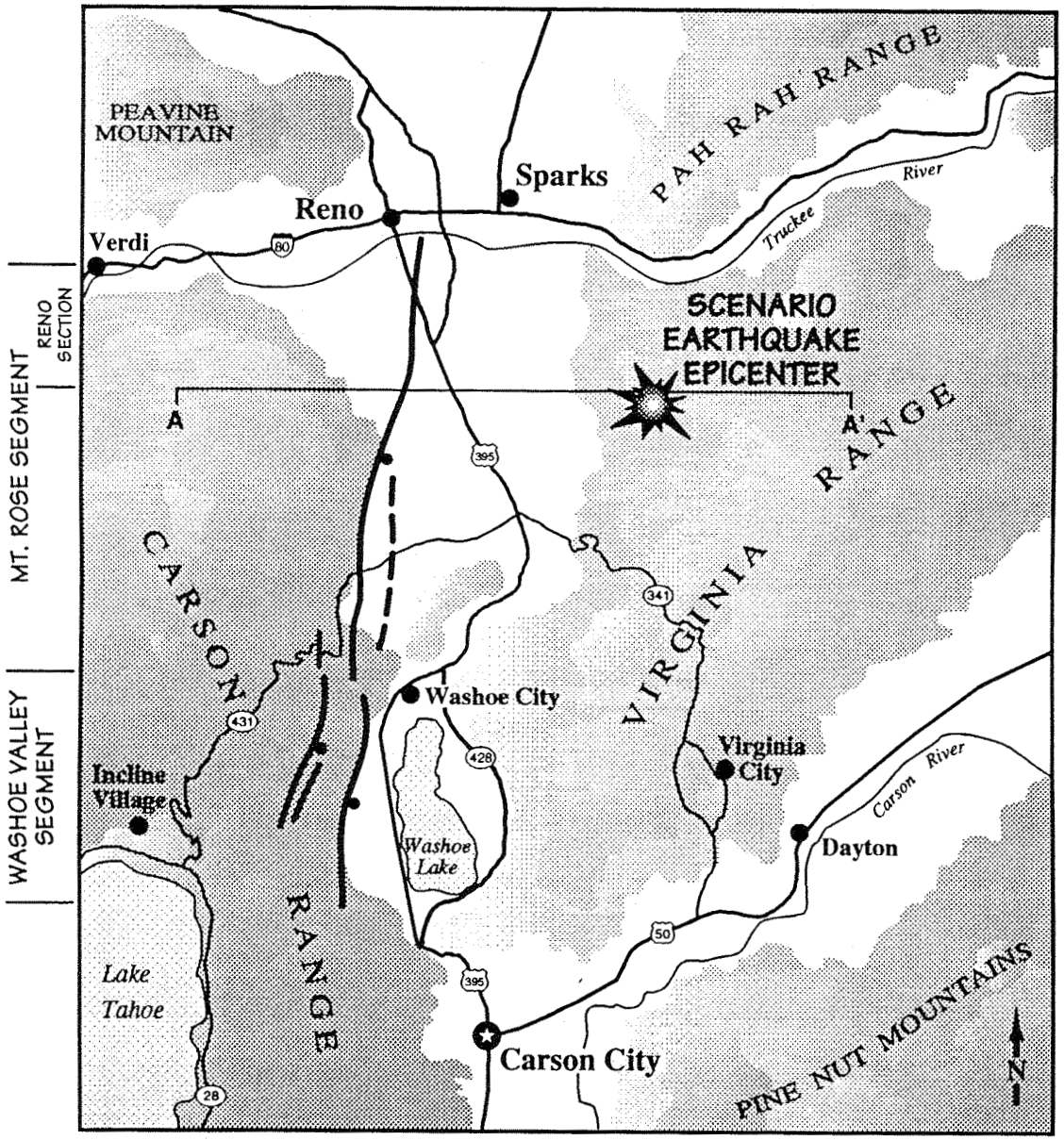
Major Earthquakes in Western Nevada

Since 1852, there have been 13 earthquakes in the western Nevada region of magnitude ~6 or greater, and two with magnitudes of 7 or greater. Thus, the statistical average of occurrence of earthquakes of magnitude 6 or greater is once every 11 years. These events are not evenly spaced in time, however. The shortest time intervals between magnitude 6 and greater earthquakes is about two months (1914 earthquakes), and the longest time is 28 years between the 1966 and 1994 earthquakes. Although there was only eight hours between two magnitude 6 events in 1869, the second was likely an aftershock of the first. The most recent earthquake was in 1994. None of these earthquakes have been as severe in the Reno-Carson City area as the scenario earthquake. Their existence proves the seismic potential for the region. Other earthquakes, many at larger distances, have been felt strongly in the area (e.g., 1872 Owens Valley earthquake, 1894 Virginia City earthquake, 1932 Cedar Mountain earthquake, and the 1954 Fairview Peak-Dixie Valley earthquake sequence), but the record seems to indicate these 13 events were the strongest. The following sections summarize some of what is known about these larger earthquakes.

The dates and times for these earthquakes are reported in local Pacific Standard Time, rather than Greenwich Meridian Time more commonly used by seismologists.

The magnitudes reported for all events except 1994 are from Rogers and others (1991). The 1994 earthquake magnitude is from the University of Nevada, Reno Seismological Laboratory. It should be noted that other magnitude estimates exist for these earthquakes. To avoid unnecessary confusion, a single modern reference was quoted. In the judgement of the foreauthor of this report, the magnitude values presented are reasonable estimates, even though future adjustments to these values may occur.

Twelve of the 13 events are shown in figure 2 (the location of the 1857 earthquake is too uncertain to plot). Also shown on this figure are earthquakes from the Central Nevada seismic belt which are not discussed here. The earthquake locations shown in this figure are based on recent research and have not been through a scientific review process. Further, this research is



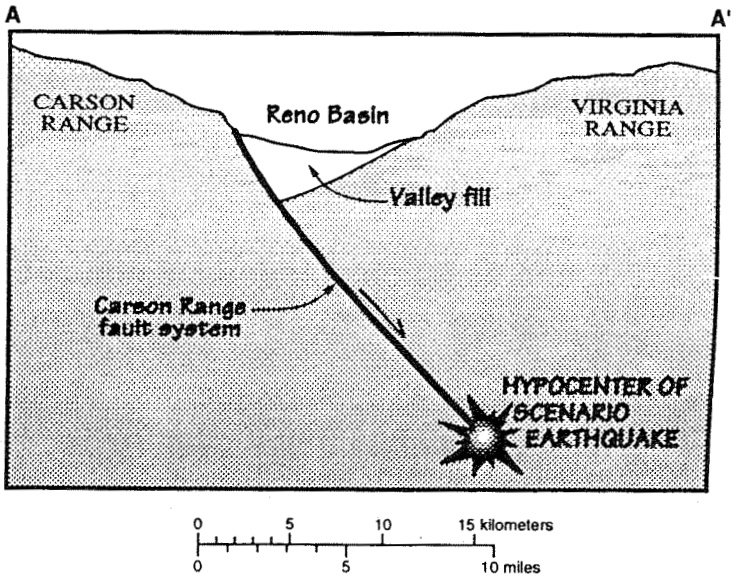


Figure 1 Simplified fault map and cross section of the scenario earthquake and causative fault. Bold lines are the faults involved in the earthquake; balls are on downthrown side. The cross section is hypothetical. Actual subsurface geology is poorly understood.

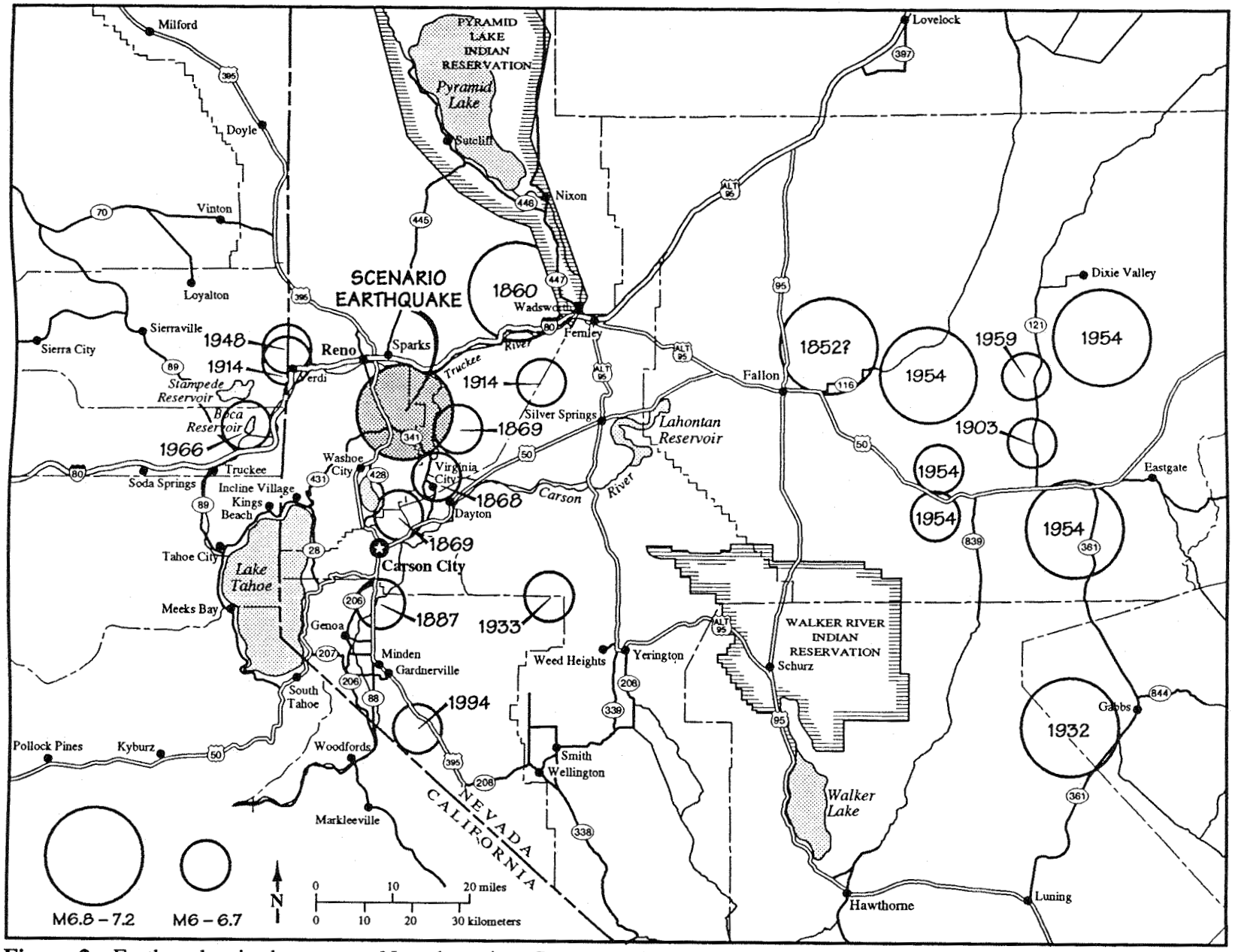


Figure 2 Earthquakes in the western Nevada region. Some locations are approximate.

ongoing, so the locations might be adjusted slightly as new data become available. This figure also shows the location of the scenario earthquake.

1852(?) Western Nevada Earthquake, M7.3

The 1852(?) western Nevada earthquake is the first earthquake on record in Nevada. Its location appears to have been in the Carson Sink region (probably near Stillwater). An 1869 account by a Piute Indian, who was a boy at the time, recalls Indians being knocked down by the event, the fall of river banks in the Carson Sink area, broken ground, and the temporary reversal of flow of the river near Stillwater Station (Gold Hill Daily News, 12/30/1869). Another potential effect of this event is a large landslide reported occurring at Slide Mountain in late November or early December of 1852 (Washoe Weekly Times, 6/10/1865). Reportedly, two men at Genoa distinctly heard and felt the shock associated with the landslide; it is unlikely that the landslide itself caused perceptible ground motion or noise that could be heard as far south as Genoa, and is more likely to have been an earthquake causing the slide. Some corroboration of this account is given by a discussion of Indian traditions, that a great many years ago, the "whole side" of Slide Mountain came down during an earthquake (Territorial Enterprise, 11/27/1894). The most direct account for placing this earthquake 1852 comes from an account in 1865 that says that the Piute Indians often talk about a "great" earthquake that occurred 13 years before (Daily Reese River Reveille, 10/17/1865). Ryall (1977) suggests this event occurred in 1845; notes by Ryall indicate that this was based on interpreting the 1869 account strictly (the Indian was a boy at the time of the earthquake and was guessed in 1869 to be about 30 years old) and a lack of felt reports in the Sierra Nevada in 1852.

1857 Western Nevada Earthquake, M6.2

Very little is known about this earthquake, especially about its exact location. The first newspaper in Nevada began in 1858. Toppozada and others (1981) examined the intensity pattern in the Sierra Nevada communities and concluded that the effects were similar to the 1860, 1868, 1869, and 1887 Nevada earthquakes, and that it was likely near the Nevada/California border. Because of the uncertainty in this event's location, it is not represented on figure 2.

1860 Pyramid Lake Earthquake, M7.0

This earthquake caused goods to shaken from shelves and general panic in Carson City, although no damage was reported (Holden, 1898; Toppozada and others, 1981). The earthquake was felt as far away as Yreka and San Francisco in California (Toppozada and others, 1981). Toppozada and others suggest that the epicenter of the event was near Pyramid Lake since seven aftershocks were reported the same day (March 15) in the Pyramid Lake area and rock slides were reported between Pyramid Lake and Carson City. This earthquake may have caused the fresh fault near Derby noted by a prospector in the 1860s; if so, the Olinghouse fault may have been the source of the event (see discussion under 1869 Western Nevada earthquake).

1868 Virginia City Earthquake, M6.0

This earthquake occurred on May 29. At Virginia City, brick buildings were cracked, some bricks shaken down, and plaster fell in nearly all brick buildings (Toppozada and others, 1981). Two foreshocks were reported in Virginia City, 14 and 5 minutes before the main event (The Daily Trespass, 5/30/1868). Toppozada and others comment that the intensity distribution for this event resembles that of the 12/27/1869 earthquake. This event may have been a foreshock to the 1869 earthquakes.

1869 Western Nevada Earthquakes, M6.7 and M6.1

The December 26, 1869 Western Nevada earthquake strongly shook western Nevada and eastern California. This event seriously damaged masonry walls in Virginia City and Washoe City, and caused some damage in communities of the Sierra Nevada foothills of California. A second large earthquake (perhaps the largest aftershock) occurred eight hours later and strongly shook Carson City, but reportedly did little damage. Slemmons (1969) reports that Dr. Gianella of Mackay School of Mines interviewed a prospector from the Wadsworth-Olinghouse area who reported that during the 1860s a fresh fault appeared in the Derby Dam area of the Truckee River Canyon. In Dr. Slemmons' judgement, the largest event in the 1860s was in 1869. Thus, Dr. Slemmons felt it was likely that this surface rupture (which he found and mapped) was from this earthquake, and that this suggests the location of the event. Toppozada and others (1981) determined that an epicenter near Steamboat Springs would better fit the damage distribution and the second earthquake as an aftershock. It was also noted that Steamboat Springs spouted most furiously to the height of 3 to 4.5 m (10 to 15 ft) after the earthquake (Gold Hill Daily News, 12/27/1869).

1887 Carson Valley Earthquake, M6.3

This earthquake occurred on June 3, 1887 and caused very strong shaking in Carson Valley. At Genoa, houses were shifted off their foundations and bricks were thrown down. At Carson City, chimneys were damaged, brick and stone walls were damaged, and plaster fell. Near Cradlebaugh's Bridge, south of Carson City, a fissure 15 m (50 ft) long opened up and mud and hot water spouted for a half an hour without abating (Earl, undated). Springs all around Carson City either increased in flow or went suddenly dry. General alarm occurred in Virginia City and Reno, but there was little damage. The earthquake appears to have occurred in Carson Valley.

1914 Reno Earthquakes, M6.0 and M6.4

In 1914 a pair of strong earthquakes shook the Reno region; the events occurred on February 18 and April 24. The first event had a magnitude of about 6 (Slemmons and others, 1965). Damage in Reno was limited to bricks falling from a chimney at the University of Nevada, broken windows, and cracked plaster (Reno Evening Gazette, 2/18/14; A. Jones, unpublished

notes). The event occurred at 10:19 AM (PST) and schools and buildings were evacuated immediately. At the University of Nevada, "the students and professors vied with one another in an attempt to be the first outside" (Reno Evening Gazette, 2/18/14). Because the strongest intensity of this event was to the west of Reno it appears that this event occurred in the Verdi area (K. Priestly, unpublished report, 1981).

The second event had a magnitude of 6.4 (Slemmons and others, 1965). This event threw down four chimneys at the University of Nevada and caused considerable glass breakage in the chemistry laboratory. China and other non-structural damage occurred in Reno. It is suggested that at least the second event occurred to the east of Reno (K. Priestly, unpublished report, 1981), which is consistent with strong shaking at Hazen.

1933 Wabuska Earthquake, M6.0

The Wabuska earthquake occurred on June 25, 1933 and was strongly felt in western Nevada. The earthquake was very severe in Virginia City with several chimneys knocked down and the Catholic Church badly damaged (Reno Evening Gazette, 6/26/33). Chimneys were thrown down in Carson City as well, and plaster fell from the assembly chamber in the State Capitol building. Numerous rockfalls occurred around Lake Tahoe, covering the highways. Reno was mostly spared from this event, experiencing only Modified Mercalli Intensity V. This event was part of a remarkably active earthquake period in western and central Nevada from about 1932 to 1934, which includes the 1932 Cedar Mountain earthquake (M7.2) near Gabbs.

1948 Verdi Earthquake, M6.0

On December 29, 1948, a magnitude 6.0 earthquake near Verdi caused Intensity VII damage to that community. The main event was preceded by several foreshocks. On December 27, notable foreshocks occurred at 5:15, 6:24, 8:21, 8:24, 9:24, and 10:04 PM (PST). The event at 9:24 PM is described as "a prolonged jolt beneath the city [Reno] for perhaps 30 seconds." On December 28, numerous earthquakes were felt, and at Verdi there were almost continuous vibrations. Following a lull of nearly 36 hours, almost everyone in a radius of 80 km (50 mi) was awakened by the mainshock at 5:53 AM on December 29th. Nearly every building in Verdi had some sort of damage. Brick parapets on the east and west side of the Verdi school building were sheared and thrown off. A wall of a grocery store was thrown down. Several chimneys were thrown down in Verdi and Floriston, and bricks thrown from many others. A chimney was also broken in Dog Valley. Windows were broken as far away as Reno. A water main between Reno and Sparks was sheared. In Verdi stoves were knocked out of line and in some cases went sliding into walls. Large boulders up to 1.5 m (5 ft) came down in the Truckee River Canyon along U.S. Highway 40 south of Verdi, knocking out both power and telephone lines. Telephone service in Reno was out for one to two days.

The earthquake is thought to have originated in Dog Valley, and to have possibly occurred along the Verdi fault (which is northerly trending as is the most severe damage) or the Dog

Valley lineament. In addition to foreshocks, "mysterious rumbles" or subterranean roars were heard in the Verdi-Reno region for about a year before the Verdi earthquake (Bell and others, 1982).

1966 Boca Valley (Truckee) Earthquake, M6.0

The 1966 Boca Valley earthquake, just northeast of Truckee, California, occurred on September 12. This earthquake caused damage to two local dams, highways, railroads, and water flumes and some minor structural damage to buildings. Damage to highways included cracked bridge abutments, settlement of engineered fill at abutments, slumping and fissuring of the highway (commonly at cut and fill contacts), and slides, slumps, and rockfalls between Boca and the Nevada/California border (Kachadoorian and others, 1967). Rockfalls, and horizontal and vertical settlement required realignment and repeated regrading of the Southern Pacific Railroad line (Kachadoorian and others, 1967). Rockfalls from this event also punctured and crushed the wooden flume in the Truckee River Canyon, and one 20-ton boulder punched a hole in the masonry wall of the Farad powerhouse (Kachadoorian and others, 1967). Building damage consisted mostly of toppled chimneys, but two buildings were racked badly. In Reno and Carson City, plaster fell and loose objects were knocked from shelves.

1994 Double Spring Flat Earthquake, M6.0

On September 12, 1994 a magnitude 6.0 earthquake occurred south of Carson Valley near Double Spring Flat. This is the mildest earthquake, in terms of its effects, in the Reno-Carson City urban corridor discussed in this paper. Due to its moderate magnitude, the sparseness of population in the epicentral area, and the time of day, the earthquake did only minor damage and caused no reported injuries. One chimney was toppled in Minden, a foundation was damaged in Double Spring Flat, and several rockfalls occurred along roadways. Ground cracking was noted in the epicentral area, but appears to be secondary in nature. A northeast trend is clear in the aftershock pattern, illuminating the buried causative fault. Several small foreshocks occurred over a 12-day period leading up to the mainshock, and background earthquakes notably occurred in the area over the year or two before the event.

THE SCENARIO EARTHQUAKE

Rationale for Selecting the Earthquake

The objective of the earthquake planning scenario is to represent a severe, but realistic earthquake disaster in the Reno-Carson City urban corridor for planning and preparedness purposes. The Carson Range fault system is the largest and most active fault system in the area, and thus is a logical choice for use as the earthquake source. The northern part of the fault system, known as

the Mt. Rose fault zone, is the actual part of the range front that is involved in the scenario earthquake. Four sections of the fault zone are failed. The northernmost section of the fault crosses into Reno and creates several surface offsets across roadways to force rerouting and roadway repair considerations. The earthquake source extends to southern Washoe Valley. The resultant size of the event is magnitude 7.1, a size that is similar, although perhaps slightly less, than what a seismic hazard analysis of the Mt. Rose fault zone would estimate to be the potential size. Even though this is only one of the many active faults in the Reno-Carson City urban corridor, this event creates damaging effects similar to what would be experienced from many other potential earthquakes in this region.

Characteristics of the Scenario Earthquake

Since it is characteristic of large Basin and Range province earthquakes to be complex and distributed in nature, rather than simple, some complexity is added to the two primary segments that fail. The resultant scenario earthquake is a total of four segments failing; the two primary segments and two additional segments, the Reno segment and the Little Valley fault.

Table 1 gives the input parameters of the four segments involved in the scenario event. Average subsurface displacement was estimated using estimated maximum surface displacement. Thatcher and Bonilla (1989) suggest that maximum surface displacement most closely approximates geodetic displacement (caused by slip at depth). This is partly because surface ruptures are commonly poorly expressed or distributed. The second assumption used is that the "average" or most likely measured offset along one or two points of a fault are about half of the maximum surface displacement; this is based on unpublished research of historical earthquakes in the Basin and Range province.

Table 1 — Earthquake Parameters for Segments Comprising the Earthquake Scenario

Segment	Dip	Ave. Displ.	Length	Fault Width
Reno	50°	1 m (3 ft)	8.6 km (5.3 mi)	15.7 km (9.7 mi)
Mt. Rose	50°	4 m (13 ft)	11.4 km (7.1 mi)	19.6 km (12.2 mi)
Washoe Valley	60°	3 m (10 ft)	8.6 km (5.3 mi)	17.3 km (10.7 mi)
Little Valley	60°	3 m (10 ft)	11 km (6.8 mi)	17.3 km (10.7 mi)

The size of the earthquake was determined by calculating the seismic moment and the related moment magnitude. Seismic moment is calculated by multiplying the area of the fault by its average subsurface displacement and by the shear rigidity. For this calculation, the base of the seismogenic zone is assumed to be at 15 km (9 mi) depth. The Reno segment is only taken to a 12 km (7.4 mi) depth since it is a secondary segment, with a smaller displacement than the others. The shear rigidity assumed was 3×10^{11} dyne/cm^2. Moment magnitude (which can simply

be considered the earthquake magnitude) is calculated by multiplying the logarithm of the moment by 2/3 and subtracting 10.7 (after Hanks and Kanamori, 1979).

The total seismic moment of the scenario earthquake is 6.1×10^{26} dyne-cm; this corresponds to a moment magnitude of 7.1. The total length of the surface rupture is about 32 km (20 mi). Several secondary breaks are indicated as well. The largest displacement of the surface is generally 2 m (6 ft), with localized portions of the central part of the Mt. Rose segment reaching up to 4 m (13 ft).

When a fault breaks, the failure moves down the fault at a speed of 2 to 3 km/sec (1.2 to 1.9 mi/sec). Thus, the earthquake happens relatively quickly. Most of the rupture occurs within about 10 seconds. Much of this time in this scenario earthquake, two rupture fronts are propagating and generating earthquake waves simultaneously. This is due to ruptures propagating in opposite directions from the hypocenter in the beginning, and parallel to each other along the Washoe Valley and Little Valley segments. Including the time it takes for waves to propagate to a site and scattering of earthquake waves, the event would be perceived at the surface to be about 20 seconds long, although this would be highly variable.

Estimated Seismic Intensity Distribution

Introduction

Earthquake **Intensity**, that is, the characterization of the felt effects, the damage, and ground deformation, is used in this scenario to convey the regional patterns of ground shaking. The particular scale used is the Modified Mercalli Intensity (MMI) scale (see Appendix). Further information on the MMI scale can be found in Richter (1958) and Steinbruggie (1982). Assignment of MMI values either after an earthquake has occurred (or in a predictive sense as in this scenario) is difficult because generalizations have to be made, subjective decisions and biases are common, and earthquake effects do not always fit conveniently into intensity categories. Nevertheless, the MMI scale is currently most useful and successful in communicating to the widest audience possible the potential damaging effects of an earthquake.

Other specific geological hazards from the scenario earthquake that are presented are surface faulting, liquefaction, and rock falls. These are hazards that would be anticipated from an earthquake such as the scenario event. These hazards can cause major disruptions and property loss, and potentially can even be life-threatening.

Estimating Earthquake Intensity

A three-step process is used to estimate the intensity distribution from the scenario event. First, geologic units are divided into velocity groups. Second, peak horizontal ground motion

from the scenario event is calculated for the area. Finally, relationships between ground motion and intensity are used to convert peak ground acceleration into intensity.

The shear-wave velocity of surficial geologic units has been shown to correlate with the severity of ground shaking (Joyner and Fumal, 1985). Thus, some shear-wave velocity characterization of the geologic units was necessary for the area covered by the scenario. After reviewing shear-wave velocity measurements from the area, the correlations shown in table 2 were developed and used.

Table 2 — Surficial Shear-Wave Velocities of Geologic Units

Velocity	Group	Representative Velocity Geologic Units
1	1500 m/s	metamorphic rocks
2	1000 m/s	granitic rocks
3	600 m/s	Tertiary and Quaternary volcanic rocks
4	400 m/s	early Pleistocene sediments, mid-Pleistocene bouldery gravels, and Tertiary sediments
5	200 m/s	Holocene and mid to late Pleistocene sediments

Peak horizontal ground acceleration was calculated using a function that attenuates ground motion with increasing distance from the earthquake source. In particular, we used a relationship developed by Boore and others (1993, 1994), which was derived primarily using data from California earthquakes. Not enough data exist in Nevada to develop a similar relationship for Nevada. Recent studies (e.g., Savage and Anderson, 1995) support the idea that the ground motion attenuation with distance in Nevada is similar to that in California. If there are differences, they would only be important at large distances. Thus, at close distances, we feel that the Boore and others (1993, 1994) relationship is reasonable to use. Their relationship considers the shear wave velocity of surficial materials and, considering a magnitude 7.1 earthquake, and a random peak acceleration component, simplifies to:

$$\mathbf{\log a = 1.314 - 0.778 \left(\log \left(d^2 + 30.03\right)^{1/2}\right) - 0.371 \left(\log Vs\right)}$$

where, **a** = peak ground acceleration in gravity units ("g's")
d = distance from source zone* (in km)
Vs = shear-wave velocity of upper 30 m (in m/s).

* The "source zone" is the surface projection of the fault. A horizontal distance is measured from the perimeter of the source zone. Within the source zone (over the top of the fault) the distance is zero.

Modified Mercalli Intensity was then calculated using relationships between peak horizontal ground acceleration and MMI developed by Krinitzsky and Chang (1988):

if $Vs \leq 400$ m/s $\quad$ **$I = (\log c - 1.320) / 0.138$**

if $Vs > 400$ m/s $\quad$ **$I = (\log c - 1.050) / 0.198$**

where, **I** = Modified Mercalli Intensity
c = a x 980 (ground acceleration in cm/sec)

Two simplifying assumptions were made in using the relationships developed by Krinitzsky and Chang (1988): 1) the coefficients of their relations can be rearranged to calculate intensity, and 2) that the far field effects, which would only affect the southeasternmost part of the study area, are not significant to this scenario and can be ignored (Krinitzsky and Chang have other relations for far field calculations).

How the intensity map was created in the GIS

The earthquake scenario is being created and managed by a Geographical Information Systems (GIS) Laboratory located at the Nevada Bureau of Mines and Geology. The major software package used to produce the intensity map is Arc/Info (version 6.1), produced by Environmental Systems Research Institute, Inc., (ESRI). A flow diagram showing the GIS process used is given in figure 3.

Geologic maps (scale 1:24,000) of the target area were **mapjoined** together to produce a comprehensive geologic map. For areas for which 1:24,000 scale maps were not available, the Reno Conterminous United States Mineral Assessment Program (CUSMAP) 1° × 2° map and the 1:250,000-scale NBMG county geologic maps were used. Geologic units of general conformity were **dissolved** together and a master geologic map of the general area was produced. Once the target area was created using the **generate** command, it was **clipped** to the part of Nevada between 38°00′ and 39°45′ north latitude and between 119°15′ and 120°00′ west longitude. Velocity group layers were then created through selecting the representative geologic units that belong to a velocity group, combining them into separate velocity layers, and dissolving the geologic units within those layers. Of particular interest for this project was velocity group 4. This group encompassed many different geologic units that had to be selected out. Once group 4 was created, this group was **mapjoined** with the other four remaining velocity groups. To create the buffers around the event, the surface projection of the fault rupture digitized; this represents the source area. To calculate the distance of the buffer around the source area, the above formulas were used for each velocity group to get the intensity buffer distance for each group. Each intensity buffer was **clipped** to the target area so all velocity groups and velocity buffers were the same area. The **union** command was used to put together each velocity group and intensity buffer. Included in the combined coverage were areas of intensities less than MMI V. The scenario only portrays intensity V and greater. Areas of intensity less than V were removed using the **dissolve** command. All the groups were then joined together with the union command and the intensity was calculated by each velocity group falling in different intensity buffers.

The intensity map created for the scenario earthquake is shown in plate 1 in the Appendix.

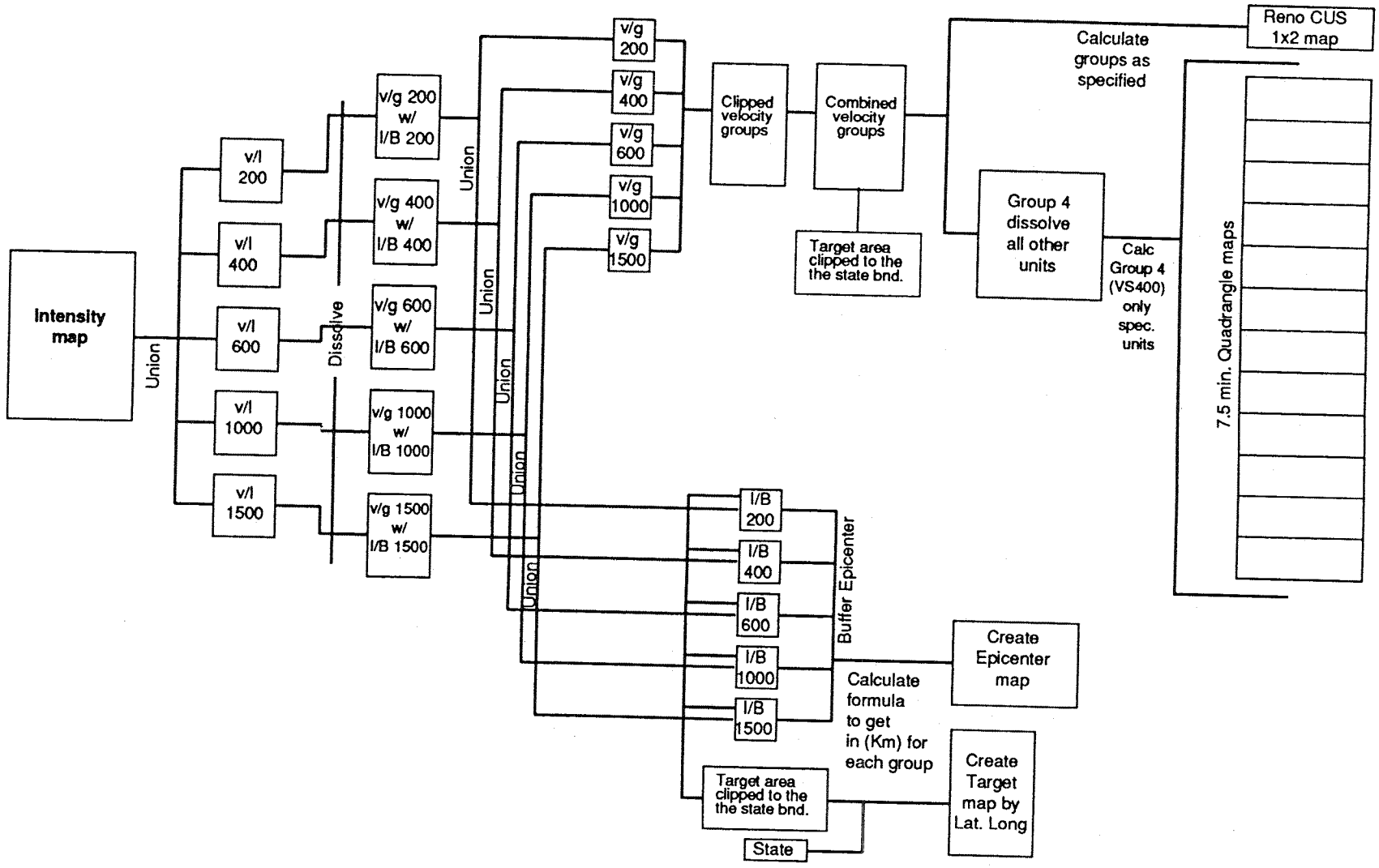


Figure 3 GIS flow diagram.

How to use the intensity map

The scenario intensity map indicates some very high intensities (MMI XIII and IX) along the Reno-Carson City urban corridor. The intensities presented are enveloping intensities, and as such, not all the area encompassed will have the indicated level. Significant pockets of the indicated intensity should be planned for, however. For example, groups of buildings constructed of unreinforced masonry would constitute potential pockets of severe damage. Earthquake intensity is strongly dependent on the design and quality of construction. A well designed and constructed building or facility can generally survive very severe shaking without incurring structural damage.

Surface Faulting Hazards

A zone of surface faulting 32 km (20 mi) long and up to 33 m (100 ft) wide is mapped along the base of the Carson Range and northward into Reno (plate 2). The ground is offset up to 2 m (6 ft) along the range front and drops to 0.5 m (1.5 ft) into southwestern Reno. Localized areas along the range front may have offsets as large as 4 m (13 ft). Several secondary breaks are indicated as well due to warping of the hanging wall. The surface ruptures follow mapped faults, and would be consistent with other earthquakes of about the same size in the Great Basin.

The faults shown are a generalization of the surface faulting. Commonly, the actual surface expression will be a zone of faulting 1 to 3 m (3 to 9 ft) wide, with a main break with much or most of the displacement, and smaller offsets, fissures, and cracks distributed throughout the rest of the zone of surface faulting. The offset values indicated are a sum of the total displacement across the zone. In some cases, the offset may be distributed across the zone (perhaps even poorly expressed if displacement is low enough, the zone is wide enough, and the faults are numerous enough), in others, especially where grabens form, individual faults within the zone may have surface offsets that are more than the indicated offset, but are canceled out by opposing faults.

Liquefaction Hazards

Background

Liquefaction is the temporary transformation of sandy water-saturated deposits from a solid state to a liquid state due to earthquake shaking. Liquefaction occurs during or shortly after earthquake shaking and can cause extensive damage. When shaken, loosely compacted, saturated sediments tend to settle, expelling pore-water. If the permeability of the sediment is such that the pore pressures cannot dissipate as fast as they are generated, they rise. When pore pressures within a deposit counter the weight of the overlying sediments, the condition of liquefaction is reached. The development of earthquake induced liquefaction is dependent on the following six principal factors:

- severity of ground shaking
- duration of shaking

- initial degree of compaction of the deposit
- grain size distribution of the deposit
- depth to the liquefiable deposit
- depth to groundwater

The severity of ground shaking is typically characterized by peak ground acceleration. The duration of shaking is directly related to the magnitude of the earthquake and how long that earthquake takes to propagate down the fault. The degree of compaction (or relative density) of a sediment has been shown to be mainly a function of age and the mode of deposition (Tinsley and Fumal, 1985). Older sediments have typically been subjected to greater burial depth and are more compact. The degree of weathering and cementation also increases with time. The relative density can be assessed by in-situ testing. The most common in-situ test is the Standard Penetration Test (SPT). SPT testing is generally carried out during geotechnical investigations and consists of driving a thick-walled sampling tube into the deposit. The driving force is supplied by a 140 pound (63 kg) weight falling a distance of 30 inches (0.76 m). The number of blows to drive the sampler one foot (0.3 m) gives a fairly good indication of the relative density of the deposit. The grain size distribution of a deposit affects liquefaction in two ways. First coarse sands and gravels may have such high permeabilities that excess pore pressures do not develop. Secondly, the presence of clays and silt tends to inhibit shaking induced settlement and therefore reduces the generation of pore pressures. The greater depth at which liquefaction occurs, the larger the pore pressures must rise to counter the weight of the overlying sediments. The presence of groundwater is not only necessary for the development of excess pore-pressure, it also exerts buoyancy effects on the weight of the overlying sediment lessening the necessary pore pressure increase to cause liquefaction.

Liquefaction induces damage through four principal modes of ground failure (Youd and Perkins, 1978):

- **Quick-condition failures** occur mostly in flat areas with high water tables and loose to moderately dense sediments extending to the near surface. Sediments lose all bearing strength and structures may sink or buried tanks and pipelines may float. Upon dissipation of excess pore pressure, settlement of the ground surface occurs. Groundwater dissipation typically occurs through the formation of sand boils and blows which may cause local inundation.

  Areas within the study region likely to experience quick-condition failure include the Double Diamond Ranch area, Washoe Lake, and Carson Valley.

- **Ground oscillation** takes place if liquefaction occurs at depth and the slope is too gentle to induce lateral displacements. Overlying soil blocks that do not liquefy may decouple from one another and oscillate on the liquefied substrate causing damage to overlying structures.

  An identified area susceptible to this form of failure is the Glendale area of Sparks, approximately from McCarran Boulevard to Vista. Here a clay layer overlies highly liquefiable sands at depths of 0 to 8 m (0 to 25 ft).

- **Lateral spreads** include the lateral displacement of surficial blocks of sediment as a result of liquefaction in a subsurface layer. Gravitational forces and internal forces resulting from earthquake shaking may cause blocks of soil to move downslope or toward a free face. This mode of ground failure is especially destructive to pipelines, utilities, bridge piers, and other structures having shallow foundations.

  Lateral spreading could occur near the Reno-Tahoe Airport drain system and other man-made cuts in areas of high ground water

- **Flow landslides** tend to occur on slopes in excess of 3°. The flows are chiefly liquefied material or blocks of intact soil riding on a liquefied substrate.

  Flow landslides are most likely in young alluvial fan deposits, particularly during periods of high groundwater.

Liquefaction susceptibility mapping

The identification of areas that are susceptible to liquefaction during this scenario earthquake were based on liquefaction susceptibility mapping in the Reno-Sparks area by Wythes (1993) and through compilations of published geology and groundwater deposits elsewhere. Groundwater data for the study area were provided by the U.S. Geological Survey Water Resources Division in Carson City.

For this scenario, two levels of liquefaction susceptibility are defined. Following previous scenario studies such as Tinsley and Fumal (1985) and Toppozada and others (1993) "high" and "moderate" designations have been assigned. The areas of liquefaction susceptibility for the scenario earthquake are shown in plate 3.

Areas with "**high**" **liquefaction susceptibility** are areas with sandy Holocene deposits and a static groundwater table within 3 m (10 ft). The areas delineated with high liquefaction susceptibility on the scenario map can be anticipated to have localized places of severe, near-surface liquefaction effects with large surface displacements (0.3 to 1 m (1 to 3 ft) settlement and 0.3 to 1.5 m (1 to 5 ft) lateral displacement) and bearing capacity failures due to quick-condition failure, and widespread minor liquefaction. Possible damage could include foundation and building damage, disruption of roadways and parking lots, possible aircraft runway damage, and damage to buried utilities.

Areas with "**moderate**" **liquefaction susceptibility** include areas with loose sandy deposits (generally Holocene) and a static groundwater table within 10 m (30 ft). The surficial effects of liquefaction at these greater depths will be less pronounced. These areas can pose a hazard to structures with deep foundations or to structures susceptible to damage from differential displacements resulting from ground oscillation. If the site is on a slope, lateral movement of the surface layer above the liquefied substrate may occur. The "moderate" liquefaction susceptibility designation was also applied to sites with near surface groundwater (within 1 m (3 ft)) but at considerable distances from the earthquake source zone. At increasing distances from the source

zone, the intensity of ground shaking diminished due to attenuation of the energy of earthquake waves, principally as they spread out. The Carson Valley could experience near surface liquefaction with quick-condition failures, lateral spreads, and flow landslides; however, for this particular scenario event, the distribution of failures in this region is expected to be less widespread than similar conditions near the earthquake source zone.

The distribution of liquefaction that will result during the scenario earthquake is dependent on many factors which can only be determined by detailed subsurface investigations. Liquefaction mapping in the Reno area by Wythes (1993) was based on a compilation of more than 600 geotechnical bore holes. The borings provided information on relative density (from SPT blow counts), grain size distribution and depth to groundwater. The susceptibility of each site to liquefaction was assessed through a widely accepted empirical procedure developed by Seed and Idriss (1982) and Seed and others (1985). Based on these data, generalizations regarding the relative susceptibility of various geologic units at various groundwater depths for the scenario event could be made.

In the Reno-Sparks area where bore hole information was sufficient, areas susceptible to liquefaction for various severities of ground shaking were contoured. Where borehole data was lacking or sparse, liquefaction mapping was based on published geological and groundwater maps. Geologic units were characterized by their relative density and typical grain size distribution based on compiled bore hole data. This statistical compilation showed a strong correlation between geologic age and relative density. It was found that Holocene alluvial plain and flood plain deposits with groundwater within 1.5 meters (5 feet) of the ground surface yielded the highest susceptibility to liquefaction. Recent alluvial fan deposits with shallow groundwater and alluvial plain deposits with groundwater to depths up to 12 m (40 ft) have the next highest susceptibility to liquefaction. These two categories of liquefaction correspond to the "high" and "moderate" designations of the scenario liquefaction map.

Areas outside Reno-Sparks were mapped using published geologic maps for the distribution of sandy deposits and groundwater data from the U.S. Geological Survey Water Resources Division, Carson City. Calculations and historical earthquakes indicate that areas of the highest susceptibility (groundwater depth less than 3 m (10 ft)) can occur out to 24 km (15 mi) with a second category of the highest susceptibility (groundwater depth less than 1 m (3 ft) occurring out to 32 km (20 mi) from this event. The moderate susceptibility category (groundwater depth less than 10 m (30 ft)) extends out to about 19 km (12 mi) from this event. Areas within the envelopes of these distances and meeting the appropriate criteria were designated on the scenario maps as potential liquefaction areas.

Rockfall, Landslide, and Snow Avalanche Hazards

Earthquakes have long been known as a major cause of landslides. Damage resulting from landslides sometimes exceeds that of ground shaking, ground rupture, or liquefaction (Wilson and Keefer, 1985). Fifty-six percent of the total damage costs resulting from the 1964 Alaskan earthquake was due to landslides (Wilson and Keefer, 1985). In a study of Japanese earthquakes

since 1964, Kobayashi (1981) determined that more than half of all deaths were caused by landslides. Where particularly hazardous conditions exist, earthquake induced and slides have caused thousands of deaths, including 18,000 people in one earthquake-induced rock avalanche in the Peruvian Andes in 1970 (Wilson and Keefer, 1985).

The mountainous terrain of the present study poses a variety of slope stability hazards which are exacerbated by the earthquake potential of the region. Kachadoorian and others (1967) report rockfall, triggered by the 1966 Boca Valley earthquake, along Interstate 80 and the railroad west of Verdi where rail traffic was blocked (Gates and Watters, 1992). A rockfall avalanche originating on Slide Mountain was possibly triggered by a large earthquake in 1852 (Slemmons and others, 1965).

Landslide hazard mapping

Potential earthquake induced landslide hazards can be assessed by considering the conditions for which landsliding resulted from earthquakes elsewhere, and through inventories of known, unstable conditions specific to the area of investigation. Keefer (1984a, 1984b), Keefer and Tannaci (1981), and Keefer and Wilson (1989) compiled earthquake-induced landslide information from 42 historical earthquakes. From this information he determined the relative abundances of various landslide types in semiarid environments. Table 3, modified from Keefer and Wilson (1989), lists the relative abundances of various landslide types. From table3 it is noted that rock falls and soil block slides are the most common types of earthquake induced landslide. Soil slumps, soil falls, and block slides are not considered to present a significant hazard at the scale undertaken in this study. Localized hazards from these slide types exist along stream banks, fault scarps, and manmade cuts and are best addressed on a site specific basis. Soil lateral spreads result from liquefaction which was considered separately above. Considering the active and historical landslides of the region, rock avalanches emanating from Slide Mountain and rotational rock slumps associated with the weak sandstones and diatomite of the sandstone of Hunter Creek (a local geologic unit in the Reno region) are also identified as landslide hazards which could be induced during the scenario earthquake. Wythes (1993) rated the relative hazard of slopes underlain by the sandstone of Hunter Creek in the Reno-Sparks region based on slope height, slope angle, lithology, and groundwater condition. Only the highest susceptibility slopes are included on the scenario map.

Areas of **"major" rock fall or landslide hazard** were delineated by identifying: 1) slopes that are greater that 100 ft (33 m) high that exceed 50% gradient and are underlain by steep bouldery outcrops as identified from aerial photographs, and 2) rotational rock slumps associated with the sandstone of Hunter Creek that were identified by Wythes (1993) as a high or high to moderate hazard. Significant rockfalls or significant landsliding can be anticipated in these areas. The southeast face of Slide Mountain has been the source for many rock avalanches, and was also included in this designation. These avalanches tend to develop into debris flows as they incorporate water from mountain lakes or snowpack. Only the areas around urban areas and transportation corridors were analyzed and presented on the map. There are many other areas not shown on the map that have this potential as well.

Areas of **"localized" rock fall hazard** were delineated by identifying areas of any slope height that had greater that 70% gradients (the angle of repose). Rocks dislodged from these slopes during earthquake shaking can roll or fall considerable distances posing a serious threat to any people or property in their path. One can expect a few to many boulders from these slopes dislodge and come down. Manmade cuts, particularly along the transportation corridors, are also susceptible to these localized rockfall hazards. Localized rock falls on transportation routes is expected to inhibit emergency response. Only the areas around urban areas and transportation corridors were analyzed and presented. There are many other areas not shown on the map that have this potential as well.

Areas of **snow avalanche hazard** are major areas of natural snow avalanche activity in the winter. The areas could experience large snow avalanches during an earthquake if the event occurs during a winter with an average or above average snow pack. Snow avalanches would consist of snow, trees, and rocks that would cross transportation routes. This will occur mostly in areas of the deepest snow pack such as northern and eastern slopes of the highest altitudes, and where snow avalanche controls are limited or absent. Localized avalanche potential is not represented, but may be present in avalanche-prone areas throughout the Tahoe Basin.

Areas of mass wasting for the scenario earthquake are shown in plate 4.

Table 3 — Relative Abundance of Earthquake-Induced Landslides

	In all historical earthquakes	**In 17 earthquakes in arid and semiarid regions**
Very abundant	(more than 100,000) Rock falls Soil slides Rock slides	(more than 10,000) Rock falls Rock slides
Abundant	(10,000 to 100,000) Soil lateral spreads Soil slumps Soil block slides Soil avalanches	(2,000 to 10,000) Soil slumps Soil falls Soil block slides Soil lateral spreads
Moderately common	(1,000 to 10,000) Soil falls Rapid soil flows Rock slumps	(100 to 2,000) Disrupted soil slides Rock slumps Soil avalanches
Uncommon	(100 to 1,000) Subaqueous landslides Slow earth flows Rock block slides Rock avalanches	(1 to 100) Rock block slides Rock avalanches Slow earth flows

GEOLOGIC HAZARDS POSED BY THE SCENARIO EARTHQUAKE

In general, the distribution of geologic hazards is what we would expect from an earthquake of this size and in this setting. Basins, valleys, and river canyons with the relatively softer geologic deposits have the highest intensities. The mountainous areas have a mix of intensities, but they are mostly lower than the valleys and basins. Several of areas of high liquefaction susceptibility correlate with areas that were swampy prior to urban development, which commonly liquefy during earthquakes. These observations serve as an informal check on the procedure used to estimate these hazards.

The following are tabulations of the geologic hazards from the scenario event for the counties and communities in the study area.

County	MMI	Liquefaction	Mass Wasting
Carson City	V-IX	O-M-H	O-L-P-S
Douglas	<V-IX	O-M-H	O-L-P-S
Lyon	<V-IX	O-M-H	O-L-P
Storey	V-IX	O-M-H	O-L-P
Washoe	V-IX	O-M-H	O-L-P-S

Community	MMI	Liquefaction	Mass Wasting
Carson City	VII-IX	O-M-H	O-L
Dayton	VI-IX	O-M-H	O
Gardnerville	VI-VII	O-M-H	O
Genoa	VII-VIII	O-H	O-P
Glenbrook	VI-IX	O-M	O-P
Incline Village	VIII-IX	O-M	O-L-S
Minden	VII	O-H	O
New Washoe City	VIII-IX	O-M-H	O
Reno	VII-IX	O-M-H	O-L
Sparks	VII-IX	O-M	O
Stateline	V-VII	O-M-H	O
Virginia City	VII-IX	O	O-P
Verdi	VIII-IX	O-M	O
Wadsworth	VI-VII	O-M	O
Zephyr Cove	V-VII	O	O-P

Abbreviations:

Liquefaction -
- H = high liquefaction susceptibility
- M = moderate liquefaction susceptibility
- O = no liquefaction susceptibility

Mass Wasting -
- P = potential rockfall and landslide hazard
- L = localized rockfall hazard
- S = snow avalanche hazard
- O = no mass wasting potential

REFERENCES

Bell, E.J., Broadbent, R., and Szumigala, Amy, 1982, Effects of the December 29, 1948, earthquake: University of Nevada, Reno, 15 p. (unpublished manuscript).

Boore, D.M., Joyner, W.B., and Fumal, T.E., 1993, Estimation of response spectra and peak accelerations from western North America earthquakes: an interim report: U.S. Geological Survey Open-File Report 93-509, 72 p.

Boore, D.M., Joyner, W.B., and Fumal, T.E., 1994, Estimation of response spectra and peak accelerations from western North America earthquakes: an interim report, part 2: U.S. Geological Survey Open-File Report 94-127, 40 p.

Earl, P.I., undated, Carson's big shake of 1887: Nevada Historical Society's "This was Nevada" series, 3 p. (unpublished)

Gates, W.C.B., and Watters, R.J., 1992, Geology of Reno and Truckee Meadows, Nevada, United States of America: Association of Engineering Geologists Bulletin, v. 29, p. 229-298.

Hanks, T.C., and Kanamori, H., 1979, A moment-magnitude scale: Journal of Geophysical Research, v. 84, p. 2348-2350.

Holden, E.S., 1898, A catalogue of earthquakes on the Pacific Coast 1769 to 1897: Smithsonian Miscellaneous Collections, no. 1087, 253 p.

Joyner, W. B., and Fumal, T. E., 1985, Predictive mapping of earthquake ground motion, *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. 203-220.

Kachadoorian, R., Yerkes, R.F., and Waananen, A.O., 1967, Effects of the Truckee, California, earthquake of September 12, 1966: U.S. Geological Survey, Circular 537, 14 p.

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

Keefer, D.K., 1984b, Rock avalanches caused by earthquakes-source characteristics: Science, v. 223, p. 1288-1290.

Keefer, D.K., and Wilson, R.C., 1989, Predicting earthquake-induced landslides with emphasis on arid and semi-arid environments, *in* Sadler, P.M. and Morton, D.M. (eds.), Landslides in a semi-arid environment: studies from the inland valleys of Southern California: Inland Geological Society of Southern California Publications, Riverside, v. 2, part 1, p. 118-149.

Keefer, D.K., and Tannaci, N.E., 1981, Bibliography on landslides, soil liquefaction, and related ground failures in selected historic earthquakes; U.S. Geological Survey Open-File Report 81-572, 39 p.

Kobayashi, Y, 1981, Causes of fatalities in recent landslides in Japan: Journal of Disaster Science, v. 3, p. 15-22.

Krinitzsky, E.L. and Chang, F.K., 1988, Intensity-related earthquake ground motions: Association of Engineering Geologists Bulletin, v. 25, p. 425-435.

Ramelli, A.R., dePolo, C.M., and Bell, J.W., 1994, Synthesis of data and exploratory trenching along the Northern Sierra Nevada Fault Zone: Nevada Bureau of Mines and Geology, 65 p.

Richter, C.F., 1958, Elementary Seismology: San Francisco, W.H. Freeman, 768 p.

Rogers, A.M., Harmsen, S.C., Corbett, E.J., Priestley, K., and dePolo, D., 1991, The seismicity of Nevada and some adjacent parts of the Great Basin, *in* Slemmons, D.B., Engdahl, E.R., Zoback, M.D., and Blackwell, D.D., eds., Neotectonics of North America, p. 153-184.

Ryall, A.R., 1977, Earthquake hazard in the Nevada region: Seismological Society of America Bulletin, v. 67, p. 517-532.

Savage, M.K., and Anderson, J.G., 1995, A local magnitude scale for the western Great Basin - eastern Sierra Nevada from synthetic Wood-Anderson seismograms: Seismological Society of America Bulletin, in press.

Schilling, J., and Szecsody, G.C., 1982, Earthquake hazards maps, Mt. Rose NE and Reno NW 7½-minute quadrangles: Nevada Bureau of Mines and Geology, Final Technical Report, U.S. Geological Survey National Earthquake Hazards Reduction Program, 63 p.

Seed, H.B., and Idriss, I.M., 1982, Ground motions and soil liquefaction during earthquakes: Earthquake Engineering Research Institute, Engineering Monograph, v. 5.

Seed, H.B., Tokimatsu, K., Harder, L.F., and Chung, R.M., 1985, Influence of SPT procedures in soil liquefaction resistance evaluations: Journal of Geotechnical Engineering, v. 111, p. 1425.

Slemmons, D.B., 1969, Surface faulting from the December 26, 1869 Olinghouse, Nevada earthquake[abs.]: Seismological Society of America, Annual Meeting, p. 23.

Slemmons, D.B., Jones, A.E., and Gimlett, J.I., 1965, Catalog of Nevada earthquakes, 1852-1960: Seismological Society of America Bulletin, v. 55, p. 537-583.

Steinbrugge, K.V., 1982, Earthquakes, volcanoes, and tsunamis; an anatomy of hazards: Skandia America Group, 392 p.

Thatcher, W., and Bonilla, M.G., 1989, Earthquake fault slip estimation from geologic, geodetic, and seismologic observations: implications for earthquake mechanics and fault segmentation, *in* Schwartz, D.P. and Sibson, R.H., eds., Fault segmentation and controls of rupture initiation and termination: U.S. Geological Survey Open-File Report 89-315, p. 386-399.

Tinsley, J.C., and Fumal, T.E., 1985, Mapping Quaternary sedimentary deposits for aerial variations in shaking 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. 101-126.

Toppozada, T.R., Real, C.R., and Parke, D.L., 1981, Preparation of isoseismal maps and summaries of reported effects for pre-1900 California earthquakes: California Division of Mines and Geology Open-File Report 81-11SAC, 182 p.

Toppozada, T.R., Borchardt, G., and Hallstrom, C.L., 1993, Planning scenario for a major earthquake on the San Jacinto fault in the San Bernardino area: California Division of Mines and Geology Special Publication 102, 319 p.

Wilson, R.C., and Keefer, D.K., 1985, Predicting aerial limits of earthquake-induced landsliding, *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. 317-346.

Wythes, T.J., 1993, Earthquake induced ground failure hazards in the Reno-Sparks region, Washoe County, Nevada [M.S. thesis]: University of Nevada, Reno, 91 p.

Youd, T.L, and Perkins, D.M., 1978, Mapping liquefaction-induced ground failure potential: Proceedings of the ASCE, Journal of the Geotechnical Engineering Division, v. 104, no. Gt4, p. 433-436.

APPENDIX

Abridged Modified Mercalli Intensity Scale

Intensity I Not felt, except by a very few people under especially favorable circumstances.

Intensity II Felt only by a few people at rest, especially on upper floors of buildings.

Intensity III Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize as an earthquake. Hanging objects may swing. Parked cars may rock slightly.

Intensity IV During the day, felt indoors by many, outdoors by few. At night some awakened, especially light sleepers. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like a heavy truck striking building. Standing cars rocked noticeably.

Intensity V Felt by nearly everybody indoors, outdoors felt by many, awakened many if not most. Frightened a few. Some dishes and windows broken. Overturned vases or small unstable objects.

Intensity VI Felt by all, many frightened and run outdoors. Some alarm. Awakened all. People made to move unsteadily.

Damage slight in poorly built buildings, small amounts of fallen plaster, cracked plaster, broken dishes and glassware in considerable quantities, also some windows, fall of knick-knacks, books, pictures, some heavy furniture moved and overturned.

Intensity VII Frightened all, general alarm, all run outdoors, some or many find it difficult to stand. Noticed by people driving cars. Waves in ponds, lakes, and running water; water turbid from mud stirred up. Some falling down of sand and gravel stream banks. Suspended objects made to quiver.

Damage negligible in buildings of good design and construction, slight to moderate in well-built ordinary buildings, considerable in poorly built or badly designed buildings, adobe houses, unreinforced masonry buildings, old walls, and spires. Chimneys cracked to considerable extent, walls to some extent. Fall of plaster in large amounts and some stucco. Numerous windows broken; furniture broken to some extent. Loosened brickwork and tiles shaken down. Weak chimneys broken at the roof line (sometimes damaging roofs) some poorly anchored chimneys along side of house may peel away and some fall. Fall of cornices from towers and high buildings. Bricks and stones dislodged. Heavy furniture overturned, with damage from breaking. Damage considerable to concrete irrigation ditches.

Intensity VIII Fright general, alarm approaches panic. Disturbs people driving cars. Trees shaken strongly, branches and trunks broken off, especially in palm trees. Liquefaction occurs locally accompanied by ejected sand and mud in small amounts. Changes in springs; amount changes, some flow more, some dry up, dry wells renew flow, temperature changes in some.

Damage slight in well built structures designed with earthquake resistance, considerable in ordinary substantial buildings, partial collapse, racked and tumbled down; panel walls thrown out from some wooden structures. Fall of walls; seriously cracked and broken solid stones. Twisting, fall of chimneys, columns, monuments, factory stacks, towers. Very heavy furniture moved conspicuously or overturned.

Intensity IX General panic. Cracked ground conspicuous. Damage considerable in specially designed structures, great in substantial masonry buildings with some collapse in large part. Buildings wholly shifted off foundations. Well designed frame structures thrown out of plumb and racked. Reservoirs damaged and underground pipes sometimes broken.

Intensity X Cracked ground, especially when loose or wet. Fissures parallel along canal and stream banks. Landslides considerable from river banks and steep coasts. Horizontally shifted sand and mud on beaches and flatlands. Changed levels in water wells. Water thrown on bank of canals, lakes, and rivers.

Some well-built structures destroyed. Most masonry buildings destroyed with their foundations. Rails bent slightly. Serious damage to dams, dikes, and embankments.

Intensity XI Widespread ground disturbance, broad fissures, earth slumps, and land slips in soft, wet ground. Ejection of large amounts of water charged with sand and mud.

Few, if any, masonry structures remain standing. Severe damage to wood-frame structures. Great damage to dams, dikes, and embankments. Bridges destroyed by wracking of support piers or pillars. Rails bent greatly. Underground pipelines completely out of service.

Intensity XII Damage total. Waves seen on ground surface. Objects thrown up in the air. Ground greatly disturbed. Waterways blocked by landslides. Large rock masses wrenched loose. Fault displacement of surface with notable horizontal and vertical displacements.

Reno-Carson City Urban Corridor

EARTHQUAKE SCENARIO PROJECT

Modified Mercalli Earthquake Intensity Map

- IX
- VIII
- VII
- VI
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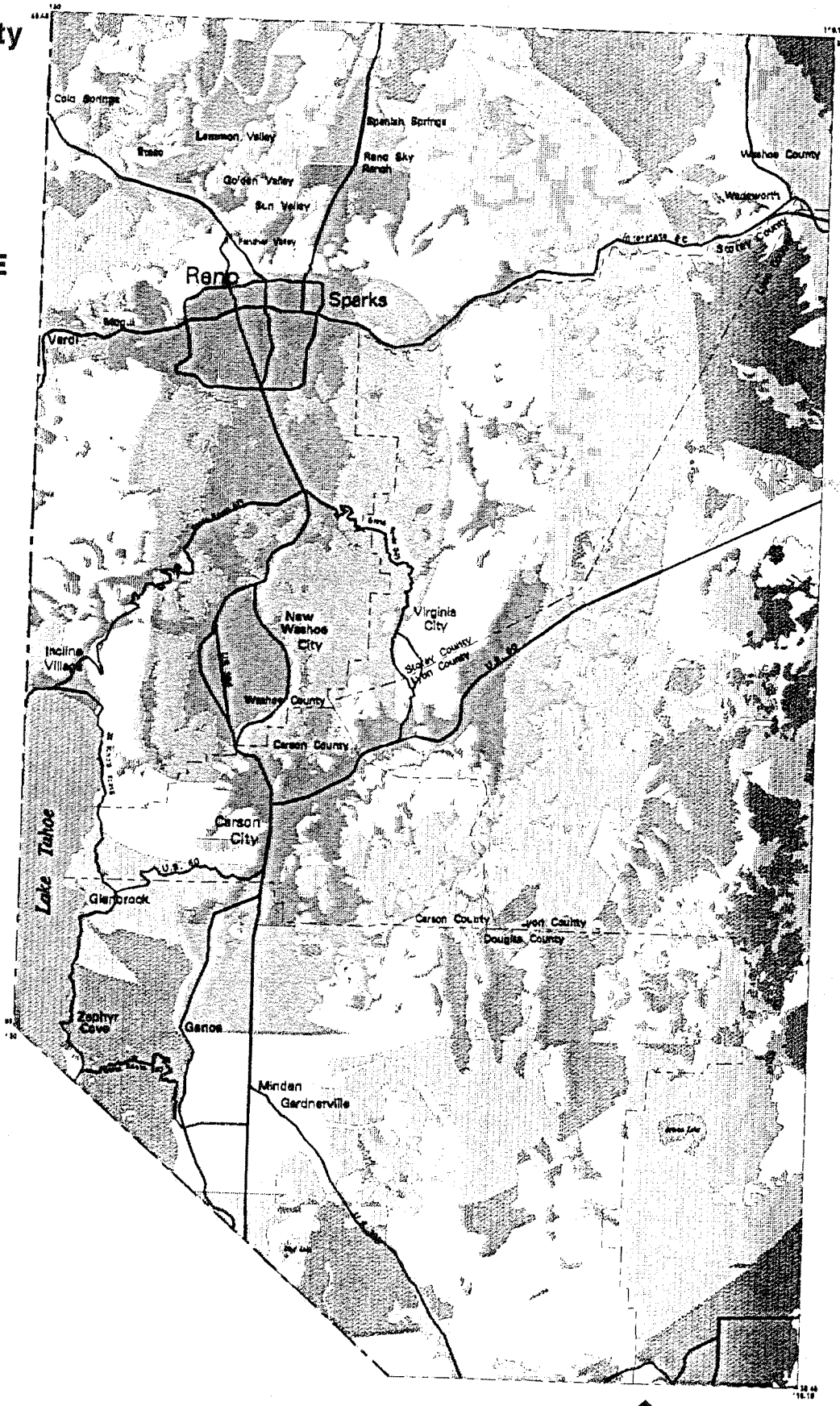

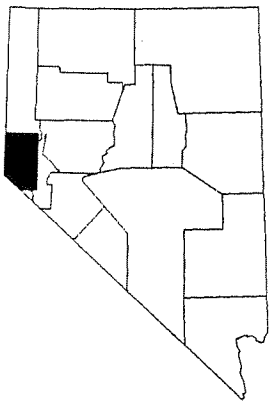

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Plate 1

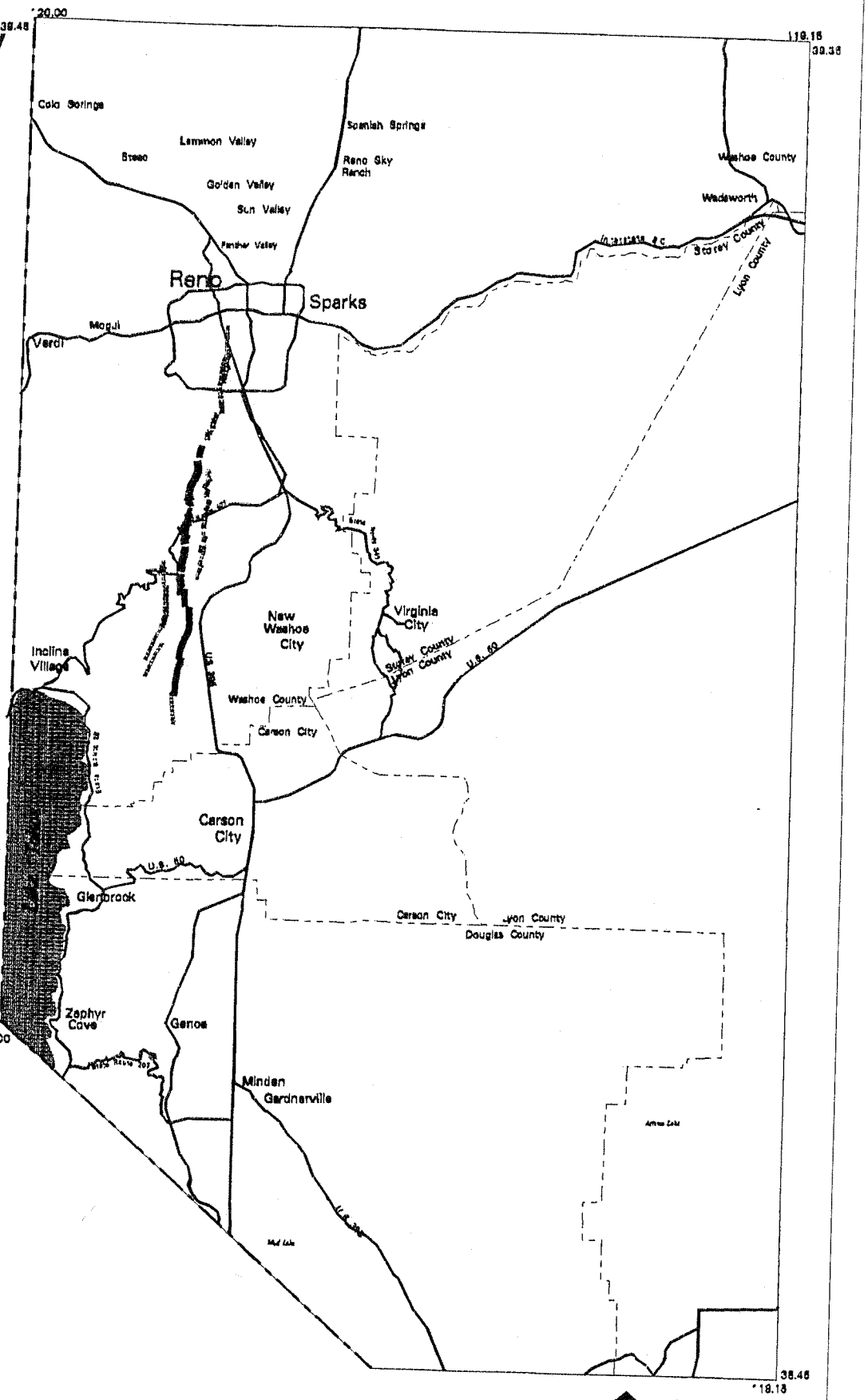
Reno-Carson City Urban Corridor

EARTHQUAKE SCENARIO PROJECT

Surface faulting during Scenario Earthquake

Vertical displacement

- 2 meters and greater (6 feet and greater)
- 1-2 meters (3 to 6 feet)
- 0.2 to 1 meters (0.7 to 3 feet)
- Less than 0.2 meters (Less than 0.7 feet)



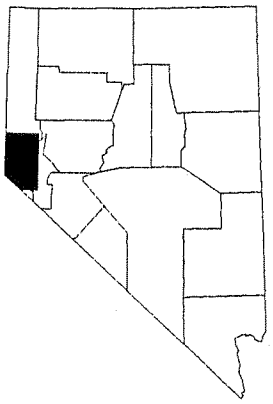


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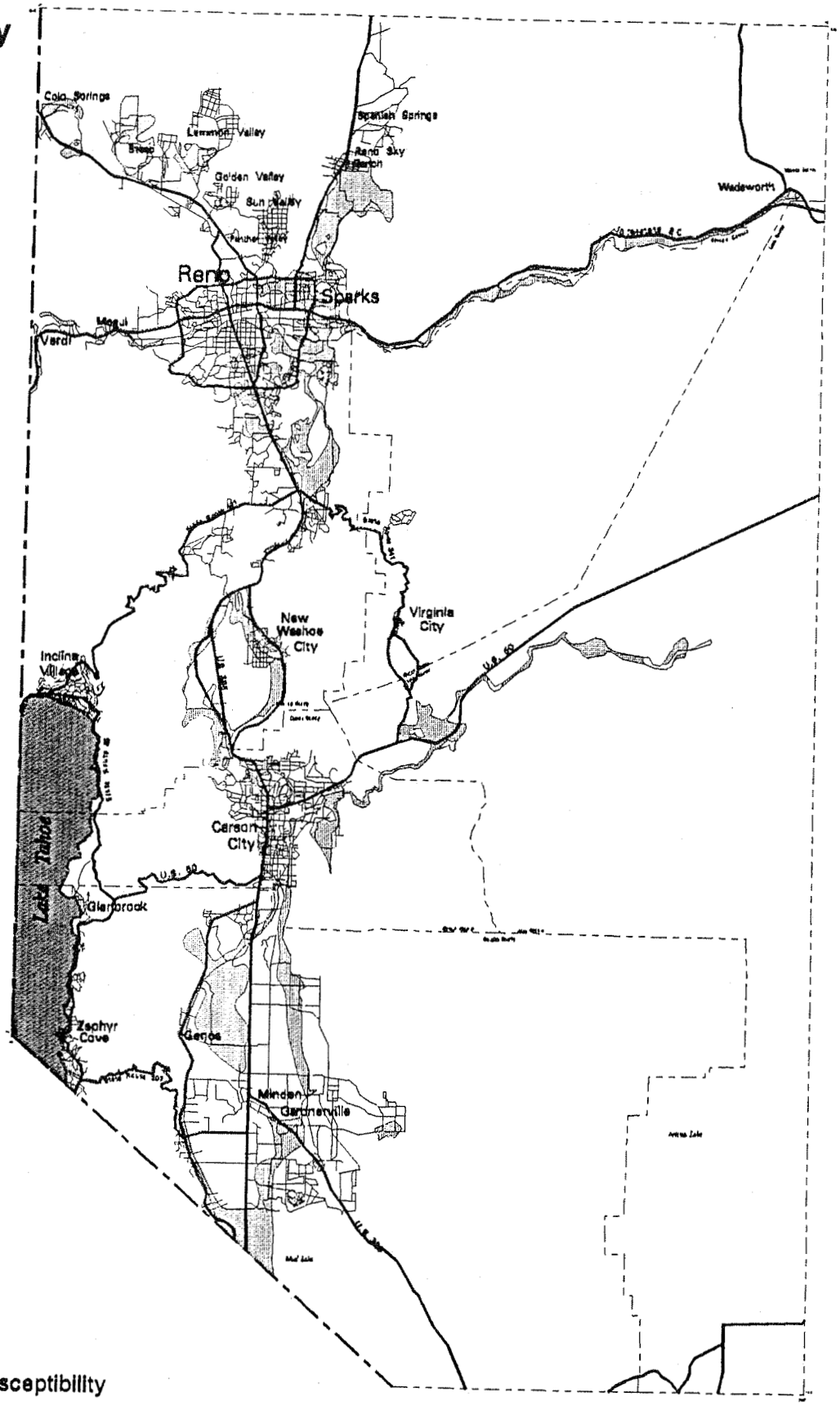
Plate 2

Reno-Carson City Urban Corridor

EARTHQUAKE SCENARIO PROJECT



Potential Liquefaction Hazard

- High liquefaction susceptibility
- Moderate liquefaction susceptibility

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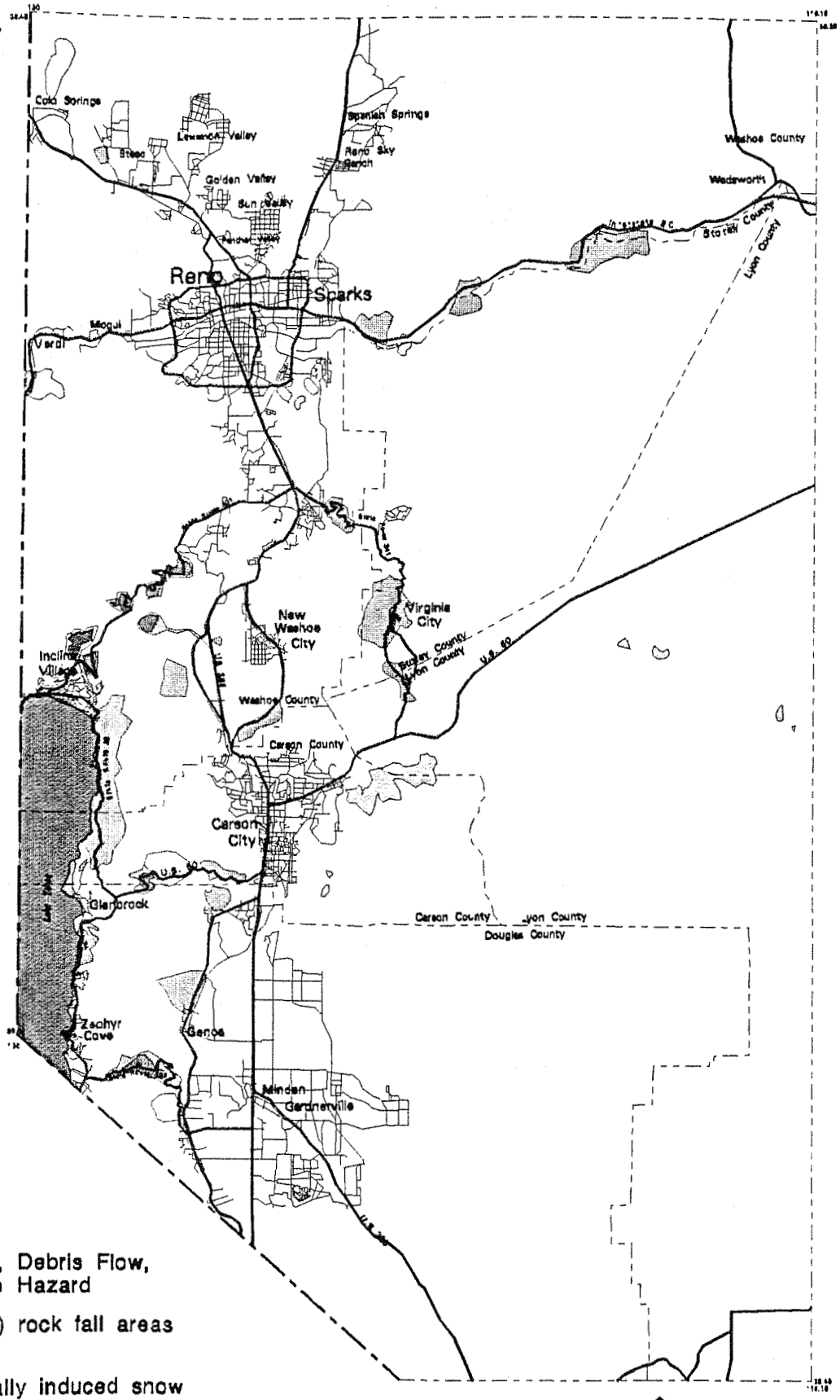
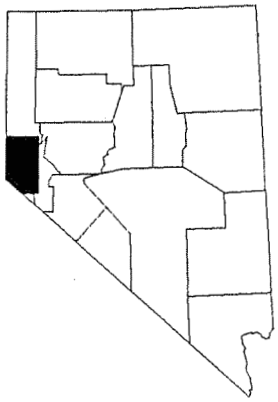
Plate 3

Reno-Carson City Urban Corridor

EARTHQUAKE SCENARIO PROJECT





Potential Mass Movement Hazard

- Potential Rockfall, Debris Flow, and Landslide Hazard
- Localized (limited) rock fall areas
- Potential seismically induced snow avalanche danger areas

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Plate 4