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UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

A Study of Earthquake Losses in the Salt Lake City, Utah Area

By

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A STUDY OF EARTHQUAKE LOSSES IN THE SALT LAKE CITY, UTAH, AREA

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PREFACE

The purpose of this report is to provide the Federal Disaster Assistance Administration and the State of Utah with a rational basis for planning earthquake disaster relief and recovery operations in the Salt Lake City, Utah, area. The maps, tables, and other data in this report have been prepared for this particular purpose only. Application of the material in this report to other types of analyses should be undertaken with considerable care, and due attention should be given to the limitations and restrictions placed on the data and conclusions stated in this report.

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A STUDY OF EARTHQUAKE LOSSES IN THE SALT LAKE CITY, UTAH AREA

SECTION 1: INTRODUCTION

This report is similar in nature and scope to "A Study of Earthquake Losses in the San Francisco Bay Area" (Algermissen and others, 1972), "A Study of Earthquake Losses in the Los Angeles, California, Area" (Algermissen and others, 1973), and "A Study of Earthquake Losses in the Puget Sound, Washington, Area" (Hopper and others, 1975). The methodologies used in the former studies have also been employed in this report, except that some techniques have been expanded or revised to accommodate new situations.

Purpose and scope of the study

The objective of this study is to determine the earthquake damage to critical facilities in the Salt Lake City area that would result from severe earthquakes that may reasonably be expected to occur along the Intermountain Seismic Belt in Utah. For the purposes of this study, the Salt Lake City area is taken to mean the following four counties in Utah: Weber, Davis, Salt Lake and Utah. Special attention is devoted to damage potential in Salt Lake City, Ogden, and Provo, the three largest cities in Utah (fig. 1). The population of the four-county area is 902,000, as shown in table 1; these figures are based on the 1970 census, adjusted to 1974 as reported by the University of Utah Department of Business and Economic Research. Table 2 shows the population distribution by city for the four counties. Unincorporated cities and towns are not included.

Six earthquakes that might occur in the Salt Lake City area were considered. The magnitude of all six events was assumed to be 7.5; two epicenters were individually considered in the vicinity of each of the three cities, Salt Lake City, Ogden, and Provo. One assumed epicenter was in the vicinity of the Wasatch fault, while the second assumed epicenter was farther west. The rationale for selection of these earthquakes is given below in this section.

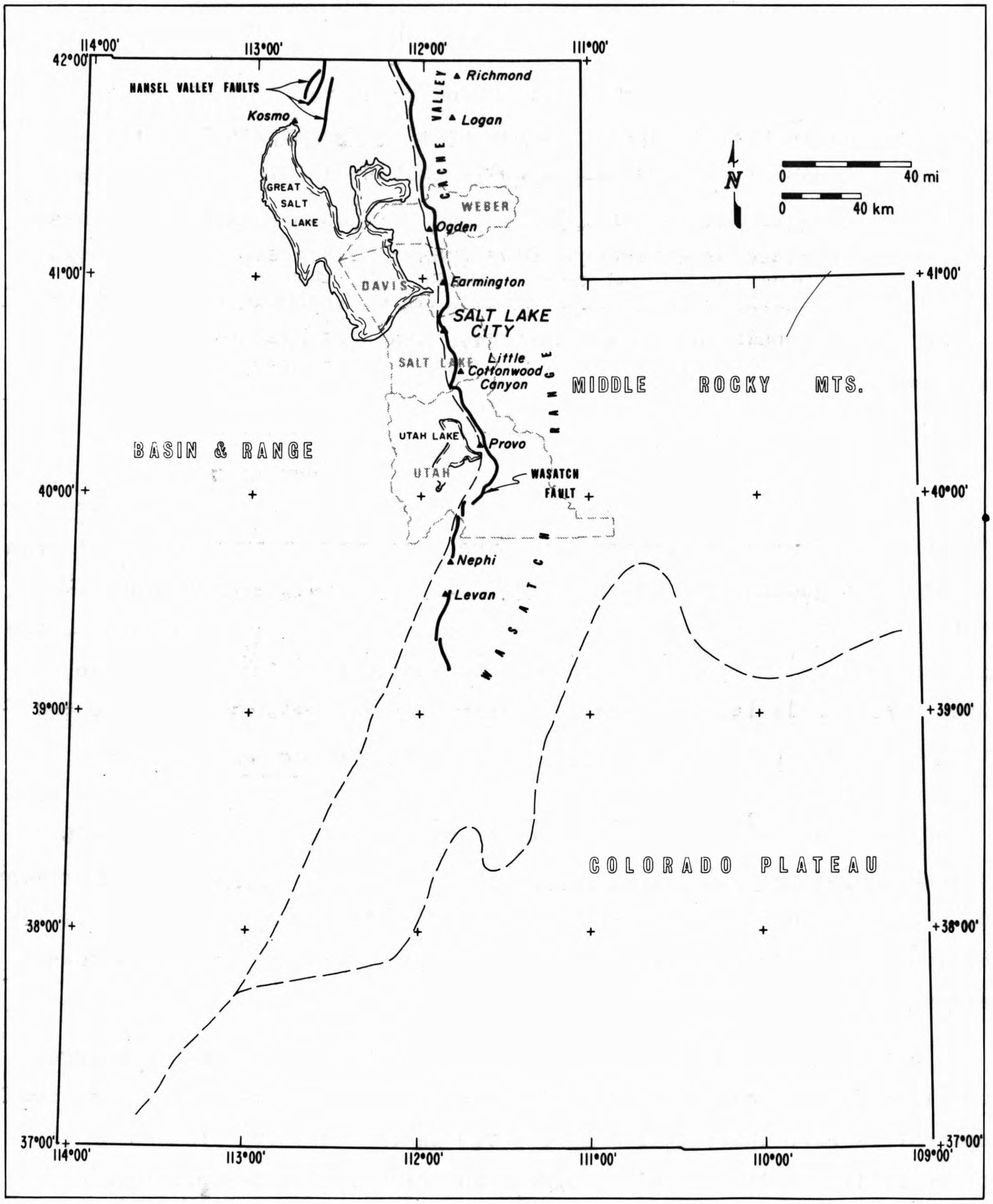

Figure 1.--Map of Utah showing the four-county study area, Basin and Range, Middle Rocky Mountains, and Colorado Plateau physiographic provinces, and the major fault zones in or near the study area.

Table 1 .--Population of the four-county study area as of July 1, 1974

[Data from (a) "County Economic Facts," Utah State Department of Development Services, Division of Industrial Promotion", and (b) census figures updated to 1974 by the Utah Population Work Committee, Bureau of Business and Economic Research, University of Utah]

County	Population
Weber	134,500
Davis	112,500
Salt Lake	495,000
Utah	160,000
Total	902,000

Table 2.--Population of cities in the four-county study area

[Data from "County Economic Facts," Utah State Department of Development Services, Division of Industrial Promotion; Census figures updated to 1974 by the Utah Population Work Committee, Bureau of Business and Economic Research, University of Utah]

Weber County

City	Population
North Ogden	6,500
Ogden	70,000
Plain City	2,000
Pleasant View	3,000
Riverdale	4,000
Roy	16,000
South Ogden	12,000
Washington Terrace	8,500

Salt Lake County

City	Population
Midvale	8.500
Murray	24,500
Riverton	3,500
Salt Lake City	178,000
Sandy	16,000
South Jordan	4,150
South Salt Lake	8,000
West Jordan	10,000

Davis County

City	Population
Bountiful	32,000
Centerville	4,500
Clearfield	15,000
Clinton	3,400
Farmington	3,200
Kaysville	6,500
Layton	17,000
North Salt Lake	3,100
South Weber	1,400
Sunset	6,500
Syracuse	2,600
West Bountiful	1,600
West Point	1,300
Woods Cross	3,500

Utah County

City	Population
Alpine	1,500
American Fork	10,000
Lehi	5,000
Lindon	1,800
Mapleton	2,500
Orem	35,000
Payson	5,500
Pleasant Grove	6,000
Provo	60,000
Salem	1,200
Santaquin	1,275
Spanish Fork	7,300
Springville	9,700

Project design

The project was divided into two separate phases of work:

1. construction of isoseismal maps, and
2. estimation of casualties and damage for each of the postulated earthquakes.

The first phase of the project was done by the U.S. Geological Survey. This part of the work included the following:

1. collection of data on historical, damaging earthquakes in Utah;
2. collection of data on faults, near-surface soil deposits, and landslide areas; field mapping of these types of data was also carried out in Salt Lake and Davis Counties;
3. selection of the location and magnitudes of the earthquakes to be simulated based on evaluation of the aforementioned data;
4. derivation of intensity, distance, and magnitude relationships for different soil types;
5. estimation of the distribution of Modified Mercalli intensity (MM)[1] for each postulated earthquake and preparation of a map showing these expected intensities.

The second, or damage-assessment, phase of the project was carried out by engineering consultants familiar with earthquake damage studies in other locales and building practices in the study area. This knowledge together with the intensity maps produced in the first portion of this study were used to estimate the extent of damage and loss of life that might result due to the individual occurrence of the postulated earthquakes. Only the two events in the vicinity of Salt Lake City were considered in this phase of the study. Although damage assessment for the events near Ogden and Provo was not carried out, isoseismal maps were produced that could serve as the basis for damage assessment studies in the future. The two earthquakes considered clearly represent the worst case situations because they are postulated to occur in the region of greatest population density and highest economic concentration

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[1]Intensity refers to the degree of shaking at a specific location. The Modified Mercalli Intensity scale, commonly used in the United States, was published in the "Bulletin of the Seismological Society of America," vol. 21, 1931, by H. O. Wood and Frank Neumann. The scale is reproduced at the end of this report.

of facilities. This phase of the project includes estimates of

1. effects on local medical resources, including hospitals, medical personnel, supplies, and services;
2. damage to facilities critical to recovery of the area after the shock, including communications, transportation, utilities, foodstuffs, debris removal, and fire fighting equipment;
3. damage to structures that might cause major loss of life, including public schools, city, county, state, and federal buildings;
4. estimated casualties and homeless.

A number of variables may have an effect on the damage and casualty estimates, and these variables need proper consideration. For instance, the number of injuries sustained is highly dependent on the time of day that the shock occurs. Accordingly, for the purposes of this study, three times of day have been assumed as follows;

1. 2:30 a.m., when the greatest proportion of the population would be at home in bed;
2. 2:00 p.m., when the greatest proportion of the population would be away from home; and
3. 4:30 p.m., the beginning of the rush hour.

The season of the year would also have an effect on the number of homeless, conflagration, landslide, and avalanche potential. Freezing and subfreezing temperatures are to be expected for long periods of time in the four-county study area from November through March. During this period, the loss of natural gas or electric power for heat would render many buildings nonfunctional. The number of homeless could therefore be much larger from a severe earthquake in Utah during the winter months than it would be in California from a similar shock.

The conflagration potential would be high during the summer months, especially during July and August, which are typically high fire-danger months in Utah due to hot, dry conditions. Strong canyon winds are common in the morning and evening during the summer months and could add to the possibility of conflagration following an earthquake.

The potential for earthquake-induced landslides is high during the spring when the ground may be saturated from rain and melting snow.

During the winter months, avalanches could occur, which might block some mountain roads or rail lines in the eastern part of the study area. For the first few hours, the large majority of the people in the affected areas excluding the injured, will not have vital immediate needs, but will require some food, shelter, and water supplies. The need for an adequate supply of water for human consumption, plus that needed for fire fighting, is probably more vital than shelter or food in the first day or two that follow the disaster; although, if an earthquake was to occur in the winter, the need for shelter from freezing temperatures might constitute a vital need. The immediate need for water cannot be met in terms of hours if the water system is out of service. Because a large number of the newer public school system buildings are earthquake-resistant, these buildings could be a major resource for temporary housing and feeding. Local stocks of nonrefrigerated foods will last for days, and in the residential areas these stocks can be judged adequate for several days. Also, many Mormon families in the area have a one-year food supply in home storage. If transportation routes are closed, however, quite a different problem exists in the distribution of foods arriving from outside the metropolitan area. Obviously, a rapid restoration of communications, transportation facilities, and public utilities is vital.

The four-county study area is unique when compared with areas containing other U.S. cities of the same size in that the nearest major population centers are Denver, Colo., located about 400 miles (644 km) from Salt Lake City; and Phoenix, Ariz., and Los Angeles and San Francisco, Calif., located about 800 miles (1,287 km) from Salt Lake City. In effect, the study area would become temporarily isolated from these distant population centers in the event of a large damaging earthquake making it necessary to rely on air transportation for rapid resupply of many essential needs.

Minimal attention is paid to long range effects of earthquake disaster. For instance, the study has not included dollar losses from property damage as these do not affect vital short term human needs. The study of temporary loss of jobs as a result of damage to factories and other places of employment, the temporary loss of transport and supply lines to and from these places of employment, and other economic dislocations are not the objective of this report. Additionally, stream and lake pollution problems from oil spills, emergency chemical discharges, and raw sewage (due to damaged treatment plants) are given secondary or no attention. In summary, the objective of this report is to emphasize the vital human needs that exist immediately after a postulated damaging earthquake, and it is hoped that this report will serve as an important data base for those federal, state, and local planning agencies responsible for supplying those needs and facilitating rapid recovery in the aftermath of earthquake disaster.

Earthquake history

Historic records of earthquake activity in Utah date back to 1853, shortly after the region was settled. Since that time, on the order of 1,000 felt events have occurred, the largest being intensity IX and magnitude 6.7. Of these felt events in Utah, 119 have generated maximum intensity V or greater (MM), 19 occurring within the study area. Table 3 lists all events that were felt in Utah and had intensity greater or equal to V.

Eight historical earthquakes have caused significant damage within the study area. The 1909 event (I_o = VII), on the Hansel Valley fault system, sent seiche waves over the railroad causeway at the north end of Great Salt Lake, and broke windows in Salt Lake City. The 1934 Hansel Valley event (I_o = IX) severely damaged a brick building in Kosmo, produced two-foot scarps in recent alluvium (the only historic event in Utah to produce surface rupture), altered ground-water flow patterns, and initiated rock slides in the epicentral area. In Salt Lake City, walls were cracked, plaster fell and adjacent tall buildings swayed severely enough to make contact with one another. Whereas the earthquake was as strong as the 1971 San Fernando, California, event, damage was minimal due to the sparse settlement of the area.

Intensity-VI earthquakes in 1910, 1943, 1949, and 1962, within the immediate Salt Lake City area, produced damage generally in the form of cracked walls, fallen plaster, toppled chimneys, and broken windows.

Table 3.--Chronological list of all earthquakes felt in Utah having Modified Mercalli intensity greater than or equal to V from 1853 to 1975. Locations, magnitudes, and times of occurrence of these events are shown.

[Short references for numbered sources are at the end of table 3.

Leaders (--) indicate information not available.]

Local time (24 hr. clock)	Local date	Lat(N)	Long(W)	I_o	Source	Location and comments
11 15	12-01-53	40.0	[2]111.8	5	5	Fort Nephi, Utah.
20 15	07-30-73	38.3	112.7	6	2	Beaver, Utah.
?	03-22-76	39.5	111.5	6	1,4,5	Moroni, Utah.
?	08-14-78	38.7	[2]112.6	5	5	Cove Creek, Utah.
22 00	07-11-80	42.0	112.2	5	1,4,5	Portage, Utah.
22 27	09-16-80	40.8	111.9	5	1,4	Salt Lake City, Utah.
19 15	03-25-81	38.0	114.0	5	1,3	Hebron, Utah.
18 25	11-07-82	--	--	6	4,5,8	Area uncertain, felt from Salt Lake City to Denver.
02 00	11-09-84	41.5	111.2	8	1,2	Near Bear Lake, Idaho, many aftershocks.
08 30	12-05-87	37.1	112.5	7	1,4,5	Kanab, Utah, massive rock slides, people thrown to ground.

Table 3.--Chronological list of all earthquakes felt in Utah having Modified Mercalli intensity greater than or equal to V from 1853 to 1975. Locations, magnitudes, and times of occurrence of these events are shown.--Continued

Local time (24 hr. clock)	Local date	Lat(N)	Long(W)	I_o	Source	Location and comments
06 55	04-20-91	37.3	113.6	6	1,4,5	Washington Co., Utah.
11 00	01-08-94	39.7	113.4	5	1,4,5	Fish Springs, Utah.
15 50	07-18-94	41.2	[2]111.9	6	1,5,6	Ogden, Utah.
06 50	12-13-99	41.1	[2]111.9	5	1,2	Salt Lake City, Utah and area to the north.
00 45	08-01-00	39.9	[2]112.0	7	1,5	Eureka, Utah, aftershocks.
21 39	11-14-01	38.5	[2]112.5	9	1	Richfield, Utah, 35 felt aftershocks.
12 50	11-17-02	37.4	113.5	8	1,2	Pine Valley, Utah.
?	12-05-02	37.4	113.5	6	1,4	Pine Valley, Utah.
03 00	11-23-03	37.1	113.6	5	1,4	St. George, Utah.
20 45	11-11-05	42.9	114.5	7	2	Shoshone, Idaho, felt in Salt Lake City and north Utah.
06 00±	04-15-08	38.4	113.0	6	1,4,5	Milford, Utah.

Table 3.--Chronological list of all earthquakes felt in Utah having Modified Mercalli intensity greater than or equal to V from 1853 to 1975. Locations, magnitudes, and times of occurrence of these events are shown.--Continued

Local time (24 hr. clock)	Local date	Lat(N)	Long(W)	I_o	Source	Location and comments
19 50	10-05-09	41.7	[2]112.3	7	2,4	Hansel Valley, Utah; at Saltair and Lucin cutoff, water waves were reported.
23 30	11-16-09	41.7	112.2	5	1,4,5	Hansel Valley, Utah.
06 00	01-10-10	38.7	112.2	[2]7	1,4	Elsinore, Utah, many aftershocks.
07 28	05-22-10	40.8	111.9	7	1,2	Salt Lake City to Ogden, Utah.
00 30	04-12-13	42.3	[2]112.0	5	12	Swan Lake, Idaho
09 06	04-08-14	41.2	111.6	5	1,4	Salt Lake City to Ogden, Utah.
10 15	05-13-14	41.3	[2]112.0	6	1,4	Ogden, Utah.
22 30	12-20-14	37.6	113.8	5	8	Pine Valley, Utah.
15 00	07-15-15	40.4	111.7	6	1,8	Provo, Utah.
11 50	07-30-15	41.8	112.2	5	1,2,7	Garland, Utah.

Table 3.--Chronological list of all earthquakes felt in Utah having Modified Mercalli intensity greater than or equal to V from 1853 to 1975. Locations, magnitudes, and times of occurrence of these events are shown.--Continued

Local time (24 hr. clock)	Local date	Lat(N)	Long(W)	I_o	Source	Location and comments
03 20	08-11-15	40.5	112.7	5	2,5,7	Stansbury Range, Utah.
23 56	10-02-15	40.5	117.5	10	5,7	Pleasant Valley, Nevada, felt I=5 in Salt Lake City, as high as VI at other Utah locations.
01 00	10-05-15	40.0	114.0	5	2,8	Ibapah, Utah.
23 25	02-04-16	40.0	[2]111.8	5	1,5,7	Santaquin, Utah.
21 35	11-19-20	41.5	112.0	5	1,5,7	Brigham City, Utah.
17 00	11-25-20	37.1	113.5	5	2,7	St. George, Utah.
03 18	09-12-21	38.8	112.1	5	4,5	Richfield, Utah.
07 12	09-29-21	38.8	112.2	8	1,2	Elsinore, Utah.
19 30	09-29-21	38.8	112.2	7	2	Elsinore, Utah.
08 32	10-01-21	38.8	112.2	8	1,2	Elsinore, Utah.
05 10	05-14-23	38.1	113.2	5	1,4	Nada, Utah.
21 15	06-06-23	41.7	111.8	5	1,5,8	Logan, Utah.

Table 3.--Chronological list of all earthquakes felt in Utah having Modified Mercalli intensity greater than or equal to V from 1853 to 1975. Locations, magnitudes, and times of occurrence of these events are shown.--Continued

Local time (24 hr. clock)	Local date	Lat(N)	Long(W)	I_o	Source	Location and comments
06 10	01-20-33	38.0	[2]112.6	6	1,5	Parowan, Utah.
08 06	03-12-34	41.80	112.91	9	5,16,17,10	Kosmo, Utah, 100 minor aftershocks.
11 20	03-12-34	41.7	112.8	8	3,4	Kosmo, Utah, aftershock.
01 10	05-06-34	41.7	112.8	6	1,3,17	Kosmo, Utah, aftershock
04 49	07-09-35	40.7	[2]111.8	5	3,17	Salt Lake City, Utah.
03 25	05-09-36	37.5	113.0	5	1,2,17	Zion National Park, Utah.
21 15	02-17-37	37.8	[2]112.5	5	2,3,17	Panguitch and Parowan, Utah.
09 50	11-18-37	41.7	[2]113.8	[2]6	3,5,9,10	Lucin, Utah.
06 37	06-30-38	40.7	[2]112.1	5	1,3,5,10	Salt Lake Valley, Utah.
23 45	04-17-42	41.5	112.3	5	1,3,10	Hansel Valley, Utah.
16 08	08-30-42	37.7	113.0	6	1,2,10	Cedar City, Utah.
05 16	09-26-42	37.7	[2]113.0	5	1,3,10	Cedar City, Utah, event in a swarm.

Table 3.--Chronological list of all earthquakes felt in Utah having Modified Mercalli intensity greater than or equal to V from 1853 to 1975. Locations, magnitudes, and times of occurrence of these events are shown.--Continued

Local time (24 hr. clock)	Local date	Lat(N)	Long(W)	I_o	Source	Location and comments
08 50	09-26-42	37.7	[2]113.0	6	1,3,10	Cedar City, Utah, event in a swarm.
04 50	01-16-43	37.7	113.0	5	3,10	Cedar City, Utah.
07 20	02-22-43	41.0	111.5	6	1,2,3,10	Salt Lake City and Bingham, Utah.
03 30	11-03-43	38.6	[2]112.2	5	1,3,10	Sevier, Utah.
18 15	11-17-45	38.0	[2]112.0	6	1,3,10	Glenwood, Utah.
19 30	05-05-46	41.7	[2]112.2	5	1,3,10	Garland and Tremonton, Utah.
04 02	03-28-47	40.6	[2]111.8	5	3,10	Murray and Salt Lake City, Utah.
06 18	11-04-48	39.2	[2]111.6	5	1,3,10	Manti, Utah.
23 50	03-06-49	40.8	111.9	6	1,2,3,10	Salt Lake City, Utah, aftershocks.
19 30	11-01-49	37.1	113.4	6	3,4,10	St. George, Utah.
18 55	01-17-50	40.5	110.5	5	3,10	Price, Utah.
15 35	05-08-50	40.0	[2]111.7	5	1,3	Payson, Utah.
13 00	09-28-52	40.4	[2]111.8	5	1,3,10	Lehi, Utah.

Table 3.--Chronological list of all earthquakes felt in Utah having Modified Mercalli intensity greater than or equal to V from 1853 to 1975. Locations, magnitudes, and times of occurrence of these events are shown.--Continued

Local time (24 hr. clock)	Local date	Lat(N)	Long(W)	I_0	Source	Location and comments
19 54	05-23-53	40.5	111.5	5	1,3,10	Lehi, Utah.
22 45	07-29-53	39.0	110.1	5	1,3,4,10	Greenriver, Utah.
20 00	10-21-53	37.8	[2]112.3	5	1,3,10	Panguitch, Utah.
15 52	02-13-58	40.5	111.5	6	1,3,10	Wallsburg, Utah.
06 31	11-28-58	39.6	[2]111.8	5	1,3,10	Nephi, Utah.
13 51	12-01-58	40.28	112.48	5	1,3,10	Nephi-Lehan, Utah, area.
20 23	12-01-58	40.46	112.61	5	1,3	Nephi, Utah.
15 20	02-27-59	38.0	112.5	6	1,3,10	Panguitch, Utah.
10 39	07-21-59	37.0	112.5	6	1,3,10	Kanab, Utah, area.
22 03	04-15-61	39.33	111.65	6	1,3,10	Ephriam, Utah.
09 12	05-06-61	39.4	110.2	5	1,3,10	Columbia and Sunnyside, Utah.
09 07	02-15-62	37.0	112.9	5	3,4	Utah-Arizona border, west of Kanab, Utah.
06 35	08-30-62	41.8	111.8	7	1,3,4,9,10	Richmond, Utah, damage near $1 million in Cache County.

Table 3.--Chronological list of all earthquakes felt in Utah having Modified Mercalli intensity greater than or equal to V from 1853 to 1975. Locations, magnitudes, and times of occurrence of these events are shown.--Continued

Local time (24 hr. clock)	Local date	Lat(N)	Long(W)	I_o	Source	Location and comments
09 04	09-05-62	40.7	112.0	6	3	Magna, Utah, area.
10 28	12-11-62	39.6	110.6	5	1	12 miles east of Price, Utah.
09 29	03-25-63	36.0	114.8	6	3,14	Boulder City, Nevada (felt in southwest Utah).
15 18	04-15-63	39.3	[2]110.6	5	1	16 miles east of Huntington, Utah (rockburst).
06 33	04-24-63	39.7	[2]110.5	[1]5	1	12 miles north of Dragerton, Utah (rockburst).
01 39	06-19-63	37.9	112.5	5	1	Northwest of Panguitch, Utah.
12 21	07-07-63	39.6	111.9	6	1,2,3	Levan, Utah.
11 33	07-10-63	40.0	[2]111.3	[1]5	1,13	Tucker, Utah, southwest of Strawberry Reservoir.
02 18	09-30-63	38.1	[2]111.2	[1]5	1,13	14 miles northeast of Boulder, Utah.
21 02	12-28-63	39.1	114.2	[2]5	3,10,13	Lehman Caves, Nevada,

Table 3.--Chronological list of all earthquakes felt in Utah having Modified Mercalli intensity greater than or equal to V from 1853 to 1975. Locations, magnitudes, and times of occurrence of these events are shown.--Continued

Local time (24 hr. clock)	Local date	Lat(N)	Long(W)	I_0	Source	Location and comments
23 44	06-05-64	39.5	110.3	[1]5	1,12	12 miles northeast of Woodside, Utah (rockburst).
11 33	10-18-64	41.9	111.8	[1]5	1,3,10	13 miles south of Richmond, Utah.
05 30	01-14-65	39.6	[2]110.3	[1]5	1,13	Sunnyside, Utah, (rockburst).
22 19	04-01-65	42.5	[2]111.4	[1]5	14	N. Bear Lake Valley, Idaho
00 46	06-29-65	39.6	110.3	[1]5	14	10 miles north of Sunnyside, Utah, (rockburst).
04 48	03-17-66	41.7	111.5	[3]6	3,12	Logan, Utah.
13 21	04-23-66	39.1	111.4	[1]5	12,14	Manti, Utah.
06 41	05-20-66	37.9	112.1	[1]5	12,14	Panguitch, Utah.
11 02	08-16-66	37.4	114.2	6	3,14	Epicenter near Caliente, Nevada, felt VI in Utah.
12 50	08-16-66	37.4	114.2	[1]5	12,14	Aftershock.
16 08	08-17-66	37.4	114.1	[1]5	3,10,12,14	Aftershock.
02 15	08-18-66	37.3	114.2	[1]5	3,10,12,14	Aftershock.

Table 3.--Chronological list of all earthquakes felt in Utah having Modified Mercalli intensity greater than or equal to V from 1853 to 1975. Locations, magnitudes, and times of occurrence of these events are shown.--Continued

Local time (24 hr. clock)	Local date	Lat(N)	Long(W)	I_o	Source	Location and comments
10 35	08-18-66	37.4	114.2	[1]5	12,14	Aftershock.
11 57	09-22-66	37.3	114.2	[1]5	3,10,12,14	Aftershock.
11 58	09-22-66	37.5	114.1	[1]6	3,10,12,14	Aftershock.
12 59	09-22-66	37.3	114.2	[1]5	14	Aftershock.
00 13	10-21-66	38.2	113.1	[1]5	12,14	Milford, Utah.
20 28	02-14-67	40.1	109.1	[1]5	12,13	20 miles east of Ouray, Utah.
11 02	05-07-67	37.0	115.0	[1]5	3,12,13	Southern Nevada.
03 20	10-04-67	38.5	112.1	7	3,9	Marysvale, Utah.
07 34	11-17-68	39.6	111.0	[1]5	13	Wattis, Utah.
05 41	03-29-70	41.6	113.7	5	3,9,13	Grouse Creek, Utah.
03 42	04-18-70	37.9	111.6	[1]5	3	10 miles north of Escalante, Utah.
15 55	05-23-70	38.1	112.4	[1]5	3	Circleville, Utah.
00 47	10-25-70	39.4	111.5	[1]5	11,13	Ephriam, Utah.
07 10	11-10-71	37.8	113.5	[1]5	13	Cedar City and Summit, Utah.

Table 3.--Chronological list of all earthquakes felt in Utah having Modified Mercalli intensity greater than or equal to V from 1853 to 1975. Locations, magnitudes, and times of occurrence of these events are shown.--Continued

Local time (24 hr. clock)	Local date	Lat(N)	Long(W)	I_o	Source	Location and comments
10 19	12-08-71	37.7	115.0	[1]6	9,13	Southeast Nevada, near Caliente.
03 21	01-03-72	38.6	112.1	6	3,13	Elsinore, Utah.
06 33	03-06-72	41.9	111.6	5	3	Lewiston, Utah.
20 15	06-01-72	38.6	112.2	5	3	Monroe, Utah.
12 42	10-01-72	40.6	111.3	5	3,9	Heber, Utah.
23 45	04-13-73	42.0	112.5	5	9,13	Malad City, Idaho.
06 57	12-28-74	42.00	111.97	[1]5	13	Lewiston-Franklin, Utah, area.
02 48	03-26-75	42.07	112.55	5	18	Malad City, Idaho.
08 31	03-27-75	42.09	112.48	7-8	18	Pocatello Valley, Idaho.
06 01	03-29-75	42.02	112.52	[1]5	18	Malad City, Idaho.

[1], Indicates intensity calculated from magnitude.

[2], Indicates that the intensity or location have been assumed for this report.

[3], Indicates value assumed on the basis of the felt area.

[4], Indicates value assumed due to cumulative effects.

Table 3.--Chronological list of all earthquakes felt in Utah having Modified Mercalli intensity greater than or equal to V from 1853 to 1975. Locations, magnitudes, and times of occurrence of these events are shown.--Continued

References: See reference list for complete reference.

1. Cook and Smith, 1967; 2. Coffman and von Hake, 1973; 3. U.S. Department of Commerce, 1928-72; 4. Hays and others, 1974; 5. Williams and Tapper, 1953; 6. Townley and Allen, 1939; 7. U.S. Department of Commerce, 1915-24; 8. H. E. Reid, unpublished records; 9. Bulletin Seismological Society of America, 1911-75; 10. U.S. Department of Commerce, 1957-73; 11. Cook, 1971; 12. Bulletin of the International Seismological Centre, 1913-73; 13. U.S. Department of Commerce, 1944-75; 14. U.S. Department of Commerce, 1930-66; 15. Dewey and others, 1972; 16. Holden, 1898; 17. Milne, 1911; 18. Waverly Person, personal communication, 1975.

The 1949 event ruptured a 10-inch watermain resulting in the loss of water to a sizable portion of the city. An intensity-VI event in 1915 caused minor damage in the Provo area.

By far the most damaging earthquake in Utah's history was the 1962 event near Richmond, north of Logan in the Cache Valley. Although the epicenter was outside the immediate study area, it was felt with intensity V and VI in Weber and Davis Counties and V or less in Salt Lake and Utah Counties. The earthquake was moderate in size ($m = 5.7$ and I_o = VII) but produced damage in three-fourths of the houses in Richmond, nine being unsafe to reoccupy. Two small commercial buildings and a church were rendered nonfunctional. More than half the chimneys on the houses in Richmond were damaged. Several large buildings in Logan, which was about 12 miles (19 km) from the epicenter, sustained major structural damage due to cracked and distorted walls, fallen ceilings and parapets. Mudslides and rockfalls closed several highways in the foothills east of the epicenter and damaged water flumes and irrigation channels, causing minor flooding. The total dollar loss was estimated at $1 million.

The most recent damaging earthquake (M=6.0) near the study area occurred in 1975 in Pocatello Valley, a remote sparsely populated area near the Utah-Idaho border. Epicentral MM intensity was estimated to be VII to VIII. The population center receiving greatest damage was Malad City, about 13.7 mi (22 km) northeast of the epicenter where MM intensity VII was observed. In Malad City, intense ground shaking damaged chimneys in old buildings, cracked plaster walls, and produced cracks around window and door frames in old and new construction. A market and warehouse of concrete block construction were cracked. Windows were broken and parapets knocked down in the commercial section of Malad City. At the high school, a tall brick chimney was knocked down. In Pocatello Valley, the amount of damage was low, but the degree of damage was higher than Malad City; for example, several ranch houses reportedly shifted on their foundations. A full metal grain bin was split open, and several others at the same location were buckled and/or partially rotated. Some chimneys in the valley were broken at the roofline and knocked to the ground. Lurch cracks were also found in the alluvium in the middle of the valley.

In Salt Lake City (MM intensity IV) the shaking was felt by most residents, and although tall buildings swayed, there was no reported damage.

Seismotectonic regime of the four-county study area

The study area lies within the eastern margin of the Basin and Range tectonic province and is flanked on the east and northeast by the Colorado Plateau and the Rocky Mountain fold belt. The area is bounded on the west by the Oquirrh Mountains and the Great Salt Lake, and the eastern portion of the area is transected by the Wasatch Range, striking largely north-northwest.

The four-county area is situated near the southern end of the ISB (Intermountain Seismic Belt) (Smith and Sbar, 1974), a north-trending zone of earthquakes extending from the Montana-Canada border to Arizona and historically the second-most active seismic area in the continental United States (Smith and Sbar, 1974). The ISB in Utah is represented by activity occurring along a complex series of steeply dipping _en echelon_ faults having a generally north-south trend. These fault zones and the historically felt earthquakes, $I_o > 5$, are shown in figure 2. The Wasatch fault zone, the only one whose trace is exposed in the study area, is seen as a series of offset, parallel or branching surface ruptures extending 160 mi (260 km) along the western margin of the Wasatch Range from the Utah-Idaho border on the north to Levan, Utah, on the south (Cook, 1971). The zone exhibits normal faulting, with the west side down or east side up, and the width of visible offset varies from a few hundred yards (metres) to about 3 mi (5 km) near Farmington, Utah. Approximately 2 mi (3.5 km) of total vertical displacement has occurred on the Wasatch fault zone. The fault scarp terraces, which mark the trace of the Wasatch fault zone within the study area, are discontinuous rises generally less than 1.2 mi (2 km) in length, with offsets as large as approximately 45 ft (14 m) at the north of Little Cottonwood Canyon (Cook, 1971).

Based on recent microearthquake studies (Smith and Sbar, 1974), the sense of contemporary movement appears to be the same as prehistorical faulting. Most of the focal depths of earthquakes in this area are less

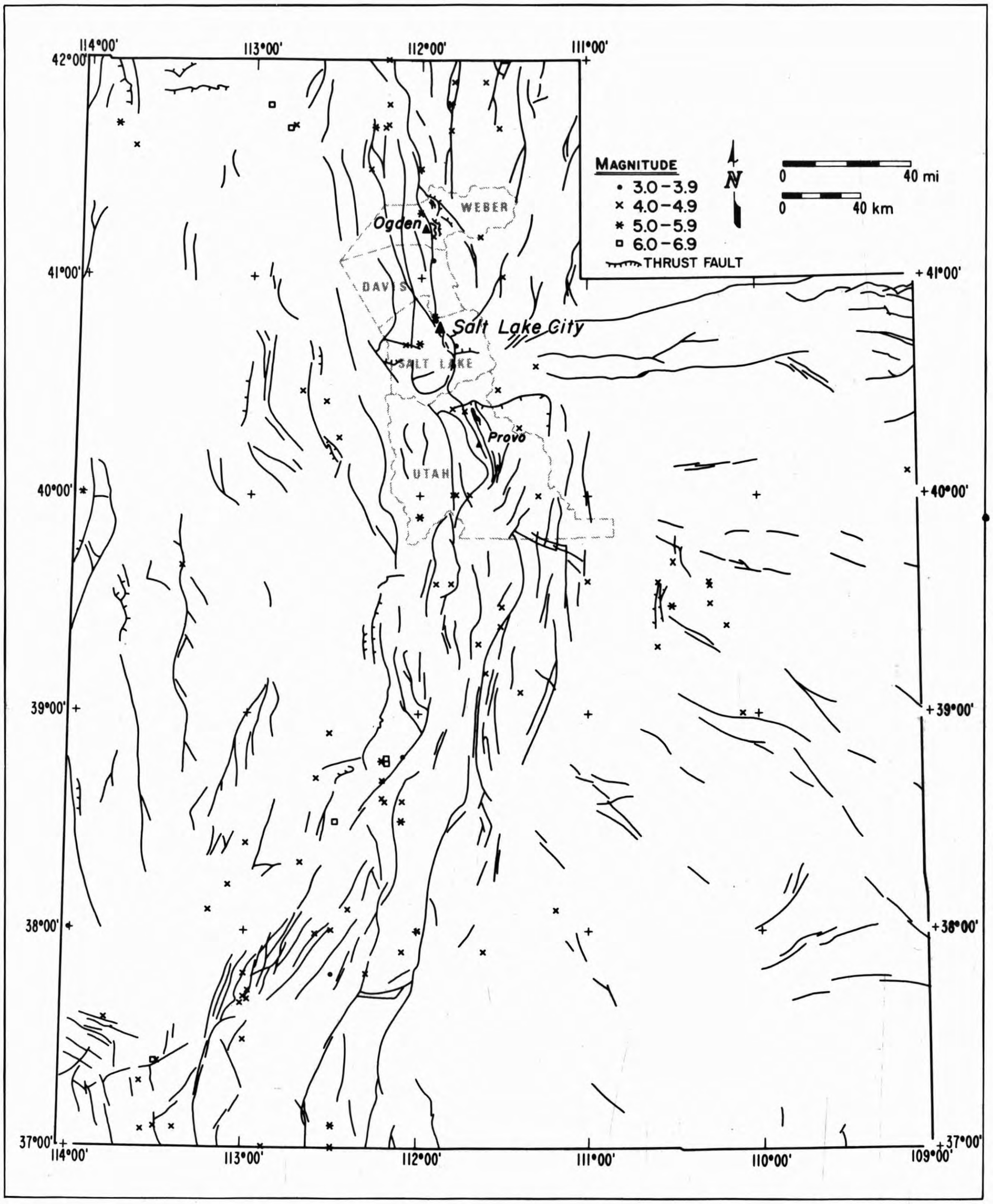

Figure 2.--Map of Utah showing the Intermountain Seismic Belt and the major fault systems.

than 9 mi (15 km), although there is an increase in the number of events in the range from 9 to 12 mi (15 to 20 km). Essentially all well-located hypocenters occur at depths less than 16 mi (25 km).

According to a recent interpretation of the ISB by Smith and Sbar (1974), ISB seismicity is principally the result of movement on intraplate boundaries, or zones of weakness, in the North American plate. The movement on intraplate boundaries is the result of westward movement of the North American plate across a mantle plume, or zone of mantle upwelling. Contemporary upwelling of the plume is causing more-rapid westerly movement of the Northern Rocky Mountain and Great Basin subplates in relationship to the more-stable part of the North American plate. In Utah these motions are reflected by predominantly normal faulting on north-trending faults, occurring as the Great Basin undergoes west and northwest crustal extension.

Rationale for earthquake selection

Six earthquakes[1] were selected for simulation in this study:

Salt Lake City vicinity

1. Magnitude 7.5, depth 10 km, location 40° 44.35'N 111° 51.16'W

2. Magnitude 7.5, depth 10 km, location 40° 42.00'N 112° 00.00'W

Ogden vicinity

3. Magnitude 7.5, depth 10 km, location 41° 12.52'N 111° 58.80'W

4. Magnitude 7.5, depth 10 km, location 41° 12.07'N 112° 7.46'N

Provo vicinity

5. Magnitude 7.5, depth 10 km, location 40° 14.00'N 111° 40.42'W

6. Magnitude 7.5, depth 10 km, location 40° 12.54'N 111° 45.82'W

Selection of the magnitude for these events was based on geological and seismological information. Geological evidence exists for the occurrence of a magnitude-7.5 event in the recent past. Little Cottonwood Canyon contains scarps with a total offset of 188 ft (57 m) and individual scarps having offsets of 10 to 45 ft (3-14 m). Some individual scarps are traceable for about 7 mi (11 km). Where the Wasatch fault

[1] Only the first two were used in the damage assessment phase of the study.

cuts a ravine north of Nephi, displacements of 120 ft (36 m) can be observed. Some of these scarps may have formed during the past 300 years (Cook, 1971). Assuming that the displacement (45 ft (14 m)) and length (7 mi (11 km)) in Little Cottonwood Canyon occurred during a single event, a magnitude-7.5 prehistoric event in the study area appears to be credible. Magnitude 7.5 is the mean value that is predicted using Bonilla and Buchanan's (1970) relations between magnitude, LD^2, L, and D, where L is fault length and D is maximum fault displacement. The predicted magnitude varies between 5.7 and 8.7. The epicentral locations that have been chosen are coincident with mapped or geophysical faults, and the strike of the assumed faults is roughly parallel to that of the known faults (figs. 14-19).

The largest historical event in the ISB is the 1959 Hebgen Lake, Mont., earthquake (M = 7.1). A larger event, M = 7.6, occurred in Pleasant Valley, Nev., in 1915, in the north-trending Nevada seismic zone, which is contiguous with the ISB. Assuming that the seismicity of the Wasatch fault zone reflects the overall seismicity of the ISB, these historical major events can be viewed as plausible upper limits for the maximum credible earthquake magnitude.

In justifying the use of an event of this magnitude for disaster-planning purposes, it is useful to estimate how often such an event might recur using the historical record. Figure 3 shows a summary of the historical record in Utah, with events grouped according to maximum intensity in the epicentral area. This figure shows that the detection of the total number of events has increased as a function of time. Rather than reflecting an increase in the natural seismicity of the region, this rise in detection level is most likely attributable to the increase in population density of Utah after 1850. Examination of the individual intensity events shows that MM-V events may have been completely detected only during the last decade. The detection of MM-VI events may be complete for the last 3 or 4 decades, and intensity-VII or greater events have probably been completely detected for the entire historical record.

Stepp's (1972) technique for minimizing the effects of incompleteness of the data sample have been employed. Table 4 and figure 4 show the required calculations. σ_λ, square root of the mean rate of earthquake occurrence (λ) divided by the time interval (T), is plotted versus

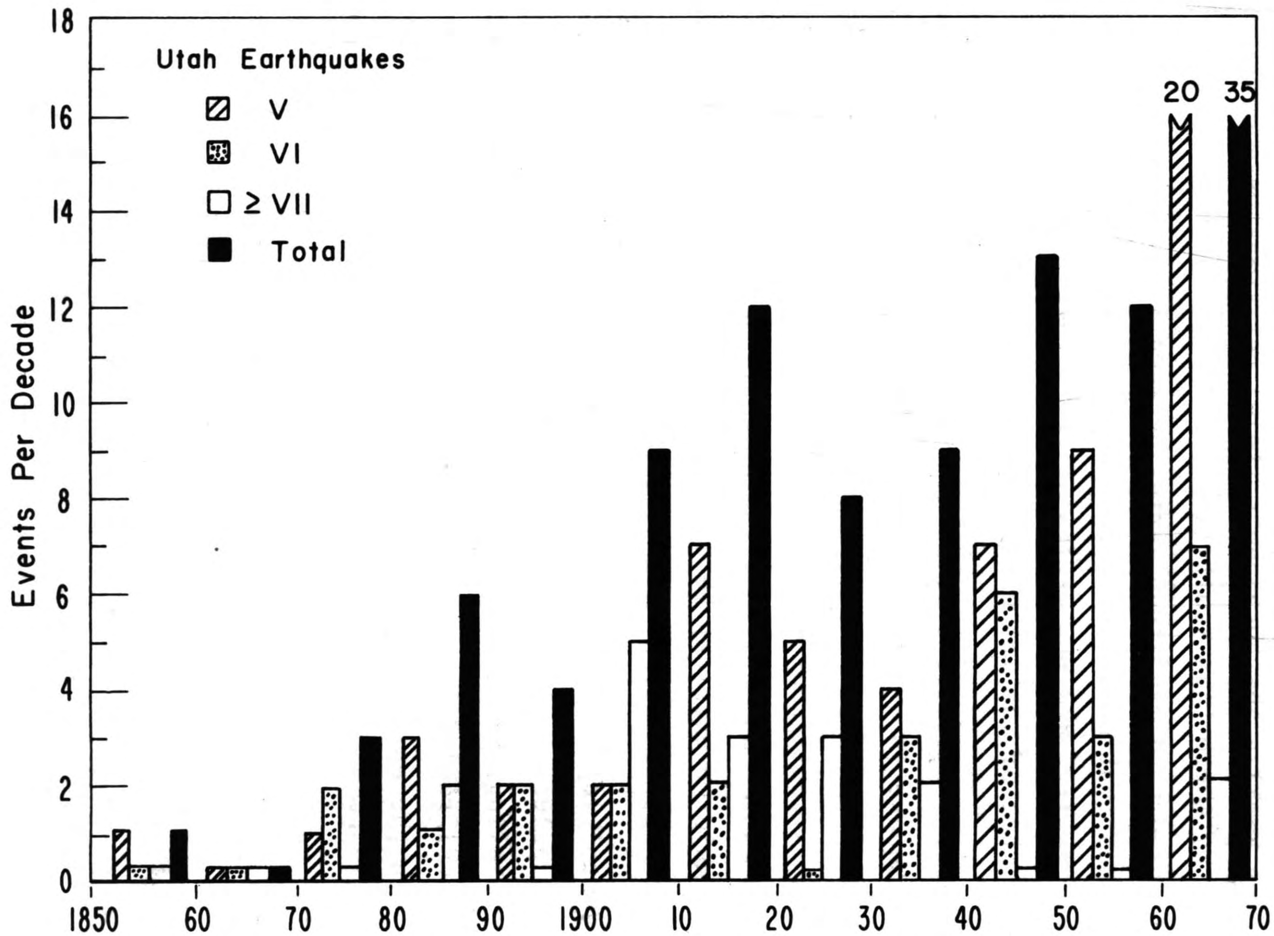

Figure 3.--Histograms showing the number of events in Utah per 10-year period versus decade. Events are grouped according to the maximum epicentral MM intensity.

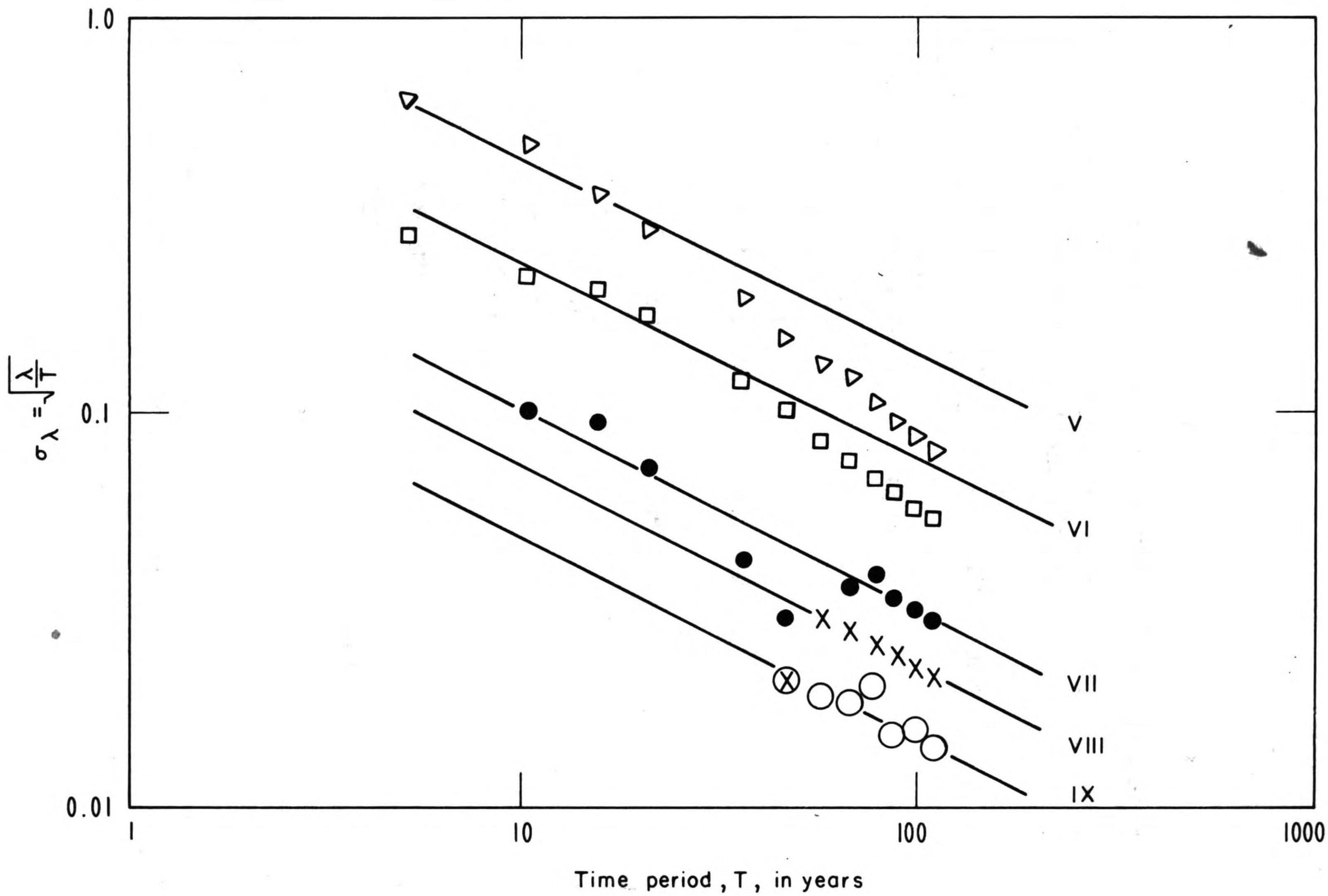

Figure 4.--The square root of the mean rate of earthquake occurrence divided by time interval versus successively longer time intervals. Data through May 1974.

Table 4.--Correction of the data of table 3 for incompleteness according to Stepp's 1972 method. Rockbursts have been excluded. Earthquakes through 1974 have been considered.

[Leaders (--) indicate no data.]

	T	V		VI		VII		VIII		IX	
Period	(years)	N	λ N/T	N	λ N/T	N	λ N/T	N	λ N/T	N	λ N/T
1970-74	5	10	2.00	2	0.40	-	--	-	--	-	--
1965-74	10	23	2.30	5	.50	1	0.10	-	--	-	--
1960-74	15	29	1.93	9	.60	2	.13	-	--	-	--
1955-74	20	32	1.60	12	.60	2	.10	-	--	-	--
1940-74	35	45	1.29	18	.51	2	.06	-	--	-	--
1930-74	45	49	1.09	21	.47	2	.04	1	0.02	1	0.02
1920-74	55	54	.98	21	.38	3	.05	3	.05	1	.02
1910-74	65	61	.94	23	.35	5	.08	3	.05	1	.02
1900-74	75	62	.83	25	.33	8	.11	4	.05	2	.03
1890-74	85	64	.75	27	.32	8	.09	4	.05	2	.02
1880-74	95	68	.72	28	.29	9	.09	5	.05	2	.02
1870-74	105	70	.67	30	.29	9	.09	5	.05	2	.02

T	$\sqrt{\lambda/T}$	$\sqrt{\lambda/T}$	$\sqrt{\lambda/T}$	$\sqrt{\lambda/T}$	$\sqrt{\lambda/T}$
5	0.63	0.28	--	--	--
10	.48	.22	0.100	--	--
15	.36	.20	.093	--	--
20	.28	.17	.071	--	--

Table 4.--Correction of the data of table 3 for incompleteness according to Stepp's 1972 method. Rockbursts have been excluded. Earthquakes through 1974 have been considered.--Continued

T	$\sqrt{\lambda/T}$	$\sqrt{\lambda/T}$	$\sqrt{\lambda/T}$	$\sqrt{\lambda/T}$	$\sqrt{\lambda/T}$
35	.19	.12	.041	--	--
45	.16	.10	.030	0.021	0.021
55	.13	.083	.030	.030	.019
65	.12	.073	.035	.028	.018
75	.105	.066	.038	.026	.020
85	.094	.061	.033	.024	.015
95	.087	.055	.031	.023	.015
105	.080	.053	.029	.022	.014

I_o	$\overline{\lambda}$
5	1.94
6	.55
7	.10
8	.05
9	.02

Least Squares Line $\quad \text{Log } \overline{\lambda} = 2.733 - 0.504\ I_o$

time interval. If the completeness of the data sample is not changing with time, the curve slopes as $1/\sqrt{T}$. A line of this slope fits intensity-V data for the most recent 15 years. Thus, the mean rate of occurrence of these events is determined using data in that time period. Similarly, intensity VI appears complete for the last 35 to 45 years, while intensity VII, VIII, and IX appear complete for the entire record. The mean rate of occurrence for each intensity for these time periods is shown at the bottom of table 4 with the least squares fit to these data. The following relations are obtained for the interval and cumulative frequency of occurrence:

Interval: $\text{Log } \overline{\lambda} = 2.73 - 0.50\, I_o$

Cumulative: $\text{Log } N_c = 3.02 - 0.53\, I_o$.

The data and fitted lines are shown in figure 5. These lines can be transformed into recurrence rates, with magnitude as the independent variable, using the Gutenberg-Richter relation (Gutenberg and Richter, 1956):

$$M = 1 + 2/3\, I_o \quad .$$

These relations are

1.52 for no. per yr per 1000 km²

Interval: $\text{Log } \overline{\lambda} = 3.49 - 0.76\, M$

Cumulative: $\text{Log } N_c = 3.81 - 0.79\, M$. (1)

The cumulative relation indicates that an earthquake of magnitude-7.5 or larger has a recurrence interval of 131 years in Utah.

Another approach for minimizing the errors of incomplete reporting is the method of extreme-values, commonly used to estimate the return period of floods. The data used in this analysis are the maximum intensities, I_j, in each year of the historical record. It is assumed that these yearly extremes follow a limiting distribution which is given by

$$F(x) = \exp\left[-\exp(-(x-U)/B)\right] \quad -\infty<x<\infty \quad , \qquad (2)$$

where x = magnitude or intensity,

U = constant to be determined by the sample of extremes,

B = constant to be determined by the sample of extremes,

$F(x)$ = probability that the largest earthquake in a year will have magnitude or intensity less than or equal to x.

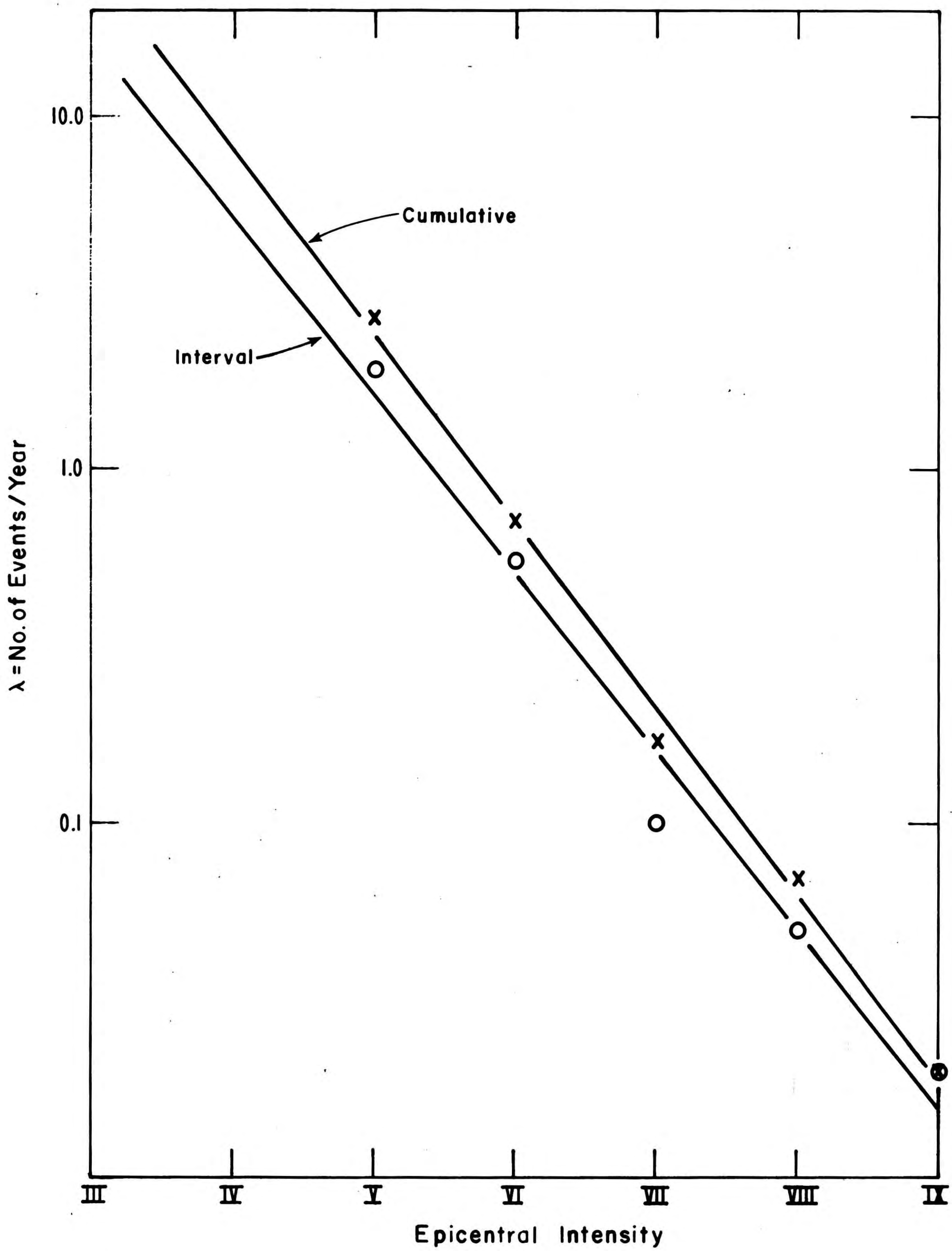

Figure 5.--The interval and cumulative frequency of recurrence for epicentral intensity-Utah earthquakes.

Because the yearly extremes are more likely to be large-magnitude events than small-magnitude events, this technique is relatively insensitive to the incomplete reporting of small-magnitude events. Equation (2) is used to predict the probability of an extreme occurrence outside the observed range of sample extremes, or conversely the return period for such an event can be estimated using

$$Rp = 1/[1 - F(x)] \quad ,$$

where Rp = the return period of earthquakes greater than or equal to x.

On the other hand, equation (2) might be inverted so as to find the magnitude which has a given return period. The choice of a design return period for structures must be carefully made, because the magnitude that has a return period of T years has a 63% probability of being exceeded in T years. This is illustrated in the following simplified example. If an event χ has a 99 percent extreme probability in a given year, then

$$Prob_1 \ [\chi \leq x] = F(x) = 0.99 \quad .$$

The return period for this event is

$$RP = 1/[1-0.99] = 100 \text{ years;}$$

the probability that this event is the largest event in 100 years is

$$Prob_{100} \ [\chi \leq x] = F(x)^{100} = 0.37 \quad .$$

Then, the probability that the given event is greater than or equal to x in a 100-year period is

$$Prob_{100} \ [\chi > x] = 1 - 0.37 = 0.63 \quad .$$

This result is in fact more general than suggested by the limitations of this illustration, in particular it is true where the underlying events have a Poisson distribution of occurrence (as seems to be the case for large earthquakes).

Both extreme probability and return period are concurrently shown on graph paper (extreme probability paper), constructed such that equation (2) plots as a straight line. Practically, the extreme probability is estimated by first ordering the sample of yearly extremes in an increasing sequence and computing

$$P(I(J)) = J/(n + 1) \quad ,$$

where J = the J^{th} value in the sequence,

n = the total number in the sample,

and $P(I(J))$ = an unbiased estimate of the probability that the yearly extreme magnitude or intensity $I(J)$ is the extreme value in a year.

These data for Utah and the corresponding plot on extreme probability paper are shown in table 5 and figure 6. The extreme-value distribution is fit by inspection to only the lowest probabilities for a given intensity in figure 6, because this results in conservative estimates of the return period, but also because intensity is an integer number and a line through the lowest probabilities yields return periods that are consistent with the notion of recurrence intervals. For instance, if intensity V were the extreme in 3 separate years, the extreme probabilities would be (if n = 3)

$$0.25, \ 0.50, \text{ and } 0.75 \quad ,$$

and the corresponding return periods would be

$$1.3, \ 2.0, \text{ and } 4.0 \quad .$$

By comparison the recurrence interval for an event of intensity V is 1 year. The return period nearest to this value is the smallest one, 1.3.

Figure 6 also compares a transformation of the recurrence relation to an extreme probability distribution suggested by Epstein and Lomnitz (1966) and the observed extreme probability. The recurrence relation,

$$\mathrm{Log}_{10} N_c(X) = a + bx \quad ,$$

is transformed by

$$U = aB/\mathrm{Log}_{10}\, e \quad ,$$

$$B = \mathrm{Log}_{10}\, e/b \quad ,$$

Table 5.--The sequence of ordered extremes I(J), from lowest to highest intensity, the sequence number (J), and the unbiased estimate of extreme probability (P(I(J))).

J	I(J)	P(I(J))	J	I(J)	P(I(J))	J	I(J)	P(I(J))
1	0.0	1.0	23	0.0	24.2	45	5.0	47.4
2	0.0	2.1	24	0.0	25.3	46	5.0	48.4
3	0.0	3.2	25	0.0	26.3	47	5.0	49.5
4	0.0	4.2	26	0.0	27.4	48	5.0	50.5
5	0.0	5.3	27	0.0	28.4	49	5.0	51.6
6	0.0	6.3	28	0.0	29.5	50	5.0	52.6
7	0.0	7.4	29	0.0	30.5	51	5.0	53.7
8	0.0	8.4	30	0.0	31.6	52	5.0	54.7
9	0.0	9.5	31	0.0	32.6	53	5.0	55.8
10	0.0	10.5	32	0.0	33.7	54	5.0	56.8
11	0.0	11.6	33	0.0	34.7	55	5.0	57.9
12	0.0	12.6	34	0.0	35.8	56	5.0	58.9
13	0.0	13.7	35	0.0	36.8	57	5.0	60.0
14	0.0	14.7	36	0.0	37.9	58	5.0	61.1
15	0.0	15.8	37	0.0	38.9	59	5.0	62.1
16	0.0	16.8	38	0.0	40.0	60	5.0	63.2
17	0.0	17.9	39	0.0	41.1	61	5.0	64.2
18	0.0	18.9	40	0.0	42.1	62	5.0	65.3
19	0.0	20.0	41	0.0	43.2	63	5.0	66.3
20	0.0	21.1	42	5.0	44.2	64	6.0	67.4
21	0.0	22.1	43	5.0	45.3	65	6.0	68.4
22	0.0	23.2	44	5.0	46.3	66	6.0	69.5

Table 5.--The sequence of ordered extremes I(J), from lowest to highest intensity, the sequence number (J), and the unbiased estimate of extreme probability (P(I(J))).--Continued

J	I(J)	P(I(J))	J	I(J)	P(I(J))
67	6.0	70.5	90	8.0	94.7
68	6.0	71.6	91	8.0	95.8
69	6.0	72.6	92	8.0	96.8
70	6.0	73.7	93	9.0	97.9
71	6.0	74.7	94	9.0	98.9
72	6.0	75.8			
73	6.0	76.8			
74	6.0	77.9			
75	6.0	78.9			
76	6.0	80.0			
77	6.0	81.1			
78	6.0	82.1			
79	6.0	83.2			
80	6.0	84.2			
81	6.0	85.3			
82	6.0	86.3			
83	7.0	87.4			
84	7.0	88.4			
85	7.0	89.5			
86	7.0	90.5			
87	7.0	91.6			
88	7.0	92.6			
89	7.0	93.7			

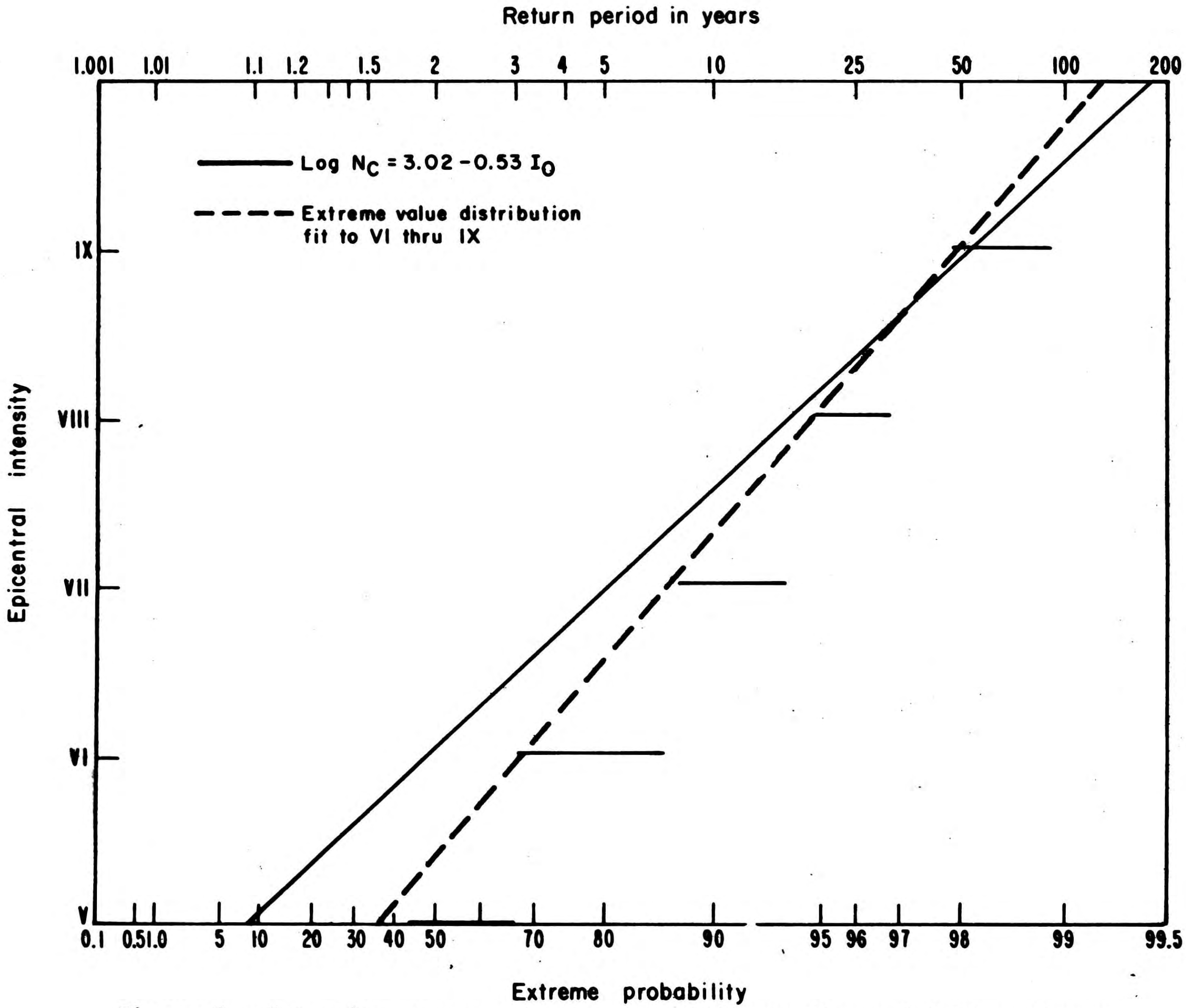

Figure 6.--Intensity versus extreme probability or the probability that a given intensity is the largest intensity in a given year. Return period or the interval in which a given intensity or greater has a 63% probability of occurrence and the recurrence relation transformed to extreme probability are also shown.

where U and B are as defined in equation (2). The values of U and B obtained are

$$U = 5.73, \quad B = 0.82 \quad .$$

The values of U and B for the observed extreme probability determined from the dashed curve in figure 6 are

$$U = 5.07, \quad B = 1.02 \quad .$$

It is seen in figure 6 that relative to the observed extreme probability the recurrence relation underestimates the probability of occurrence for I_o <VIII, and overestimates the probability for I_o >VIII. While both curves give comparable results in the region of the largest observed intensities (which are probably all reported) the curves differ above the range of observed intensities and at small intensities because of a difference in slope. The higher slope of the observed extremes is likely due to nonreporting of extreme values in a significant number of years. For this reason, it is believed that the corrected recurrence relation is a more valid estimate of the actual recurrence.

For a M = 7.5 (I_o = 9.75), these data indicate return periods of 100 years using the extreme probability distribution and 131 years using the corrected recurrence relation. In other words, the time interval for which there is a 63 percent probability of an event exceeding or equaling magnitude-7.5 may be as short as 100 years. In terms of recurrence or return period, a magnitude-7.5 earthquake appears to be a reasonable choice for the purpose of disaster planning.

SECTION 2: EARTHQUAKE INTENSITIES AND ISOSEISMAL MAPS

Materials used

The geologic data used in this study were compiled from numerous sources at scales ranging from 1:24,000 to 1:250,000. Historical intensity data for Utah were gathered from newspaper accounts, published scientific articles, and previously published lists. As complete an account as possible has been compiled for every earthquake known to have occurred in Utah or to have caused damage there. The references shown in table 3 are considered to be the original sources of information concerning the earthquakes listed.

The most detailed geologic mapping available for this study was provided by Richard Van Horn of the U.S. Geological Survey (unpub. mapping, 1975). These maps provided information on the surficial geology in Salt Lake and Davis Counties at a scale of 1:24,000. The original units of mapping were categorized into three groups: unconsolidated alluvium, semiconsolidated alluvium, and hard rock. Unconsolidated alluvium is the broadest category and includes artificial fill, landslide, talus, lake, stream, glacial, and wind deposits. Semiconsolidated alluvium includes Tertiary conglomerate, volcanic agglomerate, tuff, and some limestone. The term hard rock characterizes bedrock deposits such as limestone, dolomite, sandstone, quartzite, shale, and metamorphic or igneous rock. Additional information was obtained from Arnow, 1972; Hintze, 1972; Van Horn and others, 1972; Pashley and Wiggins, 1972; Van Horn, 1972a, b; Crittenden, 1964; Crittenden, 1965; McGregor and others, 1974; Arnow and Mattick, 1968; Mattick, 1970; Arnow and others, 1970; Cluff and others, 1974; Cluff and others, 1970, 1973. Stokes and Madsen, 1961, Stokes, 1962, Hintze, 1963, and Hintze and Stokes, 1963, were major sources of information for Weber and Utah Counties. The latter references are geologic maps of Utah compiled from many sources at 1:250,000.

Attenuation Curves

Attenuation of intensity as a function of distance in Utah was examined in order to specify intensity attenuation for the predictions in this study. The two best documented events in Utah were used: the

1962 Cache Valley earthquake and the 1934 Hansel Valley earthquake. The median, maximum, and minimum distances that each intensity was observed were plotted versus the difference between the epicentral intensity and the observed intensity. The results are shown in figures 7 and 8, where it can be seen that Ergin's 1969 relation

$$I_o - I = n \, \text{Log}_{10} \, [(\Delta^2 + h^2)^{\frac{1}{2}}/h] \quad , \qquad (3)$$

n = empirical exponent to be determined,

Δ = epicentral distance (km),

h = depth of focus (km), and

I_o = maximum intensity at the epicenter,

fits the median observations for n = 4.0. Thus, equation (3) can be used to predict the median distance at which a given intensity can be expected for an earthquake of maximum intensity I_o. For the purposes of this study, we have assumed that equation (3) estimates the intensity at a given distance at a site located on material of average seismic response or semiconsolidated alluvium. This interpretation also suggests the further assumption that the maximum distance at which a given intensity is observed represents an occurrence on material of highest seismic response, or unconsolidated alluvium, and that the minimum distance at which a given intensity is observed represents an occurrence on material of lowest seismic response, or hardrock. This interpretation of intensity-distance curves was also adopted by Neumann, 1954. One instrumentally determined point is shown in figure 8. An accelerograph at Logan State University was triggered during the Cache Valley earthquake and recorded a peak horizontal ground acceleration of 0.14g. This value was converted to intensity using Gutenberg and Richter's 1956 relation,

$$I = 3(\text{Log}_{10} \, a + 0.5) \quad ,$$

where a = acceleration in (cm/sec^2) and

I = Modified Mercalli intensity.

$I = 7.9$

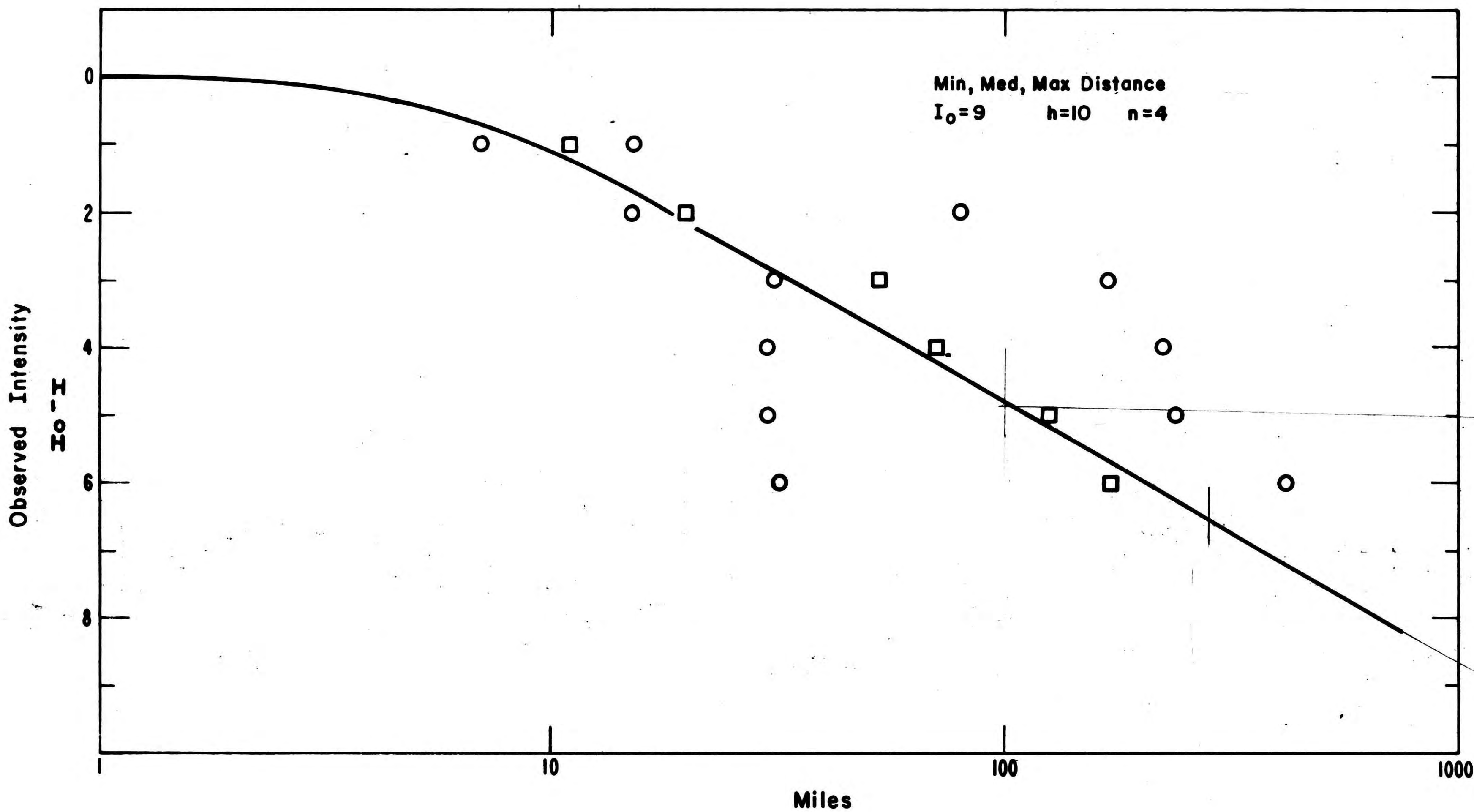

Figure 7.--Observed intensity versus epicentral distance for the 1934 Hansel Valley earthquake. Circles indicate the minimum and maximum distances at which that intensity was observed; square indicates median distance at which that intensity was observed. h=focal depth in km; I_o=max. intensity at the epicenter; n=exponent in Ergin's 1969 relation. The solid line is Ergin's 1969 curve.

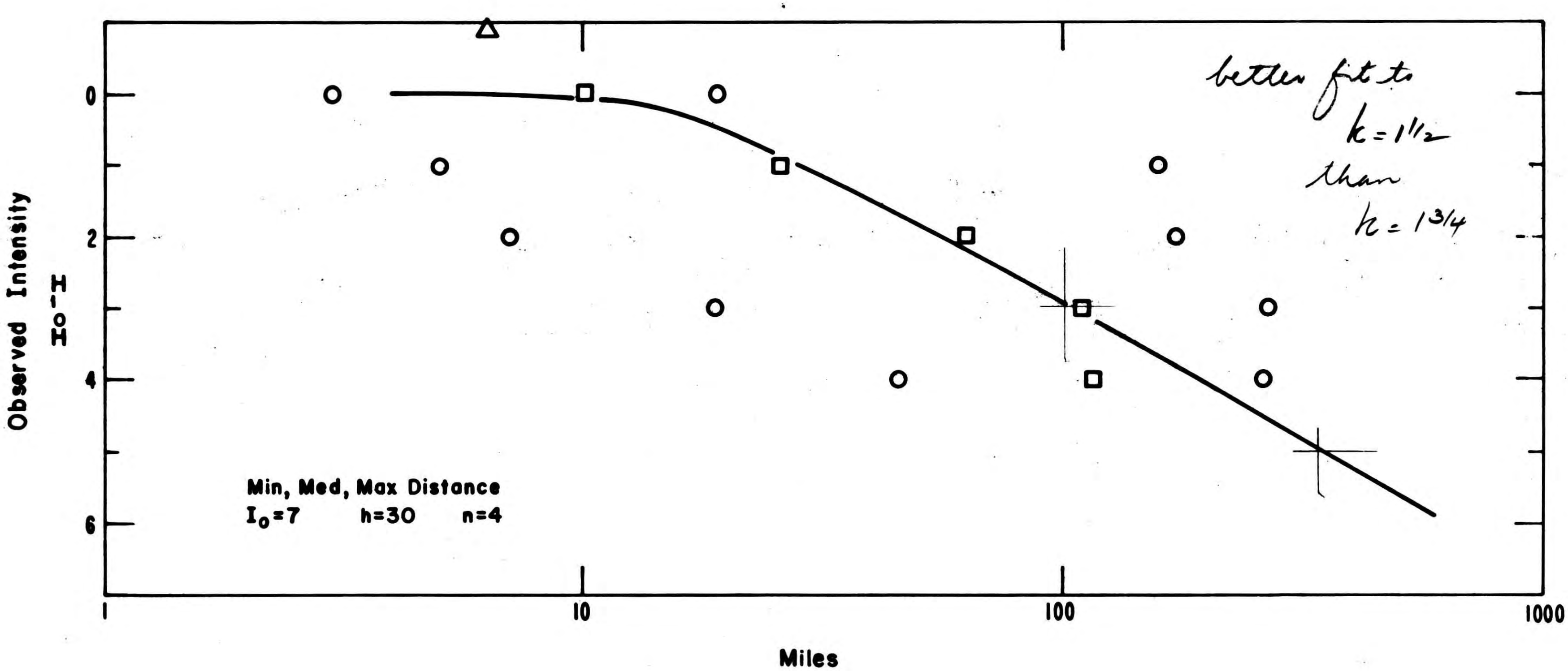

Figure 8.--Observed intensity versus epicentral distance for the 1962 Cache valley earthquake. Circles indicate the minimum and maximum distances at which that intensity was observed; square indicates median distance at which that intensity was observed. h=focal depth in km; I_o=max. intensity at the epicenter; n=exponent in Ergin's 1969 relation. The solid line is Ergin's 1969 curve. The Δ symbol indicates one point instrumentally determined using the peak acceleration recorded at Logan during this earthquake.

The predicted value of I is nearly one intensity unit too large for this distance (6.3 mi (10 km)). This difference might be accounted for by ground amplification at the accelerograph site or the fact that typical California earthquakes, on which this equation is based, are shallower than the Cache Valley event. The instrumental depth of this event was reported as 23 mi (37 km) (United States Earthquakes, 1962). The difference might also be due to the fact that the duration of acceleration greater than 0.05g was about 1.4 seconds, whereas durations of 5 to 10 seconds are expected for an earthquake of magnitude 5.8 (Page and others, 1972) at this epicentral distance. On the other hand, the intensity-acceleration relation (Neumann, 1954),

$$\log_{10} a = 0.308\, I - 0.041 \quad ,$$

gives a value of I = 7.4. This value is also greater than $I_o = 7$, although closer to the median curve possibly by virtue of the fact that Neumann used 3 earthquakes from outside of California in his sample of 10. In any case, the single point helps to establish the validity of the level of the median curve, or conversely it helps to establish the validity of these acceleration-intensity relations for estimating accelerations from predicted or observed intensities in Utah.

Because the extreme distances may not be well reported at each intensity, it is difficult to assess the shape of the curves for these values using figures 7 and 8. Consequently, we have further assumed that the curves for the extreme cases are parallel to the median curve.

In order to determine the separation between the extreme curves and the median curve, an array of 32 stations was deployed across Salt Lake Valley to measure the soil-response variation for Bingham mine blasts and an NTS (Nevada Test Site) explosion. Figure 9 shows the array configuration. The long axis of the array is approximately alined radially with both the Bingham mine and NTS. Three seismometers at each station recorded the vertical, transverse, and radial ground motion. Records for two stations recording a mine blast are shown in figure 10; they demonstrate the kind of differences that were observed between ground velocities recorded at different stations.

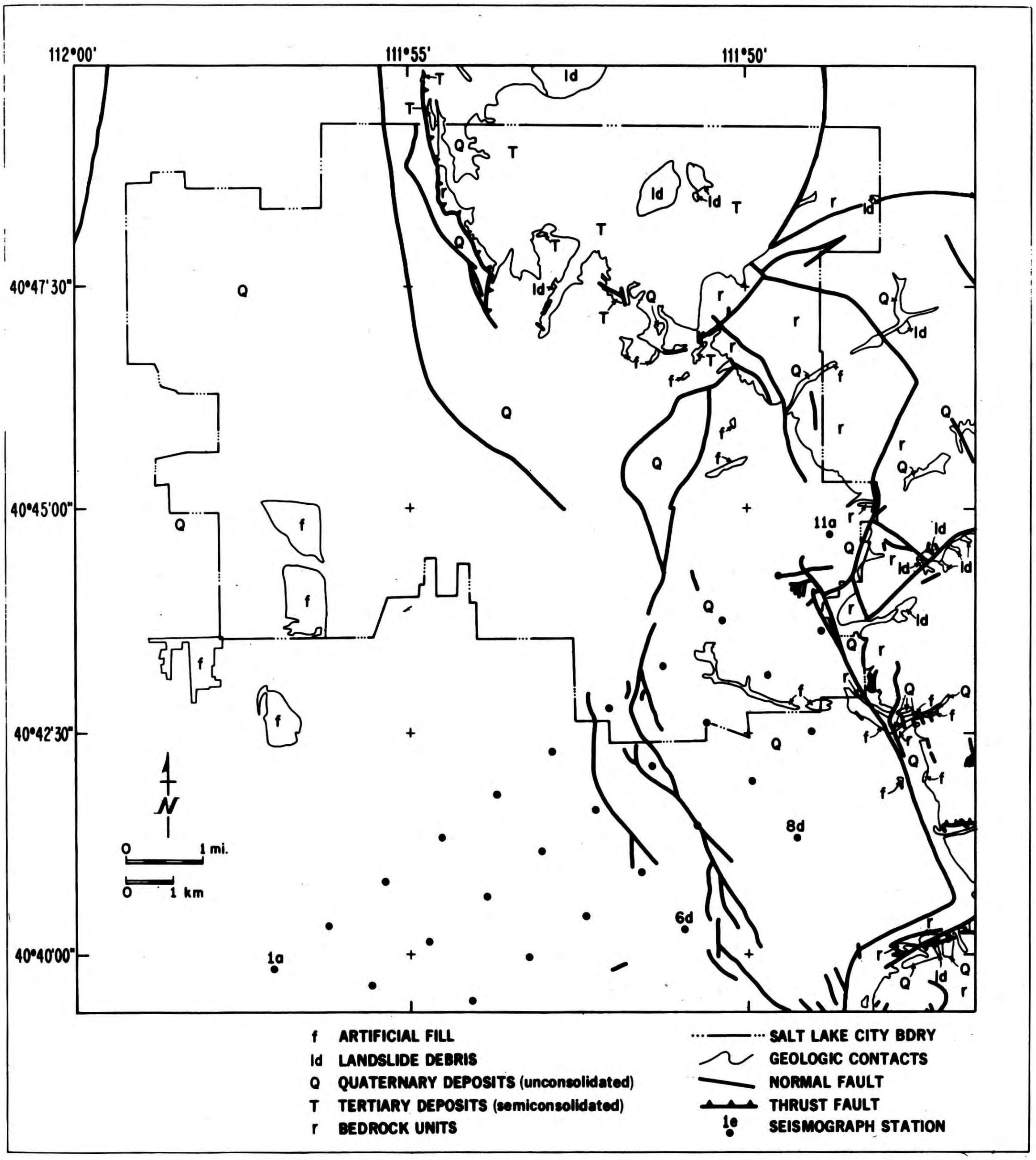

Figure 9.--Map showing the seismic array configuration in Salt Lake Valley. Each dot represents a three-component seismograph system recording on magnetic tape (L-7 system). All stations were occupied simultaneously and recorded several Bingham mine blasts as well as one Nevada Test Site nuclear blast.

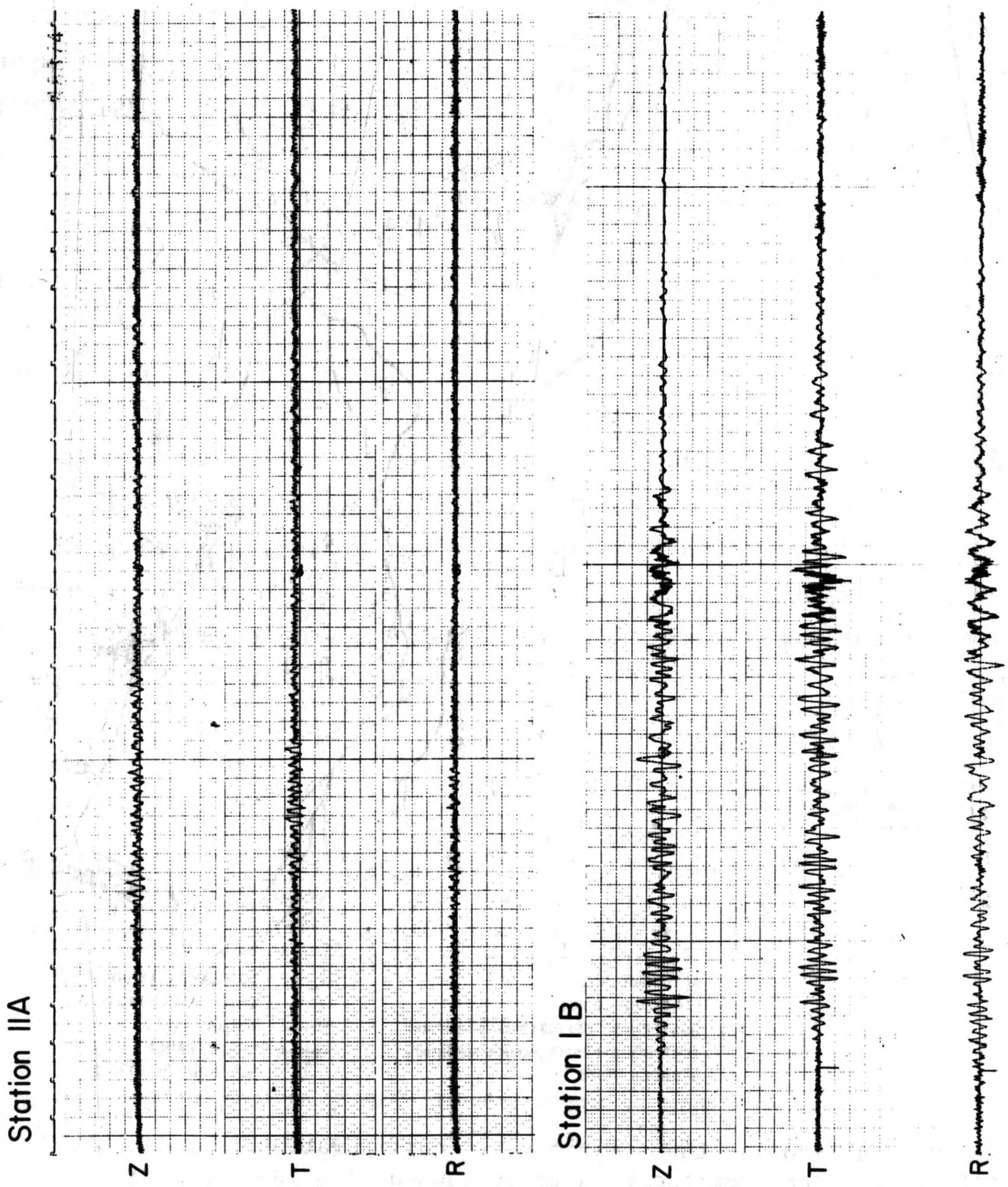

Figure 10.--Seismograph records showing vertical (Z), transverse (T), and radial (R) components of ground velocity at two stations for the same mine blast. All amplitude scales are equal.

In the analysis of these data, the peak ground velocities were read and a horizontal resultant found for each station. The peak horizontal-ground-velocity resultant at each station was corrected for distance attenuation to a common distance using Murphy and Lahoud's (1969) distance exponent

where $$v_i^{cor} = v_i \, (R_{11}/R_i)^{1.34} \quad ,$$

v_i^{cor} = distance-corrected peak horizontal ground velocity at station i,

v_i = peak horizontal ground velocity at station i,

R_{11} = distance from the shot to station 11, the arbitrarily chosen common distance, and

R_i = distance from the shot to station i.

The median corrected peak velocity was determined, and ratios of peak corrected velocity to median corrected velocity were formed. The highest ratio found was 1.6 and the lowest was 0.27. Thus, we observed a factor of six between the highest and lowest values of distance-corrected peak velocities. We assumed that the highest value relative to the median occurred on unconsolidated alluvium and that the lowest value occurred on hardrock. These velocity ratios were transformed to intensity increments to raise or lower the median-intensity increment curve using the Newmark and Rosenblueth (1971, p. 219) relation between velocity and intensity:

$$I_o - I = 4.0 \, \mathrm{Log}_{10} \, [(\Delta^2 + h^2)^{\frac{1}{2}}/h] + \mathrm{Log}_{10} \, (v_{med}/v_i)/\mathrm{Log}_{10} \, 2, \quad (4)$$

where v_{med} = the median distance-corrected peak horizontal velocity and all other parameters are as previously defined.

In order to convert the assumed magnitude 7.5 into an assumed maximum intensity, we have used Gutenberg and Richter's (1956) relation:

$$I_o = 1.5 \, (M-1) = 9.75 \quad (5)$$

That this relation is reasonable to use in Utah is demonstrated by figure 11, which compares observations in Utah with equation (5).

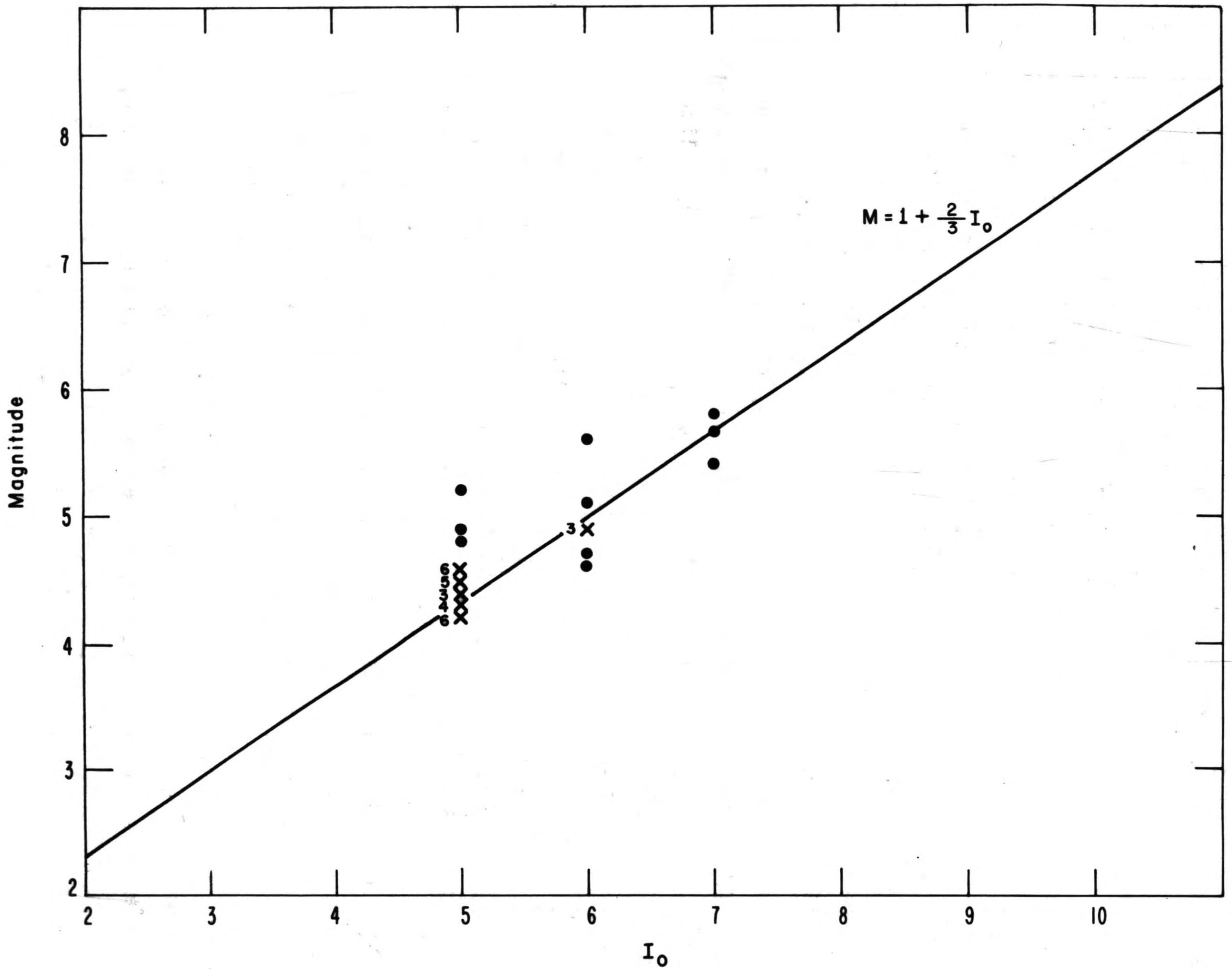

Figure 11.--Graph showing magnitude versus maximum intensity for Utah earthquakes. The line shows the Gutenberg-Richter relation. The numbers indicate the number of overlapping data points.

These data and equation (4) have been used to produce intensity attenuation curves for unconsolidated, semiconsolidated, and hard rock, as shown in figure 12. The curves have been linearly extrapolated at close-in distances, and the linear extrapolations have been used in a conservative vein because the behavior of ground motion at close-in distances is not yet well understood.

Estimating the probability of faulting

Surface faulting at a given location can be expected to accompany a magnitude-7.5 event in the Basin and Range Province on the basis of past experience (Hansel Valley, 1934, and a number of Nevada earthquakes: Pleasant Valley, 1915; Cedar Mountain, 1932; Dixie Valley, 1954; and others). The length of faulting is estimated to be 19 mi (30 km), and the maximum displacement is estimated to be 3-10 ft (1-3 m) (Bonilla and Buchanan, 1970). Two approaches might be taken to estimate damage due to faulting. It is possible to specify those mapped faults believed to be most likely to break during the assumed earthquake. This approach was used by the contracting engineers, who conducted the damage assessment phase of the study, using fault traces Cluff (1975) believes are most likely to break. These faults are shown in figure 33, for instance. The second method attempts to specify the probability of faulting on any fault in the area of interest given that a certain length of faulting will occur for the postulated earthquake. This second method is presented as an example of perhaps an alternative approach for future studies of this kind and as additional information that could be used to supplement or extend damage studies in the four-county area. The probability that faulting will occur at any given location on a fault was estimated in the following manner. Given the assumed epicentral location, a rectangle was constructed around the epicenter with one side parallel to the strike of the assumed fault. The strike of the assumed fault was chosen to approximately coincide with the strike of the observed fault on which the epicenter was placed. The side of the rectangle parallel to the fault was chosen to be 37 mi (60 km) long, while the perpendicular side was made variable in length. The length of the rectangle is justified by assuming that faulting will

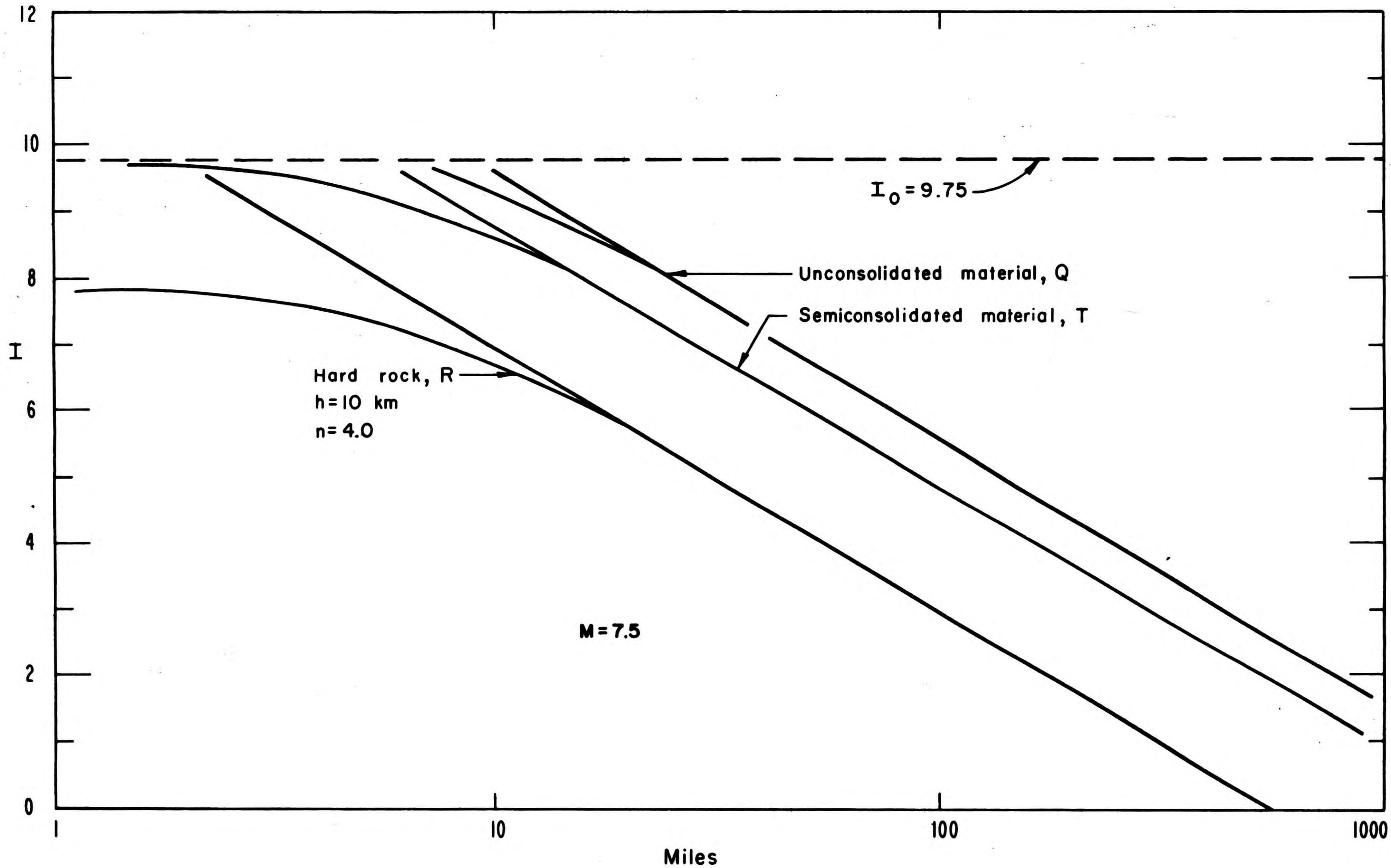

Figure 12.--Graph showing intensity versus distance for a magnitude-7.5 earthquake for locations on unconsolidated soils, semiconsolidated soils, or hard rock.

not exceed 19 mi (30 km) on either side of the given epicenter. The probability of faulting at a given point on a fault in the rectangle was defined as

$$P = 19 \text{ mi}/TL \quad ,$$

where TL = total length of faults in the rectangle.

The probability is strongly dependent on the size of the rectangle, as shown by figure 13, but in all cases P is less than 0.4. The rectangles chosen are shown in figures 14 through 19.

In order to estimate the probability of faulting in the densely populated Salt Lake City area, the longest north-south dimension of that area (7.6 mi (12.3km)) was considered the length of possible faulting (TL_1). The probability of faulting in the Salt Lake City area was then defined as

$$P_{SLC} = TL_1/TL_2 \quad ,$$

where TL_2 = the total length of faulting in the Salt Lake area.

The area used is the Salt Lake City boundary shown in figure 20, and the value of P obtained (0.28) is plotted in figure 13 for comparison.

In order to make use of these probabilities, additional information on the total possible dollar loss of buildings astride faults in the study area would be needed as a function of the area width. A curve of probable dollar loss versus area width then could be constructed from these two sets of data. The shape of this curve could be used to estimate the lowest and highest probable dollar loss due to faulting.

For planning purposes in this report, it is estimated that there will be a 15-ft (4.6-m) vertical scarp at the line of surface rupture. Then, within a 1,500-ft (457-m)-wide zone on the hanging wall side of the fault, the ground is expected to be fissured, tilted, and cracked with vertical surface offsets ranging from 1 to 3 ft (.3-.9m). Within a 200-ft (61-m)-wide zone on the foot wall side of the fault, the ground would be subject to local landslides and small vertical offsets of from 1 to 3 ft (.3-.9m). For the remainder of this report, the 1,500-ft (457-m)-wide hanging wall zone plus the 200-ft (61-m)-wide foot wall zone (=1,700 ft or 518 m) is referred to as the zone of deformation due to surface faulting.

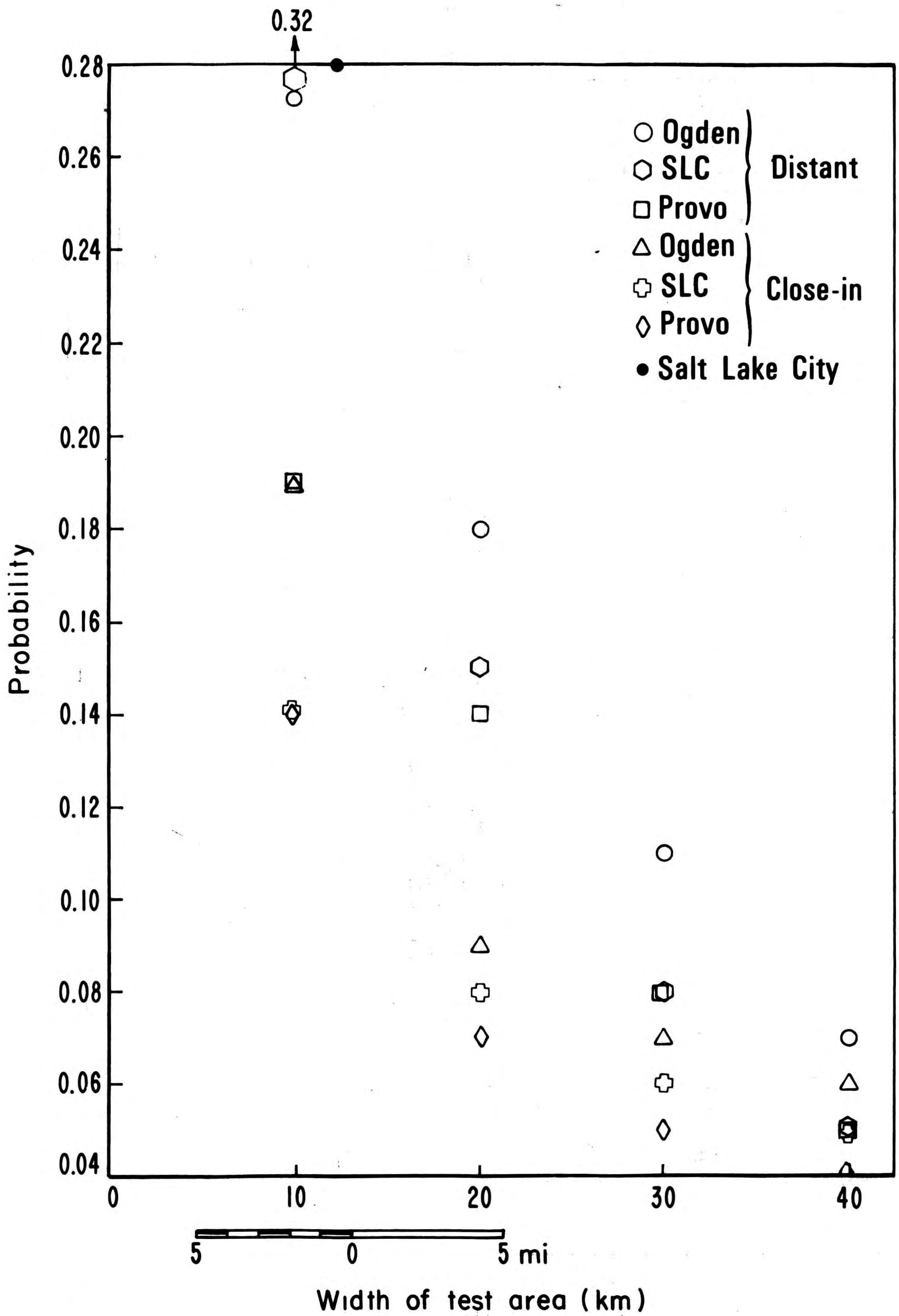

Figure 13.--Graph showing probability of faulting at given site on a fault as a function of the width of the rectangle assumed.

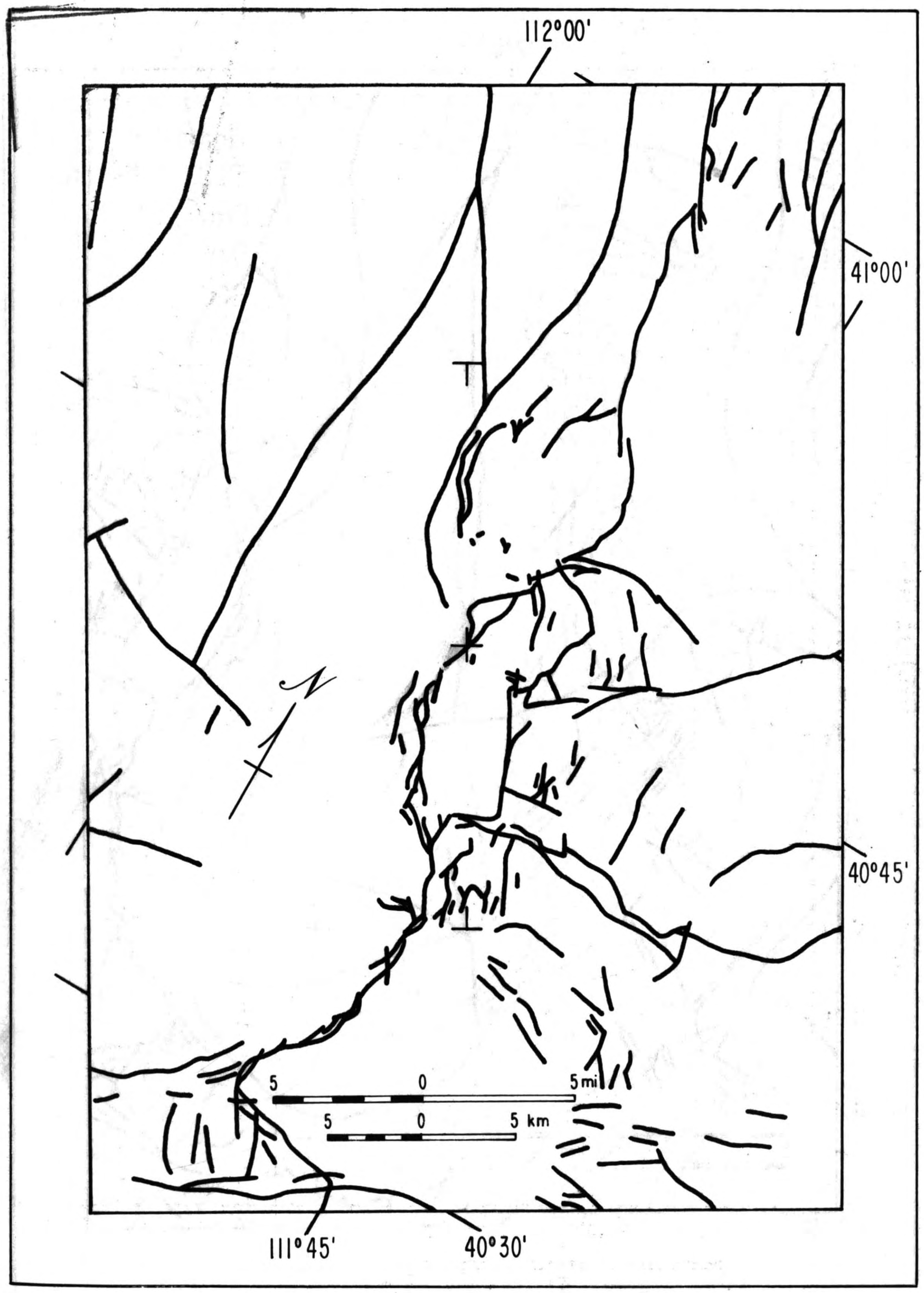

Figure 14.--Area of probable faulting for the Salt Lake City close-in event. ┼ indicates the assumed epicenter; ⊥ or ┬ indicates the ends of the assumed fault.

Figure 15.--Area of probable faulting for the Salt Lake City distant event. ┼ indicates the assumed epicenter; ⊥ and ⊤ indicate the ends of the assumed fault.

Figure 16.--Area of probable faulting for the Provo close-in event. ┼ indicates the assumed epicenter; ⊥ and ⊤ indicate the ends of the assumed fault.

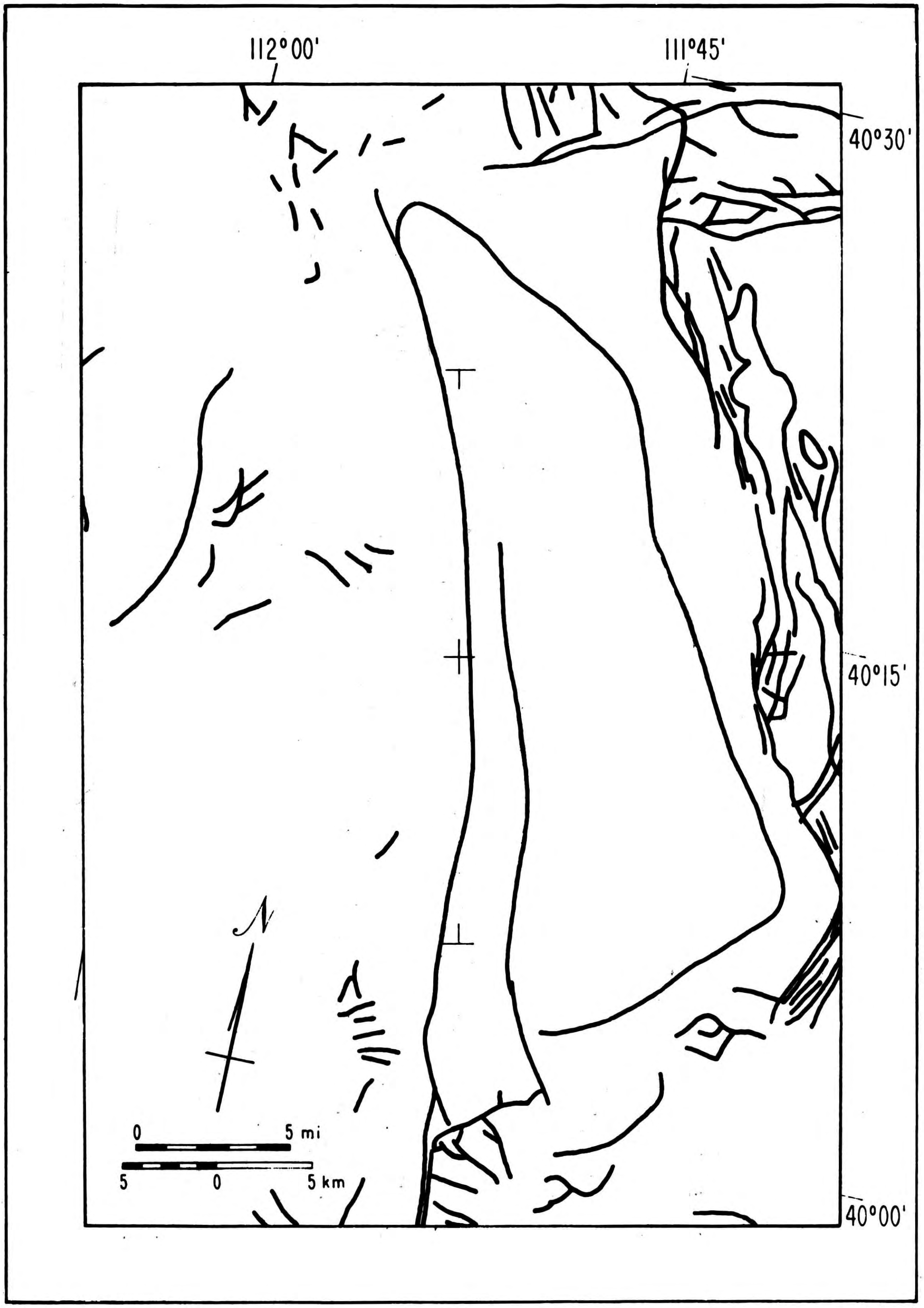

Figure 17.--Area of probable faulting for the Provo distant event. ┼ indicates the assumed epicenter; ⊥ and ⊤ indicate the ends of the assumed fault.

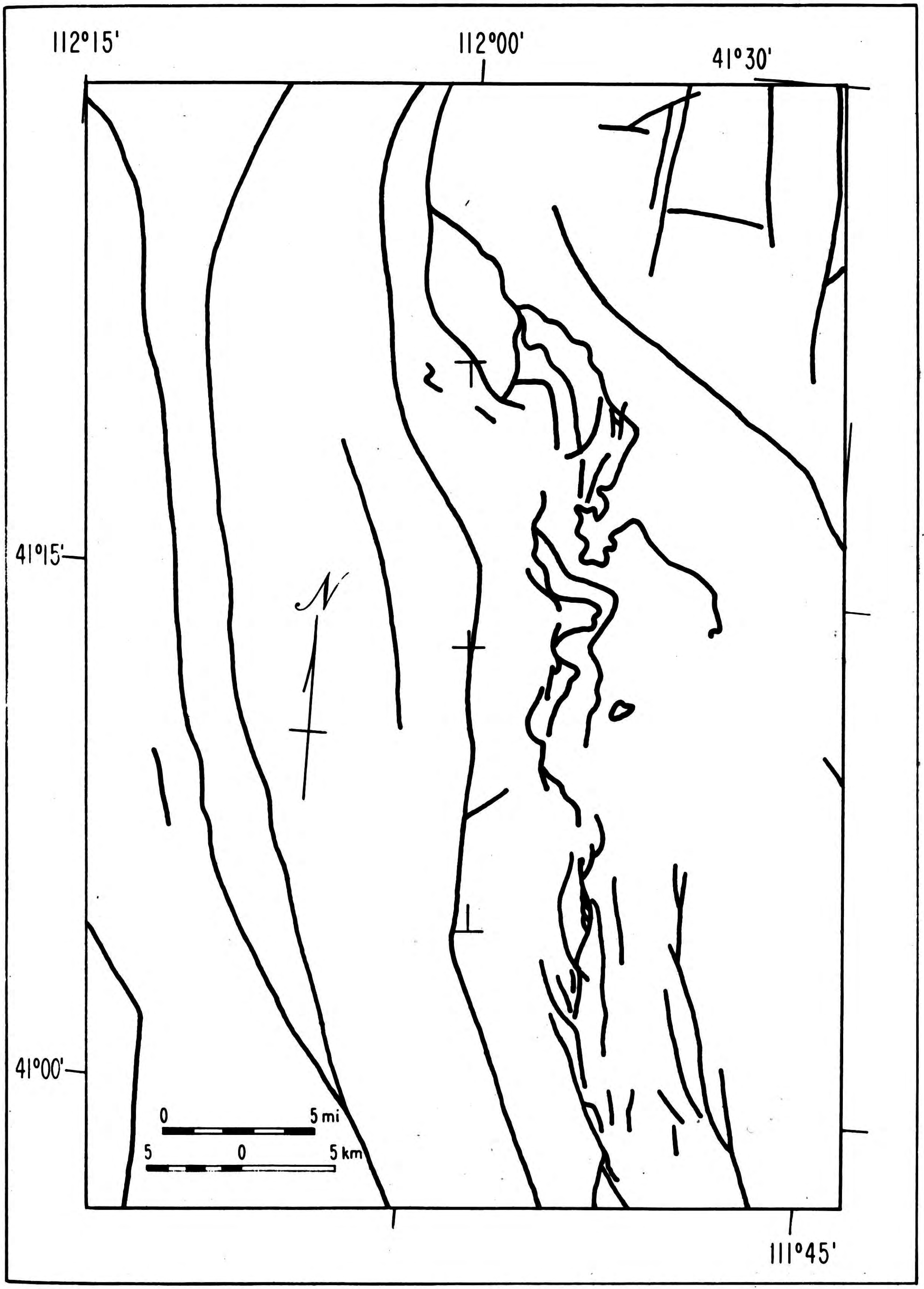

Figure 18.--Area of probable faulting for the Ogden close-in event. ┼ indicates the assumed epicenter; ⊥ and ⊤ indicate the ends of the assumed fault.

Figure 19.--Area of probable faulting for the Ogden distant event. ┼ indicates the assumed epicenter; ⊥ and ┬ indicate the ends of the assumed fault.

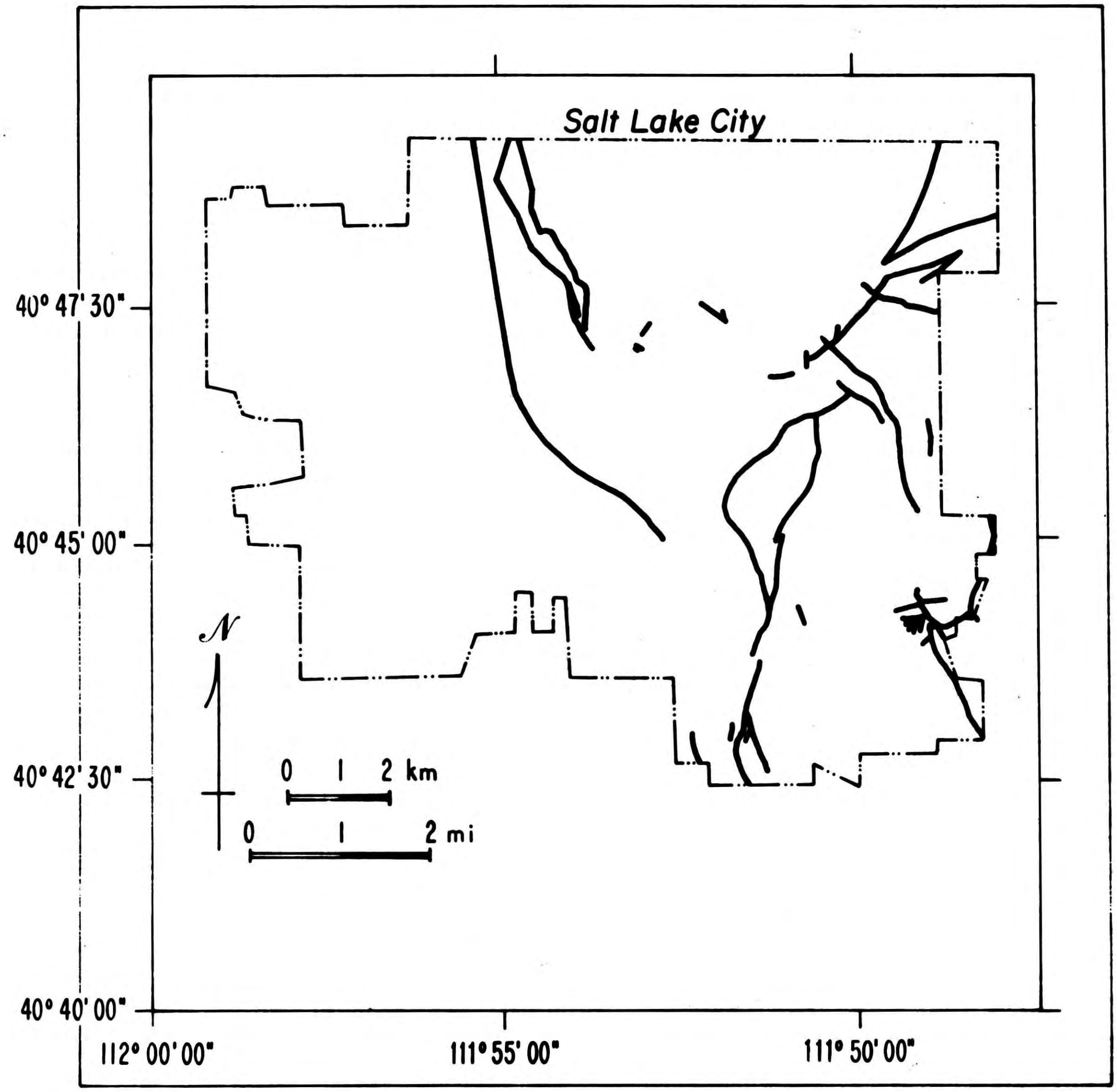

Figure 20.--Map showing Salt Lake City boundary and enclosed faulting. The total length of faulting is about 63 km, and the largest dimension of the city boundary is about 17 km.

Map descriptions

Figures 21 through 32 show the estimated Modified Mercalli intensities for the six hypothetical earthquakes. For each earthquake an enlarged map is shown of the intensities occurring in the nearest metropolitan area (that is, Salt Lake City, Ogden, and Provo). The estimated intensity at each location is dependent on the perpendicular distance from the assumed fault trace and the geologic deposit at the site. Near the end points of the assumed fault trace, the radial distance from the end point to the site is used with the proper attenuation curve to determine the intensity at that site. An area of given intensity on these maps does not imply that the entire area will experience that intensity but implies that portions of the area will experience intensities that great or smaller. (This is commonly the way isoseismals are represented and interpreted in post-earthquake studies.)

Use of this report

The numerical values associated with each problem area, such as damage to and life loss in hospitals, represent reasonable maximum expected conditions. In other words, these values are credible; they have historical data and experienced judgment behind them. The quality of the numbers will vary depending upon the extrapolation (if any) of historical data, the reliability of assumptions supporting the calculations, and the quality of the judgment behind the decisions.

Errors in the estimated intensities may stem from inaccurate estimates of the maximum magnitude earthquake for the region or a poor choice of epicentral location, focal depth, and fault trace. It is believed, however, that these items have been estimated conservatively and, thus, represent worst cases situations. Incomplete knowledge of the near-surface geology, lack of understanding of ground response to strong shaking, and variability in attenuation of ground motion can introduce additional errors in the intensities. It is impossible to estimate the errors due to incomplete information, but it is thought that the evaluations of these items represent the best possible estimates given the available data.

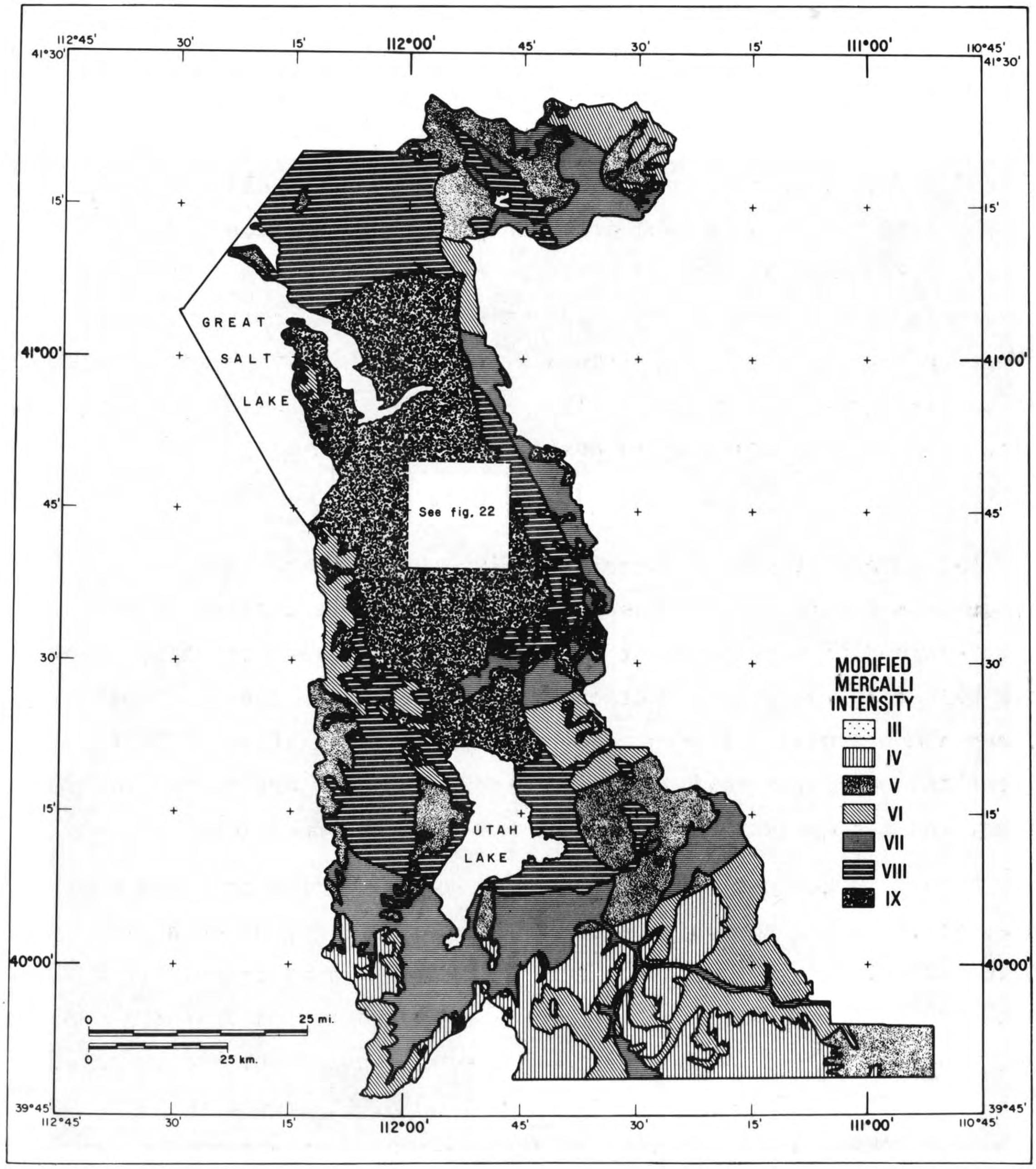

Figure 21.--Estimated Modified Mercalli intensity distribution in the four-county study area for a hypothetical earthquake of magnitude 7.5 located at 40° 44.35'N, 111° 51.16'W, 10 km deep.

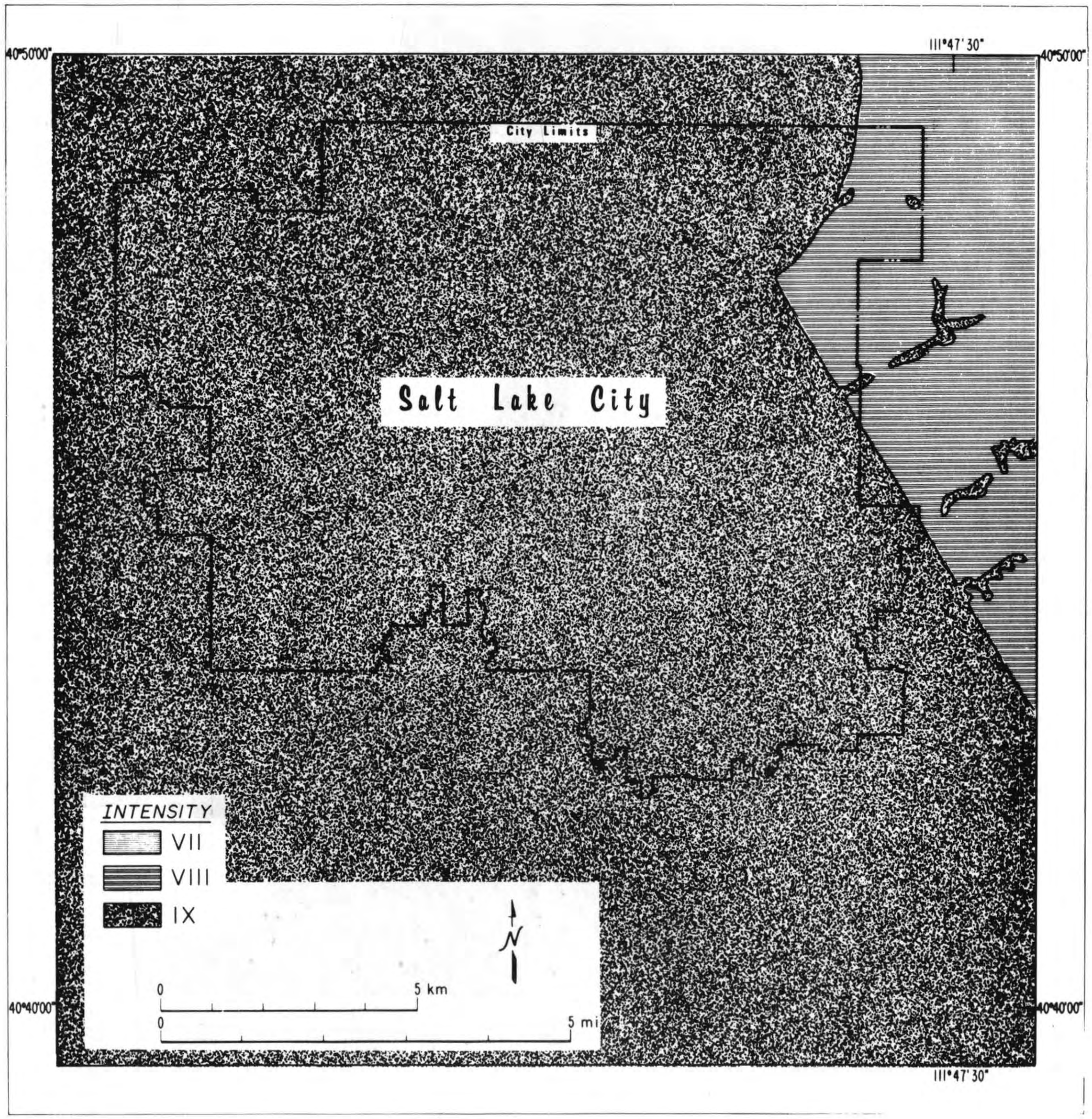

Figure 22.--Estimated Modified Mercalli intensity in the Salt Lake City area for a hypothetical earthquake of magnitude 7.5 located at 40" 44.35'N, 111° 51.16'W, 10 km deep.

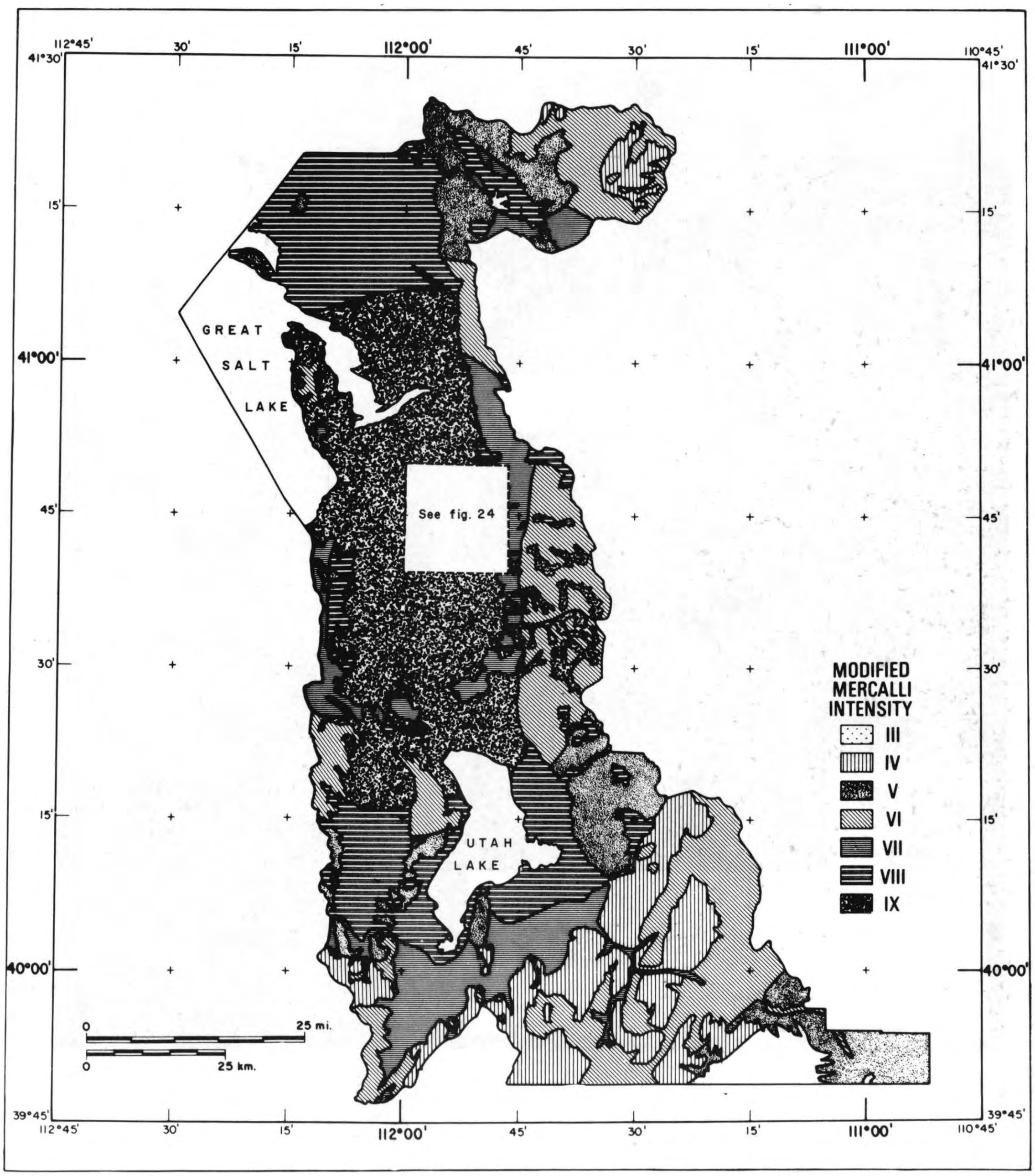

Figure 23.--Estimated Modified Mercalli intensity in the four-county study area for a hypothetical earthquake of magnitude 7.5 located at 40° 42.00'N, 112° 00.00'W, 10 km deep.

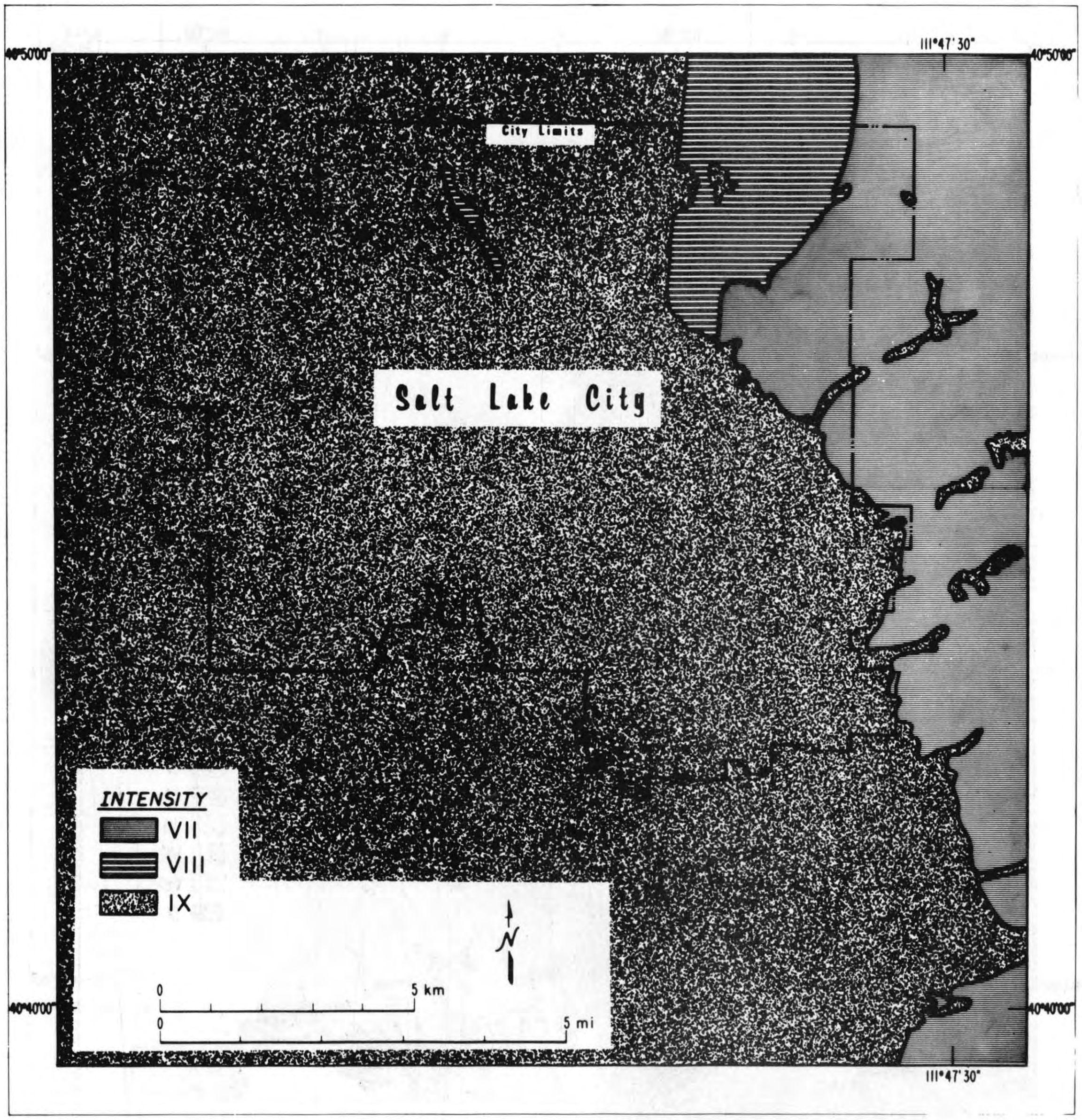

Figure 24.--Estimated Modified Mercalli intensity in the Salt Lake City area for a hypothetical earthquake of magnitude 7.5 located at 40° 42.00'N, 112° 00.00'W, 10 km deep.

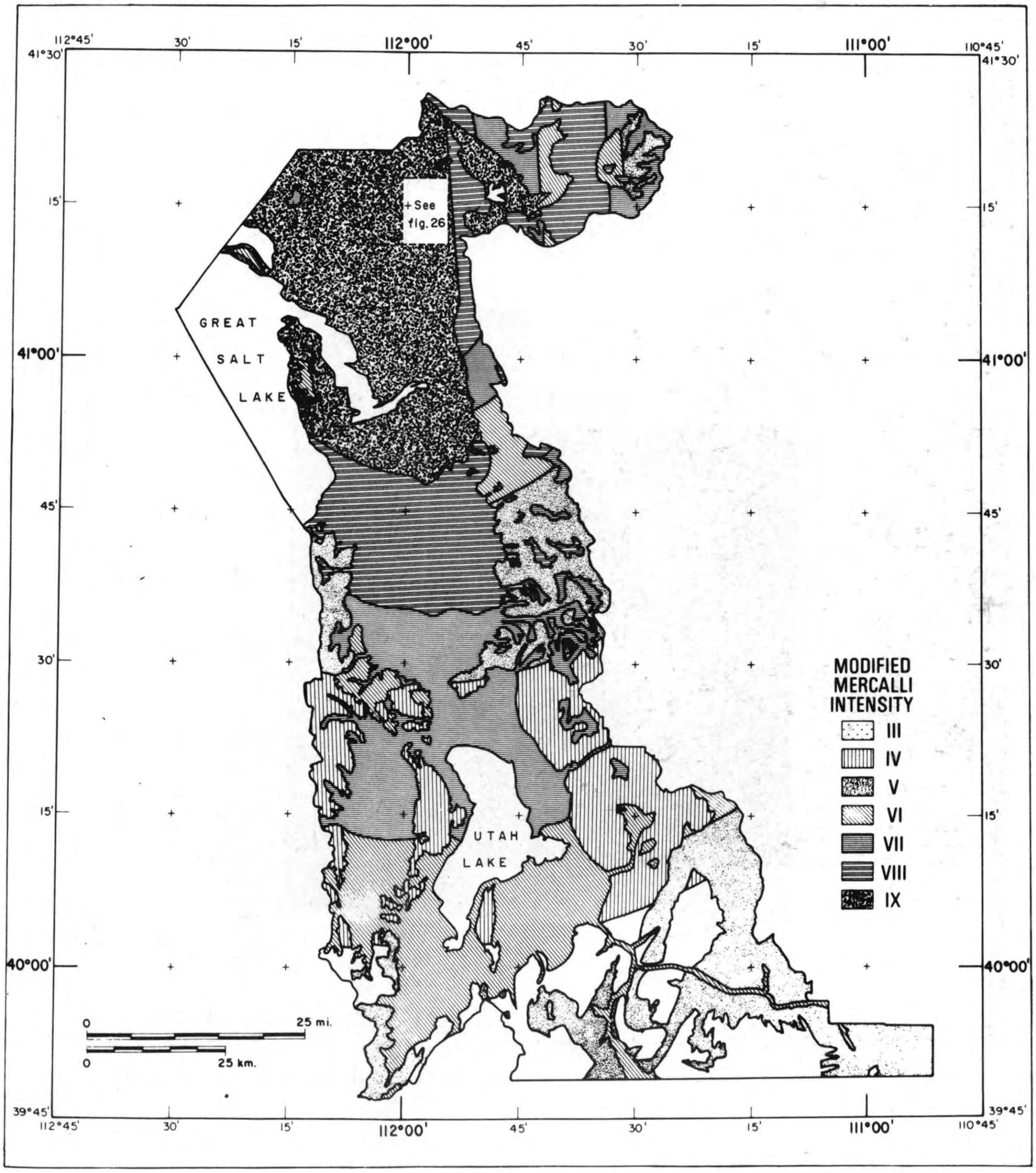

Figure 25.--Estimated Modified Mercalli intensity in the four-county study area for a hypothetical earthquake of magnitude 7.5 located at 41° 12.52'N, 111° 58.80'W, 10 km deep.

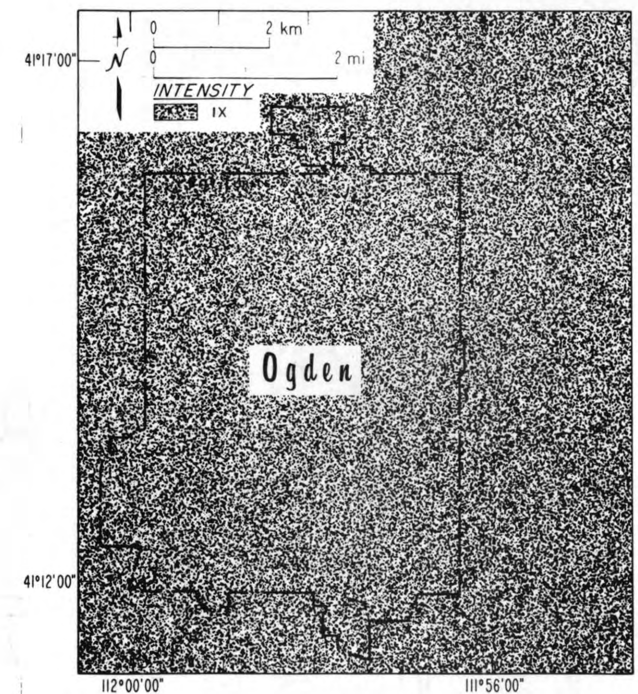

Figure 26.--Estimated Modified Mercalli intensity in the Ogden area for a hypothetical earthquake of magnitude 7.5 located at 41° 12.52'N, 111° 58.80'W, 10 km deep.

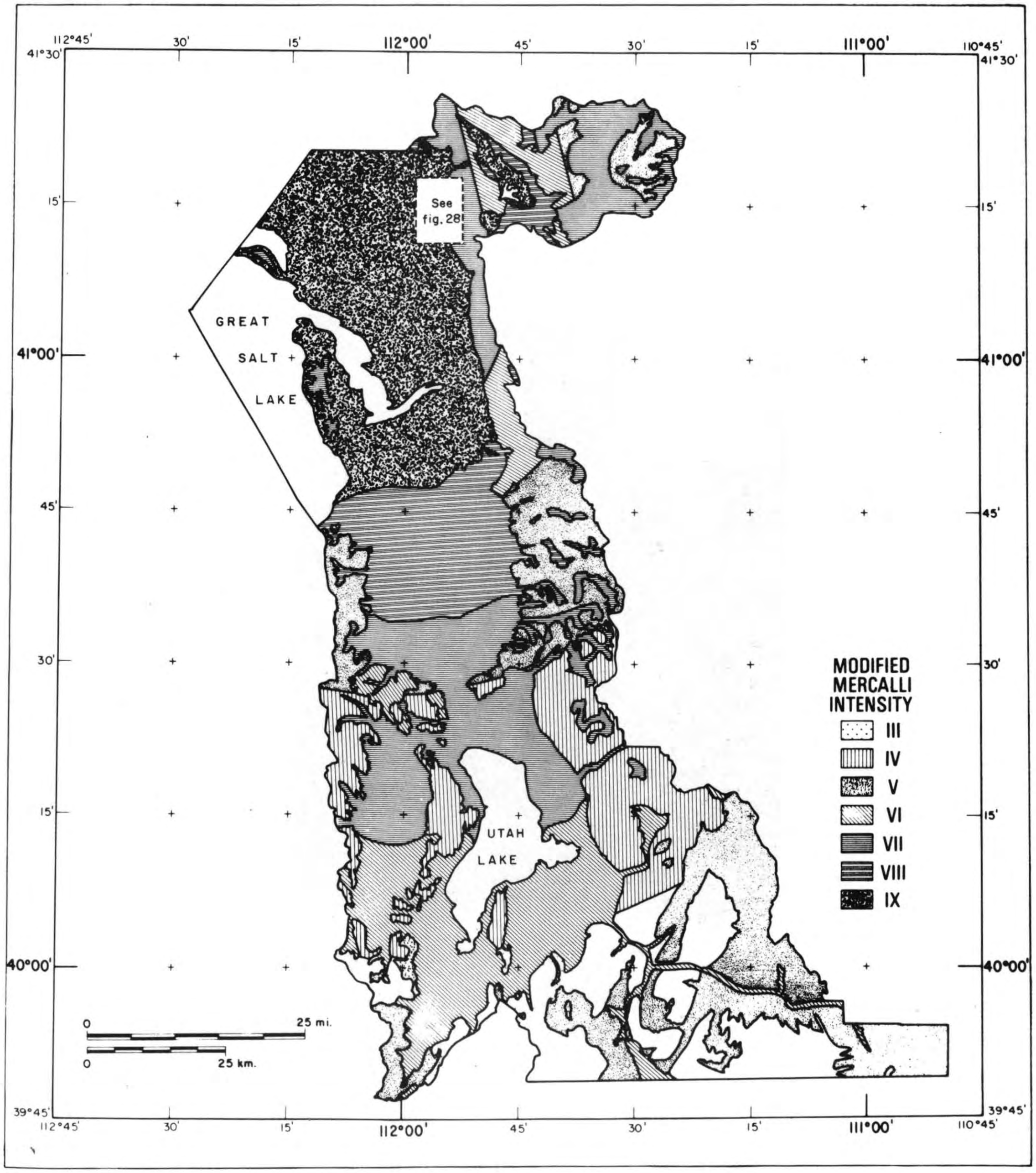

Figure 27.--Estimated Modified Mercalli intensity in the four-county study area for a hypothetical earthquake of magnitude 7.5 located at 41° 12.07'N, 112° 7.46'W, 10 km deep.

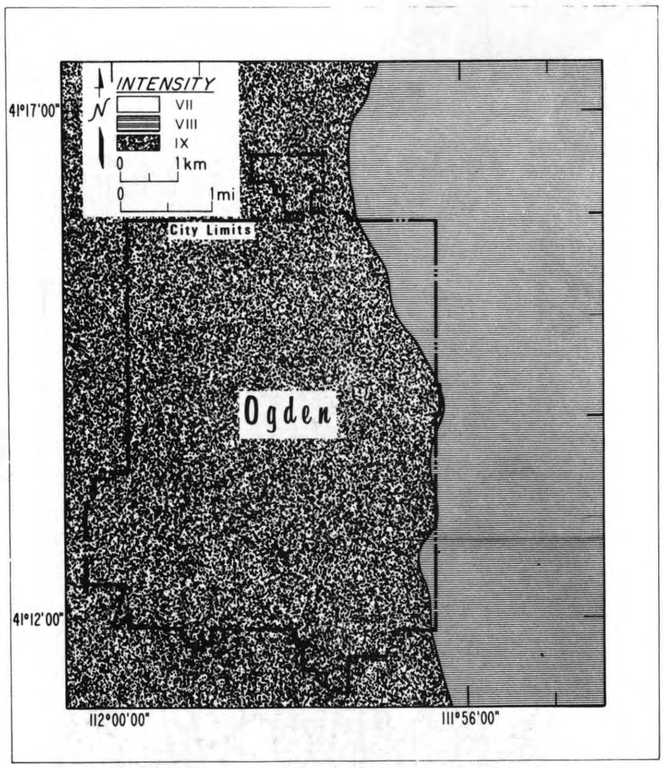

Figure 28.--Estimated Modified Mercalli intensity in the Ogden area for a hypothetical earthquake of magnitude 7.5 located at 41° 12.07'N, 112° 7.46'W, 10 km deep.

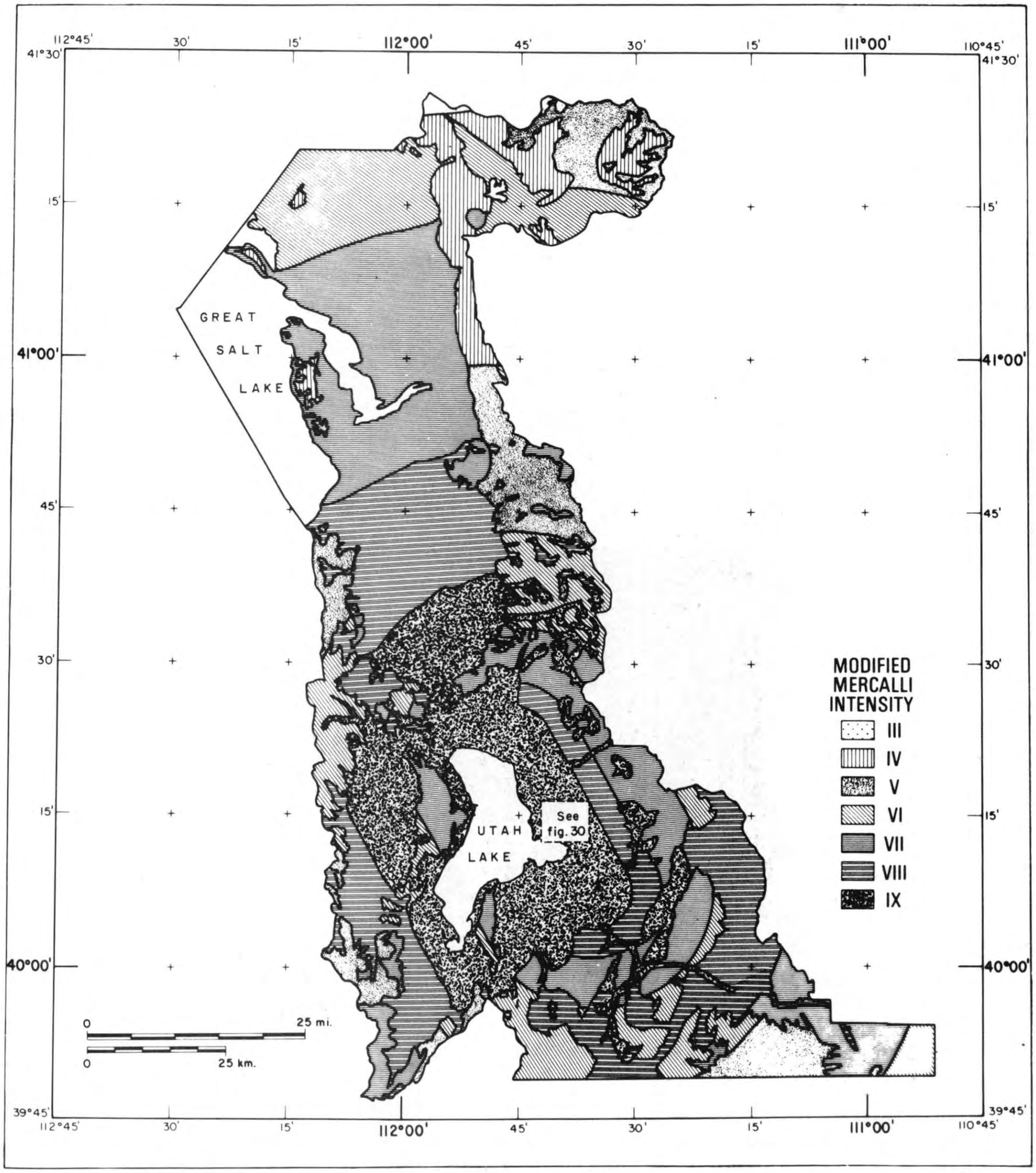

Figure 29.--Estimated Modified Mercalli intensity in the four-county study area for a hypothetical earthquake of magnitude 7.5 located at 40° 14.00'N, 111° 40.42'W, 10 km deep.

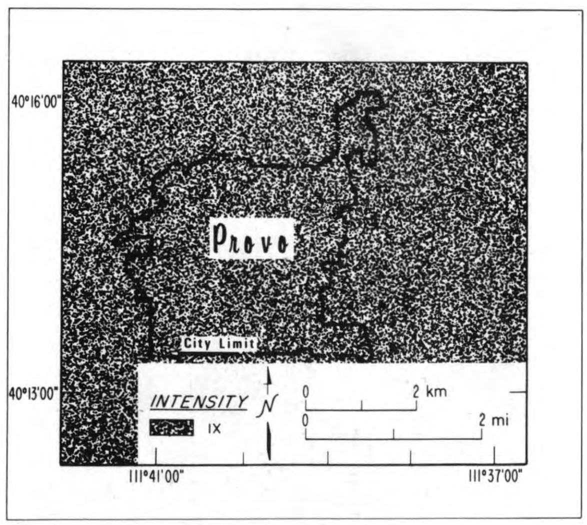

Figure 30.--Estimated Modified Mercalli intensity in the Provo area for a hypothetical earthquake of magnitude 7.5 located at 40° 14.00'N, 111° 40.42'W, 10 km deep.

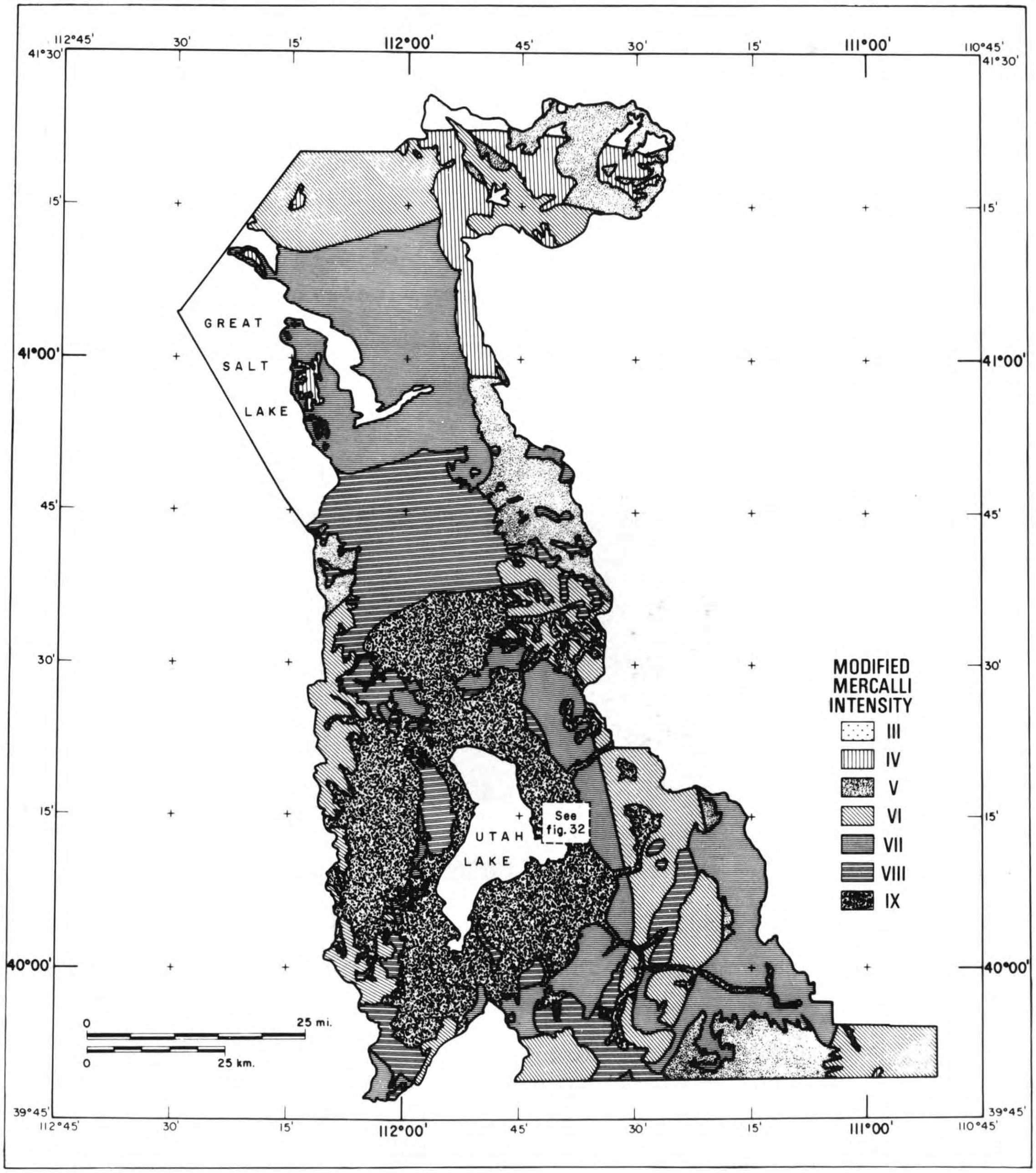

Figure 31.--Estimated Modified Mercalli intensity in the four-county study area for a hypothetical earthquake of magnitude 7.5 located at 40° 12.54'N, 111° 45.82'W, 10 km deep.

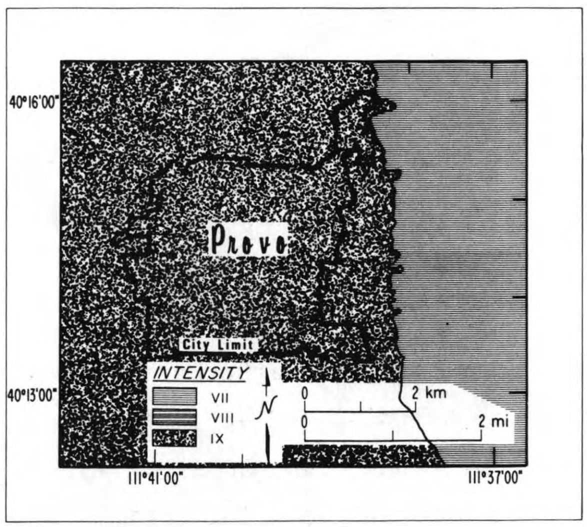

Figure 32.--Estimated Modified Mercalli intensity in the Provo area for a hypothetical earthquake of magnitude 7.5 located at 40° 12.54'N, 111° 45.82'W, 10 km deep.

In addition to the possible variations in seismological parameters, the response of buildings and structures to earthquake ground motions is not as well understood as might be expected. Therefore, the expected seismic performance of any particular building can be stated only in a statistical sense.

Planning agencies using this report should be aware that the contents are based on two postulated earthquakes. One of these earthquakes has its epicenter on the Wasatch Fault in Salt Lake City; the other has its epicenter on one of the faults in the Magna area. The resulting MM intensity map for each event (figs. 21 and 23) is unique for the particular epicenter selected. Thus, a different epicenter location would result in a different intensity map and damage pattern. Although the Wasatch Fault is quite well defined, the epicenter could occur at any place along the fault. The faults in the Magna area are not well defined, and the epicenter for the Magna event might occur on an unexpected fault. The two epicenter locations selected by the USGS for the four-county study area have resulted in a large concentration of population and buildings being located in MM zones of high intensity (VIII and IX). Both MM intensity maps also show zones of higher intensity for areas of poor soil, unstable land, manmade fills, and deep alluvium deposits.

The illustrations associated with different subject areas (hospitals, public buildings, schools, and so forth) include base maps showing the four-county study area with locations of facilities represented by dots of different sizes and shapes. The postulated length of surface faulting for each of the earthquake events is shown as a solid line labeled "WASATCH FAULT" and another labeled "MAGNA FAULT." The length and direction of each line is the assumed limit of surface fault rupture for each event. See, for example, figure 33.

It is most improbable that the maximum values established for each type of problem will occur simultaneously in any given earthquake. Summing the aggregate losses for various situations must be done with understanding and judgment. For example, as pointed out above, maximum landslide hazard conditions occur in the spring, whereas maximum fire hazard conditions occur in the summer. The population is also largely in single-family dwellings and apartment houses during the night hours, whereas a different distribution exists during the shopping and working day; therefore, the maximum casualties in dwellings (night hours) resulting from the failure of a dam would not add to the maximum casualties from this same failure in shopping areas (day hours).

Unanticipated events occur in almost every earthquake. A destructive shock may occur on an unexpected fault, as it did in the 1971 San Fernando shock, or the earthquake could occur during the height of the Christmas shopping season. In the Salt Lake area, the earthquake could occur on one of those occasional days when the ground fog or a snowstorm halts all air transportation in the area, thereby restricting aid via air. These are possible credible events but in a sense create "surprise" situations; however, they are sufficiently improbable that they have not been given consideration in this report. On the other hand, no solution stated in this report should be taken so rigidly as to preclude the unexpected, which invariably occurs in some aspects of every great earthquake disaster.

SECTION 3: BASES FOR ANALYSES

This section is a general discussion of the bases used in this report for determining the potential casualties and property damage for the two specific earthquakes chosen for study. The methods vary in keeping with the importance of the particular topic and the types of data that were available for analysis in each problem area. More specific information on certain aspects of the methodology used for a particular type of occupancy and the supporting rationale will be found in the sections discussing particular facilities.

Studies on projected earthquake casualties and damage must contain several important factors: data from relevant earthquakes; theoretical considerations, both scientific and engineering; experience, which must be tempered with engineering judgment; and time of day and season of year when the earthquake strikes. These four factors must be contained in any methodology for determining the life-hazard and property-damage potentials. The first three factors are discussed in this section. The fourth factor, time of day and season of year, was discussed previously (p. 6).

Data from relevant earthquakes

A list of U.S. earthquakes having particular significance to the purposes of this report is given in table 6. It is noteworthy that the death toll to date has never exceeded 1,000 in any single U.S. earthquake disaster. This low death toll is in sharp contrast to death tolls from some foreign earthquakes, and it is of value to briefly examine this contrast.

For one case, the Agadir, Morocco, earthquake of 1960 has been assigned the moderate Richter magnitude of 5.5-6 by various authorities. The most prevalent construction material in Agadir was older masonry; it varied from stone, with mortar of mud and sand, to more modern construction of stone or clay tile,with mortar ranging from weak mud-sand to good quality sand-cement. None of the masonry was reinforced. The second most prevalent type of construction was a very poor quality reinforced concrete that had not been designed to resist earthquake forces. In other words, Agadir was "a disaster waiting to occur," and the estimated 12,000 deaths and 12,000 injured out of a population of about 33,000 are quite understandable. The heaviest ground shaking at Agadir most likely did not

Table 6 .--Selected U.S. earthquakes, 1811-1972

[Source: A Study of Earthquake Losses in the Los Angeles, California Area, NOAA, 1973]

Name of Earthquake	Date and (local) Time	[1] Epicenter Location	[2] Maximum Modified Mercalli Intensity	[1] Richter Magnitude	Approximate Length of Surface Faulting (miles)	[3] Lives Lost	[4] Dollar Loss	Remarks
New Madrid, Missouri	Dec. 16, 1811 (about 2:15 AM) Jan. 23, 1812 (about 8:50 AM) Feb. 7, 1812 (about 10:10 AM)	36 N, 90 W	XII (for each shock)	Over 8	See remarks	1 death	---	Richter assigned a magnitude of greater than 8 based on observed effects. Surface faulting possibly occurred: see Fuller, p. 58 (Bibliography).
Charleston, S. Carolina	Aug. 31, 1886 (9:51 PM)	32.9 N, 80.0 W	X	---	None	27 killed outright, plus 83 or more from related causes.	$5,000,000 to $6,000,000	---
San Francisco Calif.	Apr. 18, 1906 (5:12 AM, PST)	38 N, 123 W	XI	8.3	190 minimum 270 possible	700 to 800 deaths.	$400,000,000 incl. fire: $80,000,000 earthquake only.	Portions of the San Andreas fault are under the Pacific Ocean.
Santa Barbara, Calif.	June 29, 1925 (6:42 AM)	34.3 N, 119.8 W	VIII-IX	6.3	None	12 to 14 deaths.	$6,500,000	The dollar loss is for the City of Santa Barbara: losses elsewhere were slight.
Long Beach, Calif.	Mar. 10, 1933 (5:54 PM, PST)	33.6 N, 118.0 W	IX	6.3	---	Coroner's report: 86. 102 killed is more probable.	$40,000,000 to $50,000,000	Epicenter in ocean. Associated with Inglewood fault.
Helena, Montana	Oct. 12, 1935 (0:51 AM, MST)	46.6 N, 112.0 W	VII	---	None	---	$50,000	First of three destructive shocks: Oct. 12, 18, and 31.
Helena, Montana	Oct. 18, 1935 (9:48 PM, MST)	46.6 N, 112.0 W	VIII	6.25	None	2 killed, "score" injured.	$3,000,000 to over $4,000,000	---
Helena, Montana	Oct. 31, 1935 (11:38 AM, MST)	46.6 N, 112.0 W	VIII	6.0	None	2 killed, "score" injured.		---
Imperial Valley, Calif.	May 18, 1940 (8:37 PM, PST)	32.7 N 115.5 W	X	7.1	40 minimum	8 killed outright, 1 died later of injuries.	$5,000,000 to $6,000,000	M. M. IX for building damage and M. M. X for faulting.
Santa Barbara, Calif.	June 30, 1941 (11:51 PM, PST)	34.4 N, 119.6 W	VIII	5.9	---	None killed, 1 hospitalized.	$250,000	Epicenter in ocean.
Olympia, Washington	Apr. 13, 1949 (11:56 PM, PST)	47.1 N, 122.7 W	VIII	7.1	None	8 deaths	$15,000,000 to $25,000,000	---
Kern County, Calif.	July 21, 1952 (4:52 AM, PDT)	35.0 N, 119.0 W	XI	7.7	14	10 of 12 deaths in Tehachapi	$37,650,000 to buildings $48,650,000 total. (incl. Aug. 22 aftershock).	M. M. XI assigned to tunnel damage from faulting: vibration intensity to structures generally VIII, rarely IX. Faulting probably longer, but covered by deep alluvium.
Bakersfield, Calif.	Aug. 22, 1952 (3:41 PM, PDT)	35.3 N, 118.9 W	VIII	5.8	None	2 killed and 35 injured in Bakersfield.	See above.	Aftershock of July 21, 1952.

Fallon-Stillwater, Nev.	July 6, 1954 (4:13 AM, PDT)	39.4 N 118.5 W	IX	6.6	11	No deaths, several injuries.	$500,000 to $700,000, incl. $300,000 to irrigation system.	M. M. IX assigned along fault trace; vibration intensity VIII. First of two shocks on same fault.
Fallon-Stillwater, Nev.	Aug. 23, 1954 (10:52 PM, PDT)	39.6 N 118.5 W	IX	6.8	19	No deaths.	$500,000 to $700,000, incl. $300,000 to irrigation system.	M. M. IX assigned along fault trace: vibration intensity VIII. Second of two shocks on same fault.
•Fairview Peak, Nevada	Dec. 16, 1954 (3:07 AM, PST)	39.3 N, 118.1 W	X	7.1	35	No deaths.	---	M. M. X assigned along fault trace; vibration intensity VII. Two shocks considered as a single event from the engineering standpoint.
Dixie Valley, Nevada	Dec. 16, 1954 (3:11 AM, PST)	39.8 N, 118.1 W	X	6.8	30	No deaths.	---	M. M. X assigned along fault trace; vibration intensity VII. Two shocks considered as a single event from the engineering standpoint.
Eureka, Calif.	Dec. 21, 1954 (11:56 AM, PST)	40.8 N, 124.1 W	VII	6.6	None	1 killed	$1,000,000	---
Port Hueneme, Calif.	Mar. 18, 1957 (10:56 AM, PST)	34.1 N, 119.2 W	VI	4.7	None	No deaths.	---	Epicenter in ocean.
San Francisco, Calif.	Mar. 22, 1957 (11:44 AM, PST)	37.7 N, 122.5 W	VII	5.3	None	No deaths, about 40 minor injuries.	$1,000,000	---
Hebgen Lake, Montana	Aug. 17, 1959 (11:37 PM, MST)	44.8 N, 111.1 W	X	7.1	14	19 presumed buried by landslide, plus probably 9 others killed, mostly by landslide.	$2,334,000 (roads and bridges) $150,000 (Hebgen Dam) $1,715,000 (landslide correction)	M. M. X assigned along fault trace. Vibrational intensity was VIII maximum. Faulting complex, and regional warping occurred. Dollar loss to buildings relatively small.
Prince William Sound, Alaska	Mar. 27, 1964 (5:36 PM, AST)	61.1 N, 147.5 W	---	8.4	400 to 500	110 killed by tsunami; 15 killed from all other causes.	$311,192,000 (incl. tsunami)	Also known as the "Good Friday Earthquake". Fault length derived from seismic data.
Puget Sound, Washington	Apr. 29, 1965 (8:29 AM, PDT)	47.4 N, 122.3 W	VIII	6.5	None	3 killed outright, 3 died from heart attacks.	$12,500,000	M. M. VII general, M. M. VIII rare.
Parkfield, Calif.	June 27, 1966 (9:26 PM, PDT)	35.54 N, 120.54 W	VII	5.5	$23\frac{1}{4}$ and $5\frac{1}{2}$	No deaths.	Less than $50,000	Damaging earthquakes in same area in 1901, 1922, and 1934. The 1966 shock had peak accelleration of 50% G.
Santa Rosa, Calif.	Oct. 1, 1969 (9:57 PM, PDT)	38.47 N, 122.69 W	VII-VIII	5.6	None	No deaths. 15 injuries. 1 heart attack.	$6,000,000 to buildings. $1,250,000 to contents.	Two shocks considered as a single event from the engineering standpoint.
Santa Rosa, Calif.	Oct. 1, 1969 (11:20 PM, PDT)	38.45 N, 122.69 W	VII-VIII	5.7	None	No deaths. 15 injuries. 1 heart attack.	$6,000,000 to buildings. $1,250,000 to contents.	Two shocks considered as a single event from the engineering standpoint.
San Fernando, Calif.	Feb. 9, 1971 (6:01 AM, PST)	34.40 N, 118.40 W	VIII-IX	6.6	12	58 deaths. 5,000 reported injuries.	$478,519,635	Many reported injuries were minor, but public or charitable services requested.

<u>ABBREVIATIONS:</u>

M. M. = Modified Mercalli Intensity

PST = Pacific Standard Time

PDT = Pacific Daylight Time (Subtract 1 hour for Pacific Standard Time)

MST = Mountain Standard Time

AST = Alaska Standard Time

<u>FOOTNOTES:</u>

[1] Slight variations will be found in various publications.

[2] M. M. Intensities are those assigned by the U. S. Coast & Geodetic Survey (now NOAA) when available.

[3] Original sources do not always clearly indicate if deaths include those attributable to exposure, unattended injury, heart attacks, and other non-immediate deaths.

[4] Value of dollar at time of earthquake. Use of these figures requires a critical examination of reference materials since the basis for the estimates vary.

exceed that experienced in the most heavily shaken areas of the 1971 San Fernando shock. Many other foreign examples could be cited; in almost all cases the masonry would be of extremely poor quality, and construction would be completely different from American practice.

The foregoing example involved ground shaking and not geologic hazards. The May 31, 1970, Peruvian earthquake may be cited as an example of large life loss due to a special geologic hazard. The single, most devastating event was the large debris avalanche that originated from the north peak of Huascaran; it fell 12,000 feet (3,658 m) and traveled seven miles (11.3 km) at an average speed of 200 miles(322 km) an hour, destroying the village of Yungay, among others. This debris slide took a toll of about 25,000-30,000 lives. Clearly, this life loss was related to a special geologic hazard, and it was of a type that could have been identified before the event.

The two foregoing examples make it readily evident that earthquake data used in the four-county study area must be founded on information from earthquakes affecting comparable construction and comparable geologic hazards. These data are best obtained from a study of U.S. earthquakes plus a few selected foreign earthquakes, such as the 1972 Managua, Nicaragua, 1967 Caracas, Venezuela, and 1960 Chilean earthquakes.

It is far beyond the report's scope and space allotment to review in detail the life-loss and property-damage data contained in studies of past American earthquakes. The bibliography lists the important reports and papers used for this study, as well as relevant material that can improve the understanding of the report user. It is, however, appropriate to briefly review those data that are of particular significance to the present study.

San Fernando earthquake of February 9, 1971

The most recent intermediate-magnitude earthquake to cause considerable damage in the Los Angeles area was the February 9, 1971, magnitude-6.6 (maximum Modified Mercalli Intensity IX) earthquake located about 7 miles (11.3 km) north of San Fernando and 24 miles (39 km) from downtown Los Angeles. Damage in San Fernando and Sylmar was severe. Appreciable damage occurred in Los Angeles City.

The 1971 San Fernando earthquake has been thoroughly studied by many authorities. Far better data on life loss, injuries, and property damage are available for this disaster than for any other American earthquake. The most important sources of relevant data that are known to the authors are the volumes published by NOAA (National Oceanic and Atmospheric Administration). The following is quoted from "Earthquake Damage and Related Statistics" by Steinbrugge and Schader (1973, p. 691):

> The Los Angeles County Coroner's Office reported 58 deaths (table 7) directly attributable to the February 9th earthquake out of a current County population of 7,032,000. The collapses at the Veterans Hospital in the foothills of San Fernando Valley immediately claimed 41 lives; 6 died later as a result of injuries sustained. This was the largest life loss at one location incident to the earthquake. Three deaths occurred at the Olive View Hospital; one due to falling building materials, and the remaining two when life supporting power supplies failed. One death occurred in the roof collapse of the old brick masonry Midnight Mission (a charitable facility) located in downtown Los Angeles. If the shock had occurred minutes before, the death toll would have been greatly increased when the upper dormitory area had been fully occupied. The one death occurred when reportedly an occupant had left the building, but was standing in front of it. A collapsing freeway bridge in the heavily shaken area of San Fernando Valley killed two persons when their truck was trapped under a fallen span. One person died from injuries resulting in a fall from the freeway. Four deaths occurred in dwellings. Heart attacks reportedly took 9 lives; however, the County Coroner's report does not list these.
>
> Information on injuries and other earthquake related emergency cases was compiled by the Hospital Council of Southern California. The information in this paragraph and in table 8 is based on their compilation. A total of 127 hospitals responded to their survey with results as shown in table 9. In addition, the Red Cross treated minor injuries for more than 3,000 persons. Thus, one may conclude that the reported injuries and related problems exceeded 5,000, and that thousands of minor self-treated injuries remained unreported.
>
> In table 8, it is important to note that emotional reactions and cardiac problems existed. The psychological aspects of earthquakes have not been adequately studied. Additionally, three of the four greatest problem areas were related to pre-earthquake engineering and/or planning, and not directly to any medical deficiencies.

Table 7.--Life loss, San Fernando earthquake

[From Los Angeles County Coroner's Records. Note: Deaths from reported heart attacks or natural causes attributed to the earthquake are not included.]

Olive View Hospital		3
Patients	2	
Employees	1	
San Fernando Veterans Administration Hospital		41
Patients	31	
Employees	10	
Victims from Veterans Administration Hospital whose deaths occurred at other hospitals		6
Deaths from residences		4
Deaths from collapse of freeway overpass		2
Death in fall from freeway overpass		1
Death from collapsing wall		1
Total		58

Table 8.--Injuries and related problems, San Fernando earthquake

[From Hospital Council of Southern California records, April 1971, 127 hospitals reporting]

Date	Outpatients treated	Inpatients admitted	Total
Feb. 9	1,524	161	1,685
Feb. 10	437	30	467
Feb. 11	367	24	391
Totals	2,328	215	2,543

Outpatient injuries or problems (in percent)		Inpatient sick or injured, excluding transfers (in percent)	
Lacerations	44	Fractures	26
Fractures or related	18	Cardiac	19
Emotional reaction	9	Head injuries	12
Contusions	8	Psychiatric	12
Cardiac	6	Burns	7
Remainder	15	Remainder	24

Disaster activity causing hospital problems in order of importance

Communications
Patient emotion
Water shortage or contamination
Power and/or fuel
Patient transportation
Personnel identification
Personnel and/or supply transportation
Physician coverage
Nursing coverage
Shortage of medical supplies
Clerical assistance
Shortage of blood type

Table 9.--Damage to hospitals in San Fernando Valley, 1971

[Source: A Study of Earthquake Losses in the Los Angeles, California Area, NOAA, 1973; Data compiled by Pacific Fire Rating Bureau]

		Facilities and Services										Earthquake Damage and Losses								
				Pre-Eq.	Licensed Bed Use***							Est. Repl. Value,	Dollar Loss		Bed	Shut-Down		Start-Up		
	Location - City	Ownership*	Year Founded**	Licensed Bed-Capac.	A. C.	Mat.	Ped.	Psy.	R-C	E. C.	Other	Bldg. & Equip. ($ Millions)	Building	Equipment	Loss	Date	Time	Date	Time	Remarks
1	Burbank	N. P.	1905	115	108	7						2.0	0	0	0	-	-	-	-	
2	Burbank	N. P.	1944	370	324	23	23					11.0		-	0	-	-	-	-	
3	Canoga Park	Prop.	1968	72								2.2	2,000	1,000	0	-	-	-	-	
4	Canoga Park	Prop.	1958	112	108		4					2.0	0	0	0	-	-	-	-	
5	Canoga Park	Prop.	1962	116	116							2.0	0	0	0	-	-	-	-	
6	Canoga Park	Prop.	1962	80	64	13	3					2.75	50,000(combined)		0	-	-	-	-	
7	Encino	Prop.	1954	189	144		18				17	6.6	0	0	0	-	-	-	-	
8	Encino	N. P.	1955	152	104	34	14					2.1	0	0	0	-	-	-	-	
9	Glendale	N. P.	1947	98	84	14						3.0	0	0	0	-	-	-	-	
10	Glendale	N. P.	1905	380	252	27	17	60	24			11.4	-	-	0	-	-	-	-	
11	Glendale	N. P.	1954	152								5.3	-	-	0	-	-	-	-	
12	Glendale	N. P.	1926	310	270	28	12					10.9	20,000	0	0	-	-	-	-	
13	Glendale	Prop.	1955	31	27	4						0.9	0	0	0	-	-	-	-	
14	Glendale			22								0.66	0	0	0	-	-	-	-	
15	Granada Hills	N. P.	1966	201	169	16	16					6.0	5,000	0	0					
16	North Hollywood	Prop.	1969	73	59	8	6					2.2	0	0	0	-	-	-	-	
17	North Hollywood	Prop.	1952	84	84							2.5	5,000	5,000	0	-	-	-	-	
18	Northridge	N. P.	1955	206	134	13	28	11	20			6.0	300,000	55,000	0	-	-	-	-	
19	Olive View	L. A. Co.	1920	888	120(post EQ)			100			25				643	2/9/71	10 A. M.	9/71	-	1,5 (OV)
	a. Medical Treatment and Care Bldg.											25.0	25,000,000			-	-	-	-	
	b. Psychiatric Bldg.											6.0	6,000,000			-	-	-	-	
	c. Central Heating Plant											1.5	375,000				-			
20	Pacoima	N. P.	1957	110	82			28				4.75	6,000,000(combined)		110	2/9/71	6 A. M.	3/2/71	-	5 (PL)
21	Panorama City	N. P.	1962	321	202	41	32			46		9.1	250,000(combined)		0	-	-	-	-	
22	Panorama City			96								3.0	-	-	-	-	-	-	-	
23	San Fernando	N. P.	1961	259								9.0	4,000,000	1,000,000	209	2/9/71	3 P. M.	3/72(tent.)		2,5 (HC)
24	San Fernando	Prop.	1922	69	69							1.4	1,000	1,000	0	-	-	-	-	3
25	Sepulveda	F. G.	1955	906	385			341	80		100	30.0	900,000(combined)		0	-	-	-	-	
26	Sherman Oaks	Prop.	1959	160	148		12					4.8	0	0	0	-	-	-	-	
27	Sun Valley	Prop.	1967	111	99	12						4.0	1,000	0	0	-	-	-	-	
28	Sylmar	F. G.	1926	365								15.0	10,000,000(combined)		365	2/9/71	6 A. M.	-	-	5 (VET)
29	Van Nuys			113								3.0	500	0	0	-	-	-	-	
30	Van Nuys	Prop.	1929	66	66							2.0	0	0	0	-	-	-	-	
31	Van Nuys	N. P.	1958	281	235	28	18					18.0	70,000	5,000	0	-	-	-	-	
32	Van Nuys	N. P.	1964	63								2.0	0	0	0	-	-	-	-	
33	Woodland Hills	N. P.	1921	180	73			10		97		5.0	0	0	0	-	-	-	-	
	Totals			6,652								223.06	52,078,500	1,067,000	1,327					

*N. P. - Non-Profit Prop. - Proprietary L. A. Co. - L. A. County F. G. - Federal Gov't.

**All structures on site not necessarily erected this date.

***A. C. - Acute General Ped. - Pediatrics R-C - Rehab. -Convalescent. Mat. - Maternity Psy. - Psychiatric E. C. - Extended Care

REMARKS:
1. Hospital not operating at licensed capacity.
2. In-patient facilities temporarily closed.
3. Only hospital functioning within 5 mile radius after earthquake.
4. Cottage style (58 occupancy) on grounds.
5. OV-Olive View, PL-Pacoima Lutheran, HC-Holy Cross VET-Veterans

NOTE: Where replacement values were unknown a value of $20,000 to $35,000 per bed was used.

> The resources of metropolitan Los Angeles were more than adequate for housing and feeding the displaced persons, and the large majority of persons having these problems were able to take care of their own needs. Despite the foregoing, one relief agency, (The American National Red Cross) reported for the period of February 9, through March 5, 1971 that they fed and housed 17,000 persons at 10 public schools used as shelters. About 175,100 meals were served by the Red Cross (66,500 in shelters which also housed refugees plus 108,600 at mass feeding locations). The availability of undamaged earthquake resistive Field Act schools (schools designed to be earthquake resistive) greatly facilitated the emergency housing and feeding, and this type of facility is an important consideration in earthquake disaster planning.

(end of quotation)

Much additional text and tabular information exist in the aforementioned paper, particularly for dwellings, light industrial buildings, and hospitals; the information on hospitals is presented in this report as table 9. The paper clearly noted that earthquake-resistive buildings performed much better than those that were not designed to be earthquake resistive.

Kern County, California, Earthquakes of July 21, 1952, and August 22, 1952

The July 21, 1952, Kern County shock (maximum Modified Mercalli Intensity XI, magnitude 7.7) had its epicenter on the San Andreas Fault. Three of the aftershocks of the 1952 earthquake had magnitudes greater than 6.0. A magnitude 5.8 aftershock on August 22, 1952, a month after the main shock, did much more damage to Bakersfield (because of its proximity to the city) than did the main shock. The main shock of this series caused extensive nonstructural damage to the taller structures in metropolitan Los Angeles, some 70-80 miles (113-129 km) from the epicenter. The intensities in the Los Angeles area ranged from V to VII.

Substantial amounts of engineering data were collected after the 1952 Kern County shocks. From the standpoint of this study, the data on reinforced and nonreinforced unit masonry are the most useful.

Unreinforced unit masonry with weak sand-lime mortar was common in the heavily hit areas. Damage to brick and concrete brick walls was severe, just as it has been in all other moderate or greater shocks.

severe, just as it has been in all other moderate or greater shocks. Destruction of this type of construction in the town of Tehechapi was particularly severe. Table 10 lists cumulative losses to unit masonry in Bakersfield, which was less heavily shaken than Tehachapi but also had aftershock damage.

It can be noted upon examining table 10 that hollow concrete block performed better than did brick or concrete brick. Hollow concrete block was a relatively new material in Kern County at the time of the earthquakes. As a result, most of it contained at least some reinforcing steel in selected grout-filled cells, and the buildings normally had some minimal form of earthquake bracing. It was therefore not surprising to find that hollow concrete block performed much better than did the other unit masonry materials. Despite the damage listed in table 10, only 2 lives were lost and 35 persons injured in Bakersfield in the August 22, 1952, shock.

Only a small amount of earthquake-resistive reinforced-brick construction existed, with the major exception being one public school complex. This school complex, with 15 earthquake-resistive brick buildings, performed quite well, and the overall damage was less than 1 percent. No collapses or near collapses occurred.

Large life loss has been associated with the failure of nonearthquake-resistive brick and other nonreinforced unit masonry structures. The 1952 Kern County earthquakes convincingly showed the effectiveness of earthquake-resistive design in significantly reducing life hazards.

San Francisco, California, earthquake of April 18, 1906

The 1906 San Francisco earthquake is of particular significance because it had a Richter magnitude approaching the probable upper limit for an earthquake and because data on the 1906 shock were well gathered; much of it is of current relevance.

The San Andreas fault rupture extended 190 miles (306 km) from San Juan in San Benito County to Point Arena in Mendocino County; then it may have continued under the Pacific Ocean to enter land at Shelter Cove in Humboldt County. The faulting certainly extended for 190 miles (306 km) and possibly as far as 270 miles (434 km). The horizontal fault displacement was not less than 10 feet (3.05 m) for most of its length.

Table 10.--Extent of damage to floor areas of structures with masonry walls, wood floors, and wood roofs in Bakersfield, 1952 Kern County earthquakes (in percent)

[Source: Bull. Seism. Soc. Am., Vol. 44, page 250 (1954]

Wall	Torn Down	Repaired	Repair or Demolition Undecided	Undamaged	Total
Brick-------	16	42	20	22	100(2,717,410 ft.^{2})
Concrete brick ------	20	40	36	4	100(230,950 ft.^{2})
Concrete----	6	12	6	76	100(1,186,680 ft.^{2})
Hollow concrete block ------	2	6	1/	92	100(488,525 ft.^{2})

1/Negligible

In places it measured more than 15 feet (4.6 m), and in one marshy ground area it measured as much as 21 feet (6.4 m). The closest San Andreas fault breakage to San Francisco was 1.5 miles (2.4 km) from the city limits. The financial and commercial center of the city, which was 9-10 miles (15-16 km) from the fault rupture, contained a number of multistory buildings, many of which are still in existence.

Statistics regarding life loss vary widely, and many contemporary publications quote figures that are unsubstantiated. The statistics given in table 11 are believed to be the most accurate of those known to the authors.

Property damage in the city of San Francisco has been estimated by various reliable authorities. The Manson Subcommittee on Statistics used assessor's records and placed the building loss (excluding contents) at $105,008,480. The Chamber of Commerce in their report (1906) approached the problem differently, using extrapolated insurance data, and derived a loss of about $350 million for buildings and their contents for San Francisco. The probable loss, including consequential damages of all kinds, was estimated by the Committee of Five (1906) to the "Thirty-Five Companies" at $1 billion. It is reasonable to use a figure of $400 million for direct earthquake and fire loss to buildings and to their contents for San Francisco and the outlying areas.

The three-day conflagration following the earthquake caused substantially more damage than did the earthquake. The area of the burned district covered 4.7 square miles (12.2 km^2) comprising 521 blocks of which 13 were saved and 508 burned.

Conflagration following earthquake is a distinct hazard for most cities in earthquake-prone areas. However, fire does not automatically follow a major earthquake; if it does, the reasons should have been apparent before the event.

In the case of the San Francisco event, portions of the water system were severely damaged by the earthquake. All of the three conduits from the main storage reservoirs to San Francisco were damaged or destroyed where they crossed the San Andreas fault and where they crossed marshy

Table 11.--Life loss in San Francisco 1906 earthquake

[Source: "Report of the Sub-Committee on Statistics," Marsden Manson, Chairman (1907?)]

Killed outright and accounted for at the Coroner's office	315
Shot for crime	6
Shot by mistake	1
Reported missing and not accounted for	352
Total	674

areas. Only the Lake Honda Reservoir (of the three total distributing reservoirs) was damaged by the earthquake; however, when the fire in San Francisco was under control, this reservoir still contained more than one-sixth of its capacity. One supply conduit from the main storage reservoirs was repaired in three days, and at no time during the conflagration were all of the distribution reservoirs empty.

Hundreds of pipe breaks occurred in the city distributing system, principally where the lines crossed filled ground and former swamps. Equally serious was the fact that probably thousands of service pipes were broken by earthquake motions and by the collapse of burning buildings. Water in vital portions of the distribution system, therefore, was not available to fight the fire, although it was available in the Western Addition residential section of San Francisco during the entire conflagration.

The 1906 earthquake marked the first test of multistory steel frame buildings and the largest test to date in the United States of this construction type near a great earthquake. A total of 17 structures ranging in height from 8 to 16 stories, with one at 19 stories, experienced the earthquake. Extensive nonstructural earthquake damage was common, and a few had known structure damage in the form of sheared bolts, bent I-beams, torn gusset plates, and other similar problems. None of these multistory buildings was so heavily damaged as to be unsafe.

Prince William Sound, Alaska, earthquake of March 27, 1964

The Prince William Sound, Alaska, earthquake ("Good Friday" earthquake) is important for the usable data on modern earthquake-resistive construction and its effect on reducing casualties. Tsunami (seismic sea wave) resulted in 110 deaths; only 15 died from other causes, including building collapses. Tsunami is not a hazard in the Salt Lake area. However, seiches on lakes could result in possible life loss and damage to structures on or near the shore.

Modern precast concrete performed poorly when compared with other construction materials; undoubtedly similar problems will occur in the Salt Lake area on a much greater scale in the event of the maximum credible earthquake on a major fault.

Multistory building damage in Anchorage is given in summary form in table 12.

The Alaska earthquake, with its Richter magnitude of 8.4 was a slightly greater shock than the 1906 San Francisco shock, with its magnitude of 8.3; both shocks are of upper limit magnitudes similar to those considered in this report. It follows, then, that the data from the 1906 San Francisco and the 1964 Alaska events are representative of the upper limit damage for similar epicentral distances, similar geologic environments, and similar construction.

Dixie Valley, Fairview Peak, Nevada, earthquake of December 16, 1954

Spectacular surface faulting was found in the area following this 7.1-magnitude event. The slight building damage near the epicenter was confined to brick masonry buildings in Fallon, Nev. which had been more severely damaged by two earlier shocks in July and August.

The earthquake is significant due to its relatively large magnitude and proximity to the Salt Lake study area. Also of importance is the fact that major structural damage occurred to tanks and to a reservoir in Sacramento, Calif., 185 air miles (298 km) away. The computed natural period of the fluids in the tanks and in the reservoir fell in the same range as the period of the ground motion, and the quasi-resonance that occurred caused large-amplitude water waves.

Hebgen Lake, Montana, earthquake, of August 17, 1959

The Hebgen Lake, Montana, earthquake had a Richter magnitude of 7.1. The proximity to Salt Lake (300 miles - 483 km) is significant. Some impressive geologic events occurred as a result of this earthquake, including an extensive and complex fault scarp system, a 43-million-cubic-yard (33-million m^3) landslide that dammed Madison Canyon and formed an 80,000-acre-foot (99 million m^3) lake, and a warping of bedrock in Hebgen Lake that resulted in a 10-foot (3-m) drop in elevation of the lake surface and a seiche in the lake that overtopped the dam four times.

Hebgen Dam, an earthfill structure with a concrete corewall, suffered significant earthquake damage. Building damage due to vibratory forces

Table 12.--Damage to multistory buildings in Anchorage, Alaska, 1964

[Source: A Study of Earthquake Losses in the Los Angeles, California Area, NOAA, 1973]

Building Name and Occupancy	Year Built	Stories	UBC Seismic Zone	Structural System: Frame	Structural System: Floors	Structural System: Exterior Walls	Structural System: Core	Principal Lateral Force Bracing System	% Damage (of replace-value)	Remarks
Airport Control Tower	1952	6 and basement	?	R/C	5 and 6 inches R/C	Insulated metal	None	R/C frame	100	Also damaged in 1954 shock.
Anchorage-Westward (hotel)	1960 1964	14 and basement	3	Steel, with some R/C columns	5½ to 6½ inches R/C on MD on steel beams	Insulated metal and R/C	See remarks	R/C shear walls	12	Landslide shifted building about 1 foot. R/C around elevators not a major core.
Cordova (office)	1960	6 and basement	2 (?)	Steel	2½ inches R/C on MD on steel joist and beams	Insulated metal and 4 inches R/C	R/C	Steel moment connections; shear walls in R/C core	20	
Elmendorf Hospital	1955	7 and basement	3	R/C	6 inches R/C	Nonstructural hollow concrete block	R/C	R/C shear walls	1 (see marks)	Lower height buildings not listed. Structural damage 1 percent; nonstructural greater.
Four Seasons (apartments)	1964	6	3	None	8 inches prestressed post-tensioned R/C; tendons not grouted	Plastered studs	R/C	Shear walls in R/C central core	100	Lift slab using steel columns.
Hill (office)	1962	8	3	Steel (see remarks)	5 inches R/C on steel beams	Insulated metal	R/C	Shear walls in R/C central core.	20-25	Central core was R/C bearing.
Knik Arms (apartments)	1950	6 and basement	2	Incomplete R/C	5½ inches R/C	R/C	R/C	R/C shear walls	Negligible	Building moved 10 to 11 feet, due to landslide.
Mt. McKinley (apartments)	1951	14 and basement	2	R/C (see remarks)	5½ inches R/C on R/C beams	R/C bearing	R/C	R/C shear walls	40	R/C interior beams and columns. Walls bearing. Almost identical to 1200 L Building.
1200 L (apartments)	1951	14 and basement	2	R/C (see remarks)	5½ inches R/C on R/C beams	R/C bearing	R/C	R/C shear walls	30	R/C interior beams and columns. Walls bearing. Almost identical to Mt. McKinley Building.
Penney (department store)	1962	5	3	None	10-inch R/C slabs on R/C columns	Precast R/C on 2 sides; R/C on 4 sides.	Essentially none	R/C exterior walls	100	Some hollow concrete block exterior walls.
Providence Hospital	1961	5 and basement	3	steel	5¼ inches R/C on MD on steel beams	Insulated metal	R/C	Shear walls in R/C central core	2½	Stair and elevator tower and lower height buildings not listed.

ABBREVIATIONS: UBC - Uniform Building Code
R/C - Reinforced concrete. Poured-in-place unless otherwise specified.
MD - Metal deck. Usually having trade name "Corruform" or "Cofar".

SOURCE: Environmental Science Services Administration, "The Prince William Sound, Alaska, Earthquake of 1964 and Aftershocks," Vol. II, Part A, page 216, (1967).

in the epicentral region (which included West Yellowstone) was slight. There was some damage to masonry veneer that was insufficiently anchored, general chimney damage occurred, and a few wooden structures left their foundations. A few buildings located in the zone of faulting were severely damaged when the fault scarps passed through the building or when the building dropped as much as 19 ft (5.8 m) vertically.

Earthquakes in Utah that have been considered in this study have been discussed above under the heading Earthquake History.

General comments

Interested readers can obtain a more detailed picture of earthquake damage to buildings by reading material listed in the selected bibliography found at the end of this report. The importance of adequate building damage data in connection with casualty estimates cannot be overestimated. Ground shaking does not kill people; it is the collapse of manmade structures such as buildings and dams that creates casualties during severe ground shaking.

The earthquake geologic hazards of faulting, structurally poor ground, and landsliding can and have been identified and are discussed elsewhere in this report.

Isoseismal maps presented in this report (figs. 21 to 24) are a summary of the expected effects at any particular location. Any application of generalized maps, such as isoseismal maps, requires an understanding of the many exceptions to the generalized rules implicit in the maps. Most important of these exceptions for the purposes of this study are the so-called long-period effects. By this is meant that certain kinds of structures such as high-rise buildings might be subject to damage at large distances from the earthquake while nearby low-rise buildings would generally not be affected.

The long-period effects are due to the changes in the seismic waves as they travel from their source. At the epicenter and in the energy-release regions, all seismic frequencies are present, and both low and tall buildings are affected. However, as these waves travel from their origins, the high-frequency components (the rapid back-and-forth motions) die out more rapidly with distance than do the long-period components (the gentle back-and-forth swaying). As a result, at distances of 50-

100 mi (80-161 km) and much further, the predominant surface motion becomes the long-period motion. These latter motions have periods of vibration that more nearly coincide with the natural periods of vibration of tall buildings than with those of low buildings. As a result, conditions bordering on quasi-resonance may occur for high-rise structures, resulting in heavy damage to them. These effects have been considered throughout this report and may or may not be specifically mentioned.

Theoretical considerations in building damage analysis

Theoretical considerations include, among others, the mathematical determination of a structure's expected performance in an earthquake having a given Richter magnitude. The mathematical analyses must include the response of structures to horizontal and vertical dynamic forces and must consider all site characteristics, such as soils and geologic hazards.

The foregoing mathematical studies would cost millions of dollars if done for all structures; time requirements would also be prohibitive. On the other hand, sufficient data can be (and have been) compiled for a sufficient sampling of structures to determine the construction materials and the type of earthquake-resisting system used in the original design. The approach used in this study, then, is to review the building's original design criteria on a class rating basis, in which a group of structures similar in construction-material type, occupancy type, and earthquake-resistance characteristics are evaluated together. The results are average values for the probable damage.

Based on the estimated building damage, it is possible to develop relationships between casualties and damage. Again, care must be used; a building might be an effective 100 percent loss from a dollar standpoint, but casualties might be few. For examples, one might cite the Penney Building in the 1964 Alaskan shock and the new multistory Olive View Hospital in the 1971 San Fernando shock; life losses were less than 1 percent of actual occupancy in each of these total property losses.

The use of existing theoretical methods by themselves has numerous weaknesses. Earthquake forces generated in moderate- to great-magnitude shocks are still imperfectly known. For example, the 1971 San Fernando earthquake is the best ever recorded from a strong motion standpoint, both in the number of records and in the strength of the earthquake. While a strong motion acceleration of 1.25G was the recorded maximum, many authorities believe that due to special site conditions surrounding the instrument's location a factor of about 0.75G might be more reasonable; others disagree. "G-value" is the acceleration due to gravity force and is one measure of the strength of an earthquake at a particular site. Obviously, a 25-50 percent difference of opinion on the earthquake design force (which is based on the G-value) will lead to quite different casualty and damage figures if no other factors are considered. On the other hand, on a class-rating approach, the overall life-loss and damage patterns from the 1971 San Fernando earthquake were within expected values.

Building codes normally determine the criteria used for the design of a building. The seismic provisions in these codes change over the years, constantly being improved or being revised to meet new construction types. These codes, from their origins to the present date, and their degrees of enforcements are well known to the authors. The UBC (Uniform Building Code) has been adopted in Utah by the various cities and counties. The largest cities, such as Salt Lake City, and the counties have adopted the latest code within 3-6 months after it was made available. The smaller cities have required more time. The history and changes of seismic design of buildings within the Salt Lake study area corresponds quite closely, therefore, with the history and changes in the seismic provisions of the UBC for the study area. This seismic design criteria is as follows:

1. Prior to 1961--Buildings designed only for gravity loads and wind forces.
2. 1961 to 1970--Building design included earthquake forces for seismic risk zone 2.
3. 1970 to present--Building design includes earthquake forces for seismic risk zone 3.

Building codes have been often criticized, and rightly so, but, beyond question, the seismic provisions represent a concensus of the current thinking of the structural engineering profession and the earthquake sciences. Finally, the intent of the codes, as expressed in "Recommended Lateral Force Requirements and Commentary" of the Seismology Committee, SEAOC (Structural Engineers Association of California) (1973, p. 34) is to design buildings that are able to resist minor earthquakes without damage; resist moderate earthquakes without structural damage, but with some nonstructural damage; and resist major earthquakes, of the intensity of severity of the strongest experienced in California, without collapse, but with some structural as well as nonstructural damage.

Obviously, the performance of the new Olive View Hospital buildings in the 1971 San Fernando earthquake was less than the intent expressed in the document by the SEAOC. Although there may be some valid criticisms regarding the buildings' designs and construction, the new Olive View Hospital structures were designed by competent engineers, the plans were reviewed by a public authority deemed superior to most, and construction (and inspection) were also considered to be competent. Clearly, the foregoing was not sufficient. It is not the point here to judge these particular buildings, but to indicate that the sole reliance on building codes, without judgment, can lead to erroneous results.

Experience in building damage analysis

Appropriate experience, which forms the basis for informed critical judgment, is vital for the synthesis of theoretical considerations and inadequate and incomplete data from relevant earthquakes into usable information. As has been mentioned, the earthquake data and experience must be relevant; the 36-percent death factor and the 36-percent injury factor experienced in Agadir, Morocco, has no significance in the present study. On the other hand, experience in the 1964 Alaska and 1971 San Fernando earthquakes is relevant, due to building design and construction being similar to that found in the Salt Lake study area.

The consultants for this study were chosen for their experience in earthquake design and earthquake effects. Some of the consultants have field inspected many significant earthquakes that have occurred in the United States and in foreign countries over the past quarter century.

In addition to their firsthand studies of earthquakes, they are well informed concerning numerous other shocks, including, among others, 1940, El Centro, Calif.; 1934, Kosmo, Utah; 1933, Long Beach, Calif.; 1924, Santa Barbara, Calif.; and 1906, San Francisco, Calif.

Earthquake geologic hazards of faulting, landsliding, and structurally poor ground have been equally well studied. For example, over 75 percent of all known historic instances of surface faulting have been studied by one or more of the consultants.

Others of the consultants are highly competent in the fields of civil-structural engineering and architecture and have been active in building and civil-works designs in the Salt Lake study area for many years. Their experience includes analysis of existing buildings and design of modifications to improve the earthquake resistance of these buildings.

The need for judgment based on experience is vital in the evaluation of the Modified Mercalli intensity maps. When Wood and Neumann introduced the Modified Mercalli Scale, they stated (1931, p. 277):

> To evaluate intensity critically, account must be taken of duration of shaking; nature of ground underneath locality and whether surface is level, gently sloping or steep; whether observers were outdoors, or indoors, in what kind of structure, on what floor, whether quiet or active, and if active how occupied; also whether the motion is rapid or slow, simple or complex, and whether it begins gradually or abruptly. This required experience. Because of the entry of these factors in different degrees no intensity scale of this kind is suitable for general use, even though correct estimates might often be made.

The lowest intensity values rely heavily on human reactions, the middle range intensity values principally relate to building damage, and the highest intensity values are strongly influenced by geologic effects. Human reactions, building damage, and geologic effects are not truly compatible. For example, items have not always fallen from shelves in buildings adjacent to major fault scarps. New building materials, new construction techniques, and new design methods have complicated the application of the Modified Mercalli scale. For one example, the phrase "good construction," used in the scale, has different meanings depending on the earthquake provisions in the building codes in different areas. In some areas, brick walls must be heavily reinforced with steel to be classified as "good construction," whereas in other areas the walls require no reinforcement to be classified as "good construction."

SECTION 4: EFFECTS ON LOCAL MEDICAL RESOURCES

Hospitals

There are 22 hospital facilities in the four-county study area; 17 of them are licensed as hospitals by the Utah State Department of Social Services, Division of Health. They range from a relatively small (35-bed) convalescent hospital to a large (570-bed) general hospital. The State licenses hospitals in two categories: general hospitals and specialized hospitals, such as psychiatric, pediatric, orthopedic, and chronic disease. This report includes both general and specialized hospitals, as well as two hospitals that do not require licensure in Utah--the VA Hospital in Salt Lake and the Air Force Hospital south of Ogden. The report also includes three new general hospitals that are under construction in the study area and that are scheduled for completion in 1976. Two are in Davis County, and one is in Weber County. The hospital in Weber County and one of the hospitals in Davis County will replace existing facilities.

Table 13 lists the 22 hospitals in the study area. The totals given in table 13 are in constant flux as obsolete facilities are closed or remodeled to meet new standards and, also, as the construction of new hospital buildings is completed.

Data collection

Identification and location of the hospital facilities were made through the use of the 1974 list entitled "Utah Hospitals," published by the Utah State Department of Social Services, Division of Health. Reference was also made to the list of "Hospital Members" of the Utah State Hospital Association. Information relating to the licensure and classification of hospitals was obtained from "Hospital Rules and Regulations," published by the Utah State Department of Social Services, Division of Health.

Other useful information on hospital facilities was obtained from the "1971 Utah State Plan for Construction of Medical Facilities" and the "Utah Health Profile," both published by the Utah State Department of Social Services, Division of Health.

Table 13.--Inventory of hospitals

[Principal sources: "Utah Hospitals," Utah State Department of Social Services, Division of Health, Bureau of Medical Care Services, Standards and Licensure Section; "Hospital Members," Utah State Hospital Association]

	General hospitals		Specialized hospitals		Military hospitals		Veterans administration hospitals	
County	Total number	Total bed capacity	Total number	Total bed capacity	Total number	Total bed capacity	Total number	Total bed capacity
Weber --------------	3	656	1	198	0	0	0	0
Davis ------------	3	348	0	0	1	45	0	0
Salt Lake ---------	6	1,734	3	234	0	0	1	580
Utah --------------	3	441	1	368	0	0	0	0
Total	15	3,179	5	800	1	45	1	580

Once the major hospitals in all categories were identified and classified, pertinent data were then compiled for each listed physical facility. When necessary, on-site inspections of medical facilities located in critical areas were conducted by an engineer or a professionally trained field consultant, in order to confirm the following data: year built, location and orientation, type of construction, number of stories, size(ft.^{2}) building condition, site description, building shape, structural characteristics, type of facility, bed capacity, and materials of construction.

Individual hospital files that contain pertinent construction information are on record with the Medical Facilities Construction Section, Bureau of Medical Care Services, Division of Health, Utah State Department of Social Services. Additional information was collected through personal interviews with the Facilities Construction staff. Certain vital data on personnel and facilities for a representative number of hospitals were obtained by direct interview with a staff member of the hospital in some cases and by correspondence with the hospital administrator in other cases.

Data on the VA Hospital were obtained from Engineering Services of the VA Hospital, Salt Lake City, and from a seismic study of the hospital for the Veterans Administration, Washington, D.C. Data on the military hospital at Hill AFB were obtained from one consultant's personal knowledge of the facility, from onsite inspections, and from hospital staff data supplied by the hospital administration.

Information regarding the total number of physicians and surgeons and of registered nurses that are licensed in the state of Utah and located in one of the four counties in the study area was obtained from the March 1975 lists available through the Utah State Department of Business Regulation in Salt Lake City. Data on the distribution of these medical professionals were also obtained from the latest edition of "Utah Health Profile" (including a 1974 up-date prepared by the State of Utah, Division of Health). See table 14.

Figure 33 shows the location and geographic distribution of all

Table 14.--Distribution of physicians, surgeons, registered nurses and hospitals in the four-county area

[Source: 1975 License List, Utah State Department of Business Regulation; "Utah Health Profile," prepared by the Utah State Division of Health; "Utah Hospitals," published by the Utah State Division of Health]

County of practice	Physicians and surgeons		Registered nurses		Hospitals	
	Total number	Percent	Total number	Percent	Total number	Percent
Weber	182	12	750	16	4	18
Davis	71	5	518	11	4	18
Salt Lake	1,119	73	2,766	59	10	46
Utah	151	10	633	14	4	18
Totals	1,523	100	4,667	100	22	100

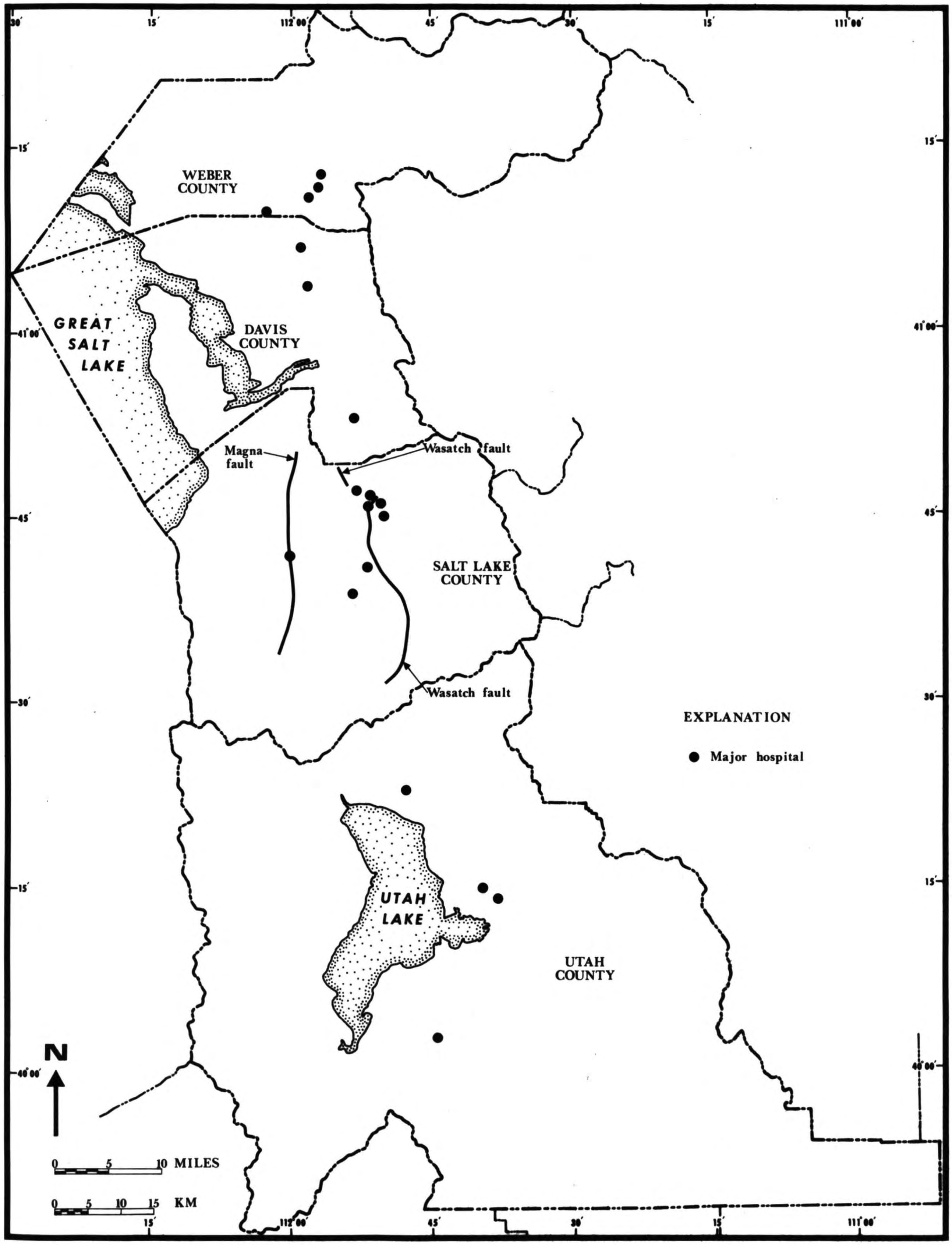

Figure 33.--Hospitals. (One dot may represent more than one facility. Shown fault breakage is assumed for planning purposes.)

types of major hospitals in the study area; table 15 gives the bed capacities for all types of hospitals listed on table 13.

Analysis

The tactical and logistical problems to be faced by major hospitals and other health facilities after a severe earthquake will be considerable, including many which will be unexpected. The care of the injured immediately following the main shock clearly will become one of the greatest area-wide problems. Although one might assume that most of the hospitals would be in operation, data from the San Fernando earthquake of 1971 indicate that it is highly possible that many hospital facilities and medical centers could be more severely damaged than would originally be suspected and, thus, could be a burden rather than an aid after a major earthquake.

Analysis of health facilities is complicated by the fact that many hospitals are composed of several buildings that were built at different times using varying construction materials and physical configurations. In meeting the needs of an expanding population in the four-county study area and after recognizing the advantages of new technological equipment, hospital buildings may be renovated or enlarged by the addition of annexes attached to the original building, perhaps as often as three or four times within a period of 20 years. For example, a major medical facility may have the most modern equipment available, but it may be located in an old structure; although a new addition may have been completed in 1970, the main control center for the communication system could still be housed in the part of the building complex constructed before 1940.

The analysis has been generalized in order to make the methodology easier to apply in future studies. As a basis for the generalized damage data,the information that was gathered and has been discussed in previous paragraphs was analyzed. In most cases, construction drawings were available; in other specific situations, the consultants had personal knowledge of the hospital facility. Conclusions regarding hazard to life and property damage were derived from the correlation of the isoseismal maps with the known earthquake resistance of each class of structural system.

Table 15.--Hospital bed capacity

[Source: 1974 "Utah Hospitals," published by the Utah State Division of Health]

County	Number of hospitals with varying bed capacities				
	30-99 bed capacity	100-200 bed capacity	200-300 bed capacity	300-500 bed capacity	500 or more bed capacity
Weber -------------	0	3	0	1	0
Davis -------------	2	2	0	0	0
Salt Lake ---------	3	2	1	2	2
Utah --------------	2	0	1	1	0
Totals -----	7	7	2	4	2

The following is a summary of the methodology used for hospitals. Table 16 used in conjunction with table 13 gives a reasonable estimate of the hospital populations by type of function. Table 17 is a general summary of expected deaths and damage patterns. This table is applicable to typical, modern earthquake-resistant, multistory hospitals built in the study area after 1970. These figures have been increased for older hospitals by factors ranging from 25 percent to 100 percent. For one-story buildings of earthquake-resistant construction, the figures have been reduced 25 percent. The end results of using the information in tables 13, 16, and 17 are given in tables 18 and 19.

Hospital communications--The communication networks within most of the hospitals consist of telephones, a wire-transmitted public-address system for voice paging, wire-transmitted patient-call systems, and radio pocket page systems. All of these can be operated on emergency power. Some hospitals have additional systems such as code-a-phones and pneumatic tubes. Impairment of any of these communication networks would depend on vulnerability of the equipment and of the auxiliary power to shaking damage or to damage from faulting. See table 19 for the estimated percent of nonfunctioning of communications and auxiliary power for hospitals in different shaking-intensity areas.

Emergency communications between hospitals in Salt Lake County consist of a radio system installed and operating in all of the larger hospitals. These radios are four-channel 100w base stations containing the following frequencies:

1. Hospital Emergency Administration Radio, H.E.A.R.
   155.340

2. State of Utah Emergency Services Wasatch Front Repeater
   155.025 and 155.985

3. Utah Highway Patrol Statewide Coordinating Channel
   155.505

4. Hospital back-up frequency
   155.280

The H.E.A.R. system is a tone-coded dial system to prevent interference in day-to-day use with other hospitals. Each ambulance in the

Table 16.--Hospital populations as a function of bed capacity

[Source: Response to questionnaires and interviews with staff members of hospitals]

	Hospital population per bed		
	2:00 p.m.	4:30 p.m.	2:30 a.m.
Nurses on duty	0.26	0.18	0.10
Doctors on duty	.09	.07	.01
Other staff on duty	.99	.54	.19
Outpatients	.16	.12	.02
Visitors	.71	.46	.05
Inpatients	.89	.92	.87

Table 17.--Hospital deaths and damage percentages

Modified Mercalli Intensity	Percent1/ deaths (hospital population)	Beds2/	Percent of beds lost due to impairment(nonfunctioning) of facilities3/						
			Access routes	Elevators	Auxiliary power	Communication	Medicine	Utilities	
								Inside	Outside
VI	0	0	0	0	0	0	0	0	0
VII	0	5	0	10	0	0	5	2	5
VIII	1	20	5	30	2	0	50	10	10
IX	3	50	10	70	30	20	75	20	25

1/Unadjusted for time of day.
Hospitalized injuries to deaths is 4:1;
nonhospitalized injuries to deaths is 30:1.

2/Total bed loss from all causes.

3/Impairment losses are non-cumulative.

Table 18.--Hospital deaths

County	Wasatch fault, magnitude=7.5			Magna fault, magnitude=7.5		
	2:30 a.m.	2:00 p.m.	4:30 p.m.	2:30 a.m.	2:00 p.m.	4:30 p.m.
Weber----------------	11	23	17	8	16	13
Davis----------------	13	27	20	11	24	17
Salt Lake-----------	123	248	195	84	171	134
Utah-----------------	27	53	43	10	21	16
Totals--------	351	174	275	232	113	180

Table 19.--General hospital damage

County	Bed loss Number	Bed loss Percent	Impairment (or nonfunctioning) in percent of total: Access	Elevators	Auxiliary power	Communications	Medicines	Water
			Wasatch fault, magnitude = 7.5					
Weber	225	26	7	41	3	8	64	4
Davis	221	56	12	79	34	22	82	34
Salt Lake	2,043	80	23	87	52	35	87	52
Utah	448	55	16	72	36	36	79	41
Totals	2,937							

County	Bed loss Number	Bed loss Percent	Impairment (or nonfunctioning) in percent of total: Access	Elevators	Auxiliary power	Communications	Medicines	Water
			Magna fault, magnitude = 7.5					
Weber	155	18	4	27	2	0	45	3
Davis	175	44	9	62	26	17	69	26
Salt Lake	1,266	50	10	70	30	20	74	30
Utah	176	22	5	32	5	2	48	6
Totals	1,772							

city is equipped with a mobile dial-type four-channel transmitter. The operator merely dials the code number for the hospital that is desired. The tone rings only in the hospital dialed by ambulance. In the event of a major disaster, the hospitals are instructed to push the tone-code disable button, which disables the tone so that dials are not needed to contact hospitals.

The Salt Lake City-County Emergency Operating Center, located in the basement of the Metropolitan Hall of Justice, will be net control in the event of a major disaster. The radio is located in the same room as the Emergency 911 Operators for 24-hour dispatching. Operators are instructed to dial the all-call number, which tones all the above hospitals, to save time and provide service for emergency units without dial system.

The above information was made available by the Salt Lake County Office of Emergency Services. According to a representative of this office, the hospitals in the other three counties in the study area also have this emergency radio system and can communicate with hospitals and emergency services in the same county and in the other counties.

Salt Lake County also has a paramedic radio system used by the paramedics in the field. These units are portable two-frequency units used to send E.K.G. and heart telemetry information on the 450 Mhz band. The units can also send voice on a two-way basis to and from hospitals and can send telemetry one-way only to hospitals. Five of the hospitals in Salt Lake County have the paramedic radio system capability. Other hospitals in Salt Lake are unable at the present time to receive direct communications from paramedic rescue units when they are using their portables. Currently three paramedic rescue units have this radio feature. All rescue units have the H.E.A.R. system in their rescue trucks.

Damage to hospital equipment--A hospital contains a multitude of mechanical, electrical, and plumbing systems. Damage to any of these systems could seriously impair hospital efficiency. Especially important in this regard would be damage to elevators. A building may receive only slight damage to the structure, and yet elevators could be inoperable due to swinging of counterweights that could damage cables and tower walls. Elevator cars would be damaged by falling debris. By referring to table 19, it can be seen that there could be a 70-80 percent bed loss in hospitals due to nonfunctioning elevators in Utah, Davis, and Salt Lake Counties from an earthquake on the Wasatch fault and about a 40 percent bed loss in Weber County. These values are less for the earthquake on the Magna fault. Lack of functioning elevators would result in a large percentage of beds that would not be usable on the upper floors. The eight largest hospitals (over 200 beds) in the study area are multistory and have an average of 7 elevators each. The other hospitals have an average of two elevators each. Two one-story hospitals in the area have no elevators.

Eight of the hospitals in the study area, which responded to questionnaires on their facilities, indicated that they all had at least one emergency generator as an auxiliary power source. Four of the hospitals had two or more generators. Most of these generators were listed as diesel powered and ranged from 100kw to 500kw in power output. Two of the hospitals indicated that they were supplied by more than one outside electrical power source. Experience from past earthquakes has shown that generators that are not properly anchored to the structure will move across the floor and in some cases overturn. This type of movement will render the generators nonfunctional by severing lines and causing the turning gear to stop. Table 19 indicates that about one-half of the auxiliary power sources in Salt Lake County hospitals and one-third of these power sources in Davis and Utah County hospitals would be nonfunctional from a 7.5-magnitude earthquake on the Wasatch fault. Impairment of auxiliary power sources would be much less from a 7.5-magnitude earthquake on the Magna fault. Impairment would be small from both events in Weber County, because all of the hospitals there are in a lower intensity zone than are hospitals in the other three counties.

The hospital at Hill Air Force Base is a new, steel frame building designed for strong (seismic zone 3) earthquake forces. Damage to the structure should be slight from either postulated earthquake. Electrical and mechanical equipment in the hospital has been anchored to the structure and braced to resist strong earthquake forces. The central heating plant building north of the hospital has also been designed to resist strong earthquake forces. However, some of the equipment lacks proper anchorage. This includes the boilers, switching units, and battery racks. Work is in progress, however, to correct these deficiences. The large standby diesel generator in the boiler plant is anchored to its foundation and should remain functional following an earthquake.

Helicopter landing facilities--Of the eight hospitals responding to questionnaires, only one had a helicopter landing pad. This was for temporary landing on the parking ramp behind the hospital. This parking ramp could be nonfunctional in the event of a magnitude-7.5 earthquake and should not be considered for planning purposes. At least two large hospitals in Salt Lake City have specially designed permanent helicopter landing pads. One of these is on a low roof section and connects to the hospital tower via a concrete runway for stretchers and medical personnel. The other hospital has a permanent landing pad across the street from the emergency entrance. Other hospitals indicated that helicopters had landed previously on lawn areas around the buildings. Also, helicopters could land on certain wide streets adjacent to hospitals in the study area, where there are no overhead utility lines.

Hospitals within fault zones--Hospital buildings located within the zone of deformation due to surface-fault rupture would be severely damaged. See section 1, page 1-10 of this report for a discussion of the zone of deformation. Referring to figure 33, it can be seen that two hospitals in the Salt Lake City area are within these zones of deformation--one on the Wasatch fault, the other on the Magna fault. The University Hospital in Salt Lake City is about 0.25 miles (0.4 km) uphill from the Wasatch fault, and would at least be subject to severe ground shaking during the postulated event on the Wasatch fault. The fault lines on figure 33 show the locations of postulated surface faulting used for planning purposes in this study. Two other hospitals in Salt Lake City, the VA Hospital in Salt Lake City, and the military hospital near Ogden are very close to other documented branches of the Wasatch fault that are not shown on figure 33. Also the State Mental Hospital in Provo is within a few feet of the Wasatch fault in that area. Eight other hospitals in the four-county study area are within one mile (1.6 km) of documented faults.

Accessibility to hospitals--Hospital beds in the study area that could be considered nonusable due to accessibility problems from debris-clogged streets, landslide, freeway-crossing damage, and other factors should be less than 25 percent from the 7.5-magnitude earthquake on the Wasatch fault and 10 percent or less from the 7.5-magnitude earthquake on the Magna fault. See table 19. Access to the two hospitals near the postulated fault ruptures, as shown on figure 33, would be considerably restricted. Five hospitals in the study area are located on the foothills of the Wasatch Range on rather steep slopes. These hospitals are subject to restricted access from earthquake-induced landslides. Two of these facilities are also very near documented faults.

All of the hospitals in the study area are located in residential areas, and debris in streets would be mostly from fallen trees and branches and from power poles and lines that would be down. No hospital was located across a bridge or freeway overpass, where collapse of such a structure from earthquake forces would render the hospital completely inaccessible.

Health manpower

Health-manpower problems at hospitals in the four-county study area have been discussed in the section on "Hospitals" and need not be repeated here. However, additional deaths, injuries, and transportation problems when away from the hospitals may affect health manpower. The following discussion of transportation problems throughout the four-county study area will emphasize problems for physicians, surgeons, and registered nurses, but the general findings are applicable to all types of health manpower.

Data collection

A primary source of information for this section was the Utah State Department of Business Regulations, Department of Registration, Salt Lake City, Utah. The department's computer program was used to provide the names and addresses of doctors (medical and surgical in all their branches) and registered nurses within the four-county study area (table 20).

Using the latest edition of "Utah Health Profile" (including a 1974 update), prepared by the State of Utah, Department of Social Services, Division of Health, Bureau of Health Statistics, the total number of licensed physicians, dentists, pharmacists, registered nurses, and licensed practical nurses in each of the four counties is listed in table 21. Also included in the table are numbers of other categories of medical manpower in active practice, by county, which were obtained using the latest edition of "Health Manpower," also prepared by the Bureau of Health Statistics, and the 1974 update mentioned earlier.

Analysis

As standard procedure after a disaster, medical specialists and personnel are expected to report immediately to the hospital to which they are attached. If for any reason they are unable to reach their hospital, it is then expected that they will report to the nearest hospital available to them. In this regard, it is important to correlate the locations of the hospitals with respect to major transportation arterials and medical-manpower resources. Table 20 gives the number and distribution of physicians, surgeons, and registered nurses and the number of hospitals in the four-county study area.

Table 20.--Distribution of physicians, surgeons, registered nurses, and hospitals in four-county area

[Sources: Utah State Department of Business Regulations; Utah State Department of Social Services, Division of Health]

County of practice	Physicians surgeons		Registered nurses		Hospitals	
	Total no.	Percentage	Total no.	Percentage	Total no.	Percentage
Weber	182	12	750	16	4	18
Davis	71	5	518	11	4	18[1]
Salt Lake	1,119	73	2,766	59	10	46
Utah	151	10	633	14	4	18
Totals	1,523	100	4,667	100	22	100

[1] Includes two new hospitals scheduled for completion in 1976

Table 21.--Professional medical-manpower resources by county of practice

[Source: "Utah Health Profile," "Health Manpower 1973," and 1974 provisional updated numbers, published by the State of Utah, Department of Social Services, Division of Health, Bureau of Health Statistics]

Health-service profession	County			
	Weber	Davis	Salt Lake	Utah
Chiropractors	21	9	92	23
Dentists	103	60	370	94
License practical nurses	234	167	1,125	563
Naturopaths	6	0	14	2
Optometrists	13	7	38	11
Osteopaths	6	0	4	2
Pharmacists	91	75	365	81
Physical therapists	12	6	72	12
Physicians and surgeons	182	71	1,119	151
Podiatrists	4	1	19	5
Registered nurses	750	518	2,766	633

A review of the data in table 20 suggests that the relatively high percentage of physicians and surgeons in Salt Lake County is due to the fact that nearly 50 percent of the hospitals in the study area are located in Salt Lake County. This suggests that many physicians living in Davis County probably commute to hospitals in Salt Lake and Weber Counties. This may change with the completion of two new hospitals in Davis County in 1976. In general, the relative percentages of specific hospital personnel versus hospitals in table 20 indicates that most of the physicians, surgeons, and registered nurses probably reside in the same general areas where they work.

Considering the number of working hours in a week, it is more than likely that the medical manpower will be home or otherwise away from their places of employment when the postulated earthquake strikes. Under these circumstances, some medical personnel will not be available because of damage to transportation routes. The difficulty or ease with which the medical personnel will be able to reach their hospital stations will depend on the conditions of the ground transportation.

As it is reasonable that the residence and commuting habits of the medical manpower do not differ significantly from that of the general public, it is likely that most of the personnel will use automobiles, or buses in a few cases, and that the movements of these vehicles will be limited by the conditions of the freeways and surface streets. Blocked streets due to fallen overpasses, building debris, landslides, and so forth, in the Intensity-VIII and -IX areas will present difficulties, but these will not be so severe that alternate routes cannot be used in the vast majority of cases. It is reasonable to assume that the problems of transporting the injured to hospitals and to other centers will take even longer than will be required for the uninjured medical personnel to arrive. It should be expected that much of the freeway system will be partially closed in specific areas, due to the effects from fault displacement, local subsidence, lurch cracking, or landslides; further details are discussed in Section 6 under "Transportation."

Lack of telephone communication will create problems in handling assignments of hospital personnel. If the majority of the able personnel report to some hospital, then re-assignments could be handled by use of the hospital emergency-radio-communications network discussed under "Hospitals." However, experiences in past earthquakes indicate that radio communications will be seriously impaired owing to the loss of commercial electrical power and failures of emergency generating equipment because of inadequate anchorage of generating units, batteries, and fuel systems.

On the basis of the analysis developed in Section 5, "Estimated Casualties and Homeless," the estimates of deaths to selected health manpower at nonhospital locations were developed and are shown in table 22. Serious injuries (requiring hospitalization) are expected to number about four times the deaths.

It is likely that most of the hospital personnel, who have not been incapacitated, will be able to report either to their regular hospital or to an alternate location closer to their residences.

Magnitude 7.5 on the Wasatch fault--expected damage patterns.--For health manpower, transportation problems, deaths, and injuries will be most severe in Salt Lake County, because of its relatively high population, the density of population in congested areas, and its proximity to the postulated Wasatch fault rupture. (See table 22 for deaths to health manpower.) In this county, many doctors have offices in high-rise buildings in the downtown area of Salt Lake City. At least 50 percent of these buildings are of older non-earthquake-resistant construction, and partial collapse of one of these buildings should be considered for planning purposes.

Although Davis County is also located in an area of Mercalli Intensity IX, it has no congested areas or high-rise buildings. After completion of the two new hospitals in this county, there should be an increase in the numbers of doctors and nurses working and residing in Davis County; but doctors' offices will probably remain in small, one-story buildings.

Both Ogden in Weber County and Provo in Utah County contain some congested areas and high-rise buildings, but the population in these areas is much less than that of Salt Lake City, and these areas will only be subject to shaking of Intensity VIII. The numbers of deaths and injuries to doctors and nurses for each of these counties will therefore be smaller.

Table 22.--Deaths to physicians and nurses at nonhospital locations.

[Expected hospitalized injuries to deaths is 4:1]

County	Wasatch fault, magnitude = 7.5 Physicians surgeons	or	Magna fault, magnitude = 7.5 Registered nurses
Weber	2		7
Davis	0		1
Salt Lake	15		37
Utah	0		2
Totals	17		47

Access to the University Medical Center and the VA Hospital, both near the east foothills of Salt Lake City, may be difficult, because these facilities are located on the east side of the postulated surface fault rupture and transportation routes could be severed. For additional discussion on damage to highways and overpasses, see the "Transportation" section of this report.

Magnitude 7.5 on the Magna fault--expected damage patterns.--Deaths and injuries to doctors and nurses from an event on the Magna fault should be the same as from the Wasatch fault event, because the congested areas in the four counties are subject to the same shaking intensities from both events.

Transportation problems should not be as severe for the Magna event, because the postulated surface fault rupture occurs approximately seven miles (11.3 km) west of Salt Lake City and would not sever any highway from Salt Lake City to a hospital in the west valley area.

Medical supplies

Data collection

Hospital supply is normally achieved through shipments from drug-supply wholesalers and hospital supply houses located in the service area convenient to medical facilities. If the buildings and warehouses of these medical-supply companies were damaged or destroyed, supplies would have to be sought elsewhere in the outlying areas or be brought in from distant sources. Damage to local transportation routes could also effectively reduce re-supply to hospitals.

The principal source of data for this section was the Utah State Department of Business Regulations, Department of Registration, Salt Lake City. A list of retail drug stores licensed in Utah in 1975 was made available through the Department's computer program. A list of wholesale drug stores was also made available by this agency.

The locations of the major wholesale-drug houses and medical-surgical supply warehouses were documented, tabulated, and related to the respective counties in the study area. The total number of wholesale-drug and medical-surgical suppliers is listed by county in table 23, and their locations are shown in figure 34. All but one of the suppliers are located in Salt Lake County. Field inspections on building structure and storage methods were completed on two of the drug wholesalers and medical-surgical suppliers in Salt Lake City. A field inspection was made of the supply house in Ogden, and information on a facility in Magna, Salt Lake County, was received by discussion with the owner's representative.

The data received on licensed retail drug and pharmacy locations are summarized in table 24.

Analysis

The losses to medical supplies for hospital use and for direct public use may be considered as the losses to supplies stocked by wholesale and by retail facilities. For study purposes, retail medical supplies are limited to those contained in pharmacies, while wholesale supplies are restricted to those contained in the 21 drug-wholesaler locations and 5 medical-surgical supply houses in the four-county study area.

Table 23.--Drug and medical-surgical supply houses

[Sources: Utah Department of Business Regulations; local phone directories]

County	Total number of drug supply houses	Total number of medical-surgical supply houses
Weber	1	0
Davis	0	0
Salt Lake	20	5
Utah	0	0
Totals	21	5

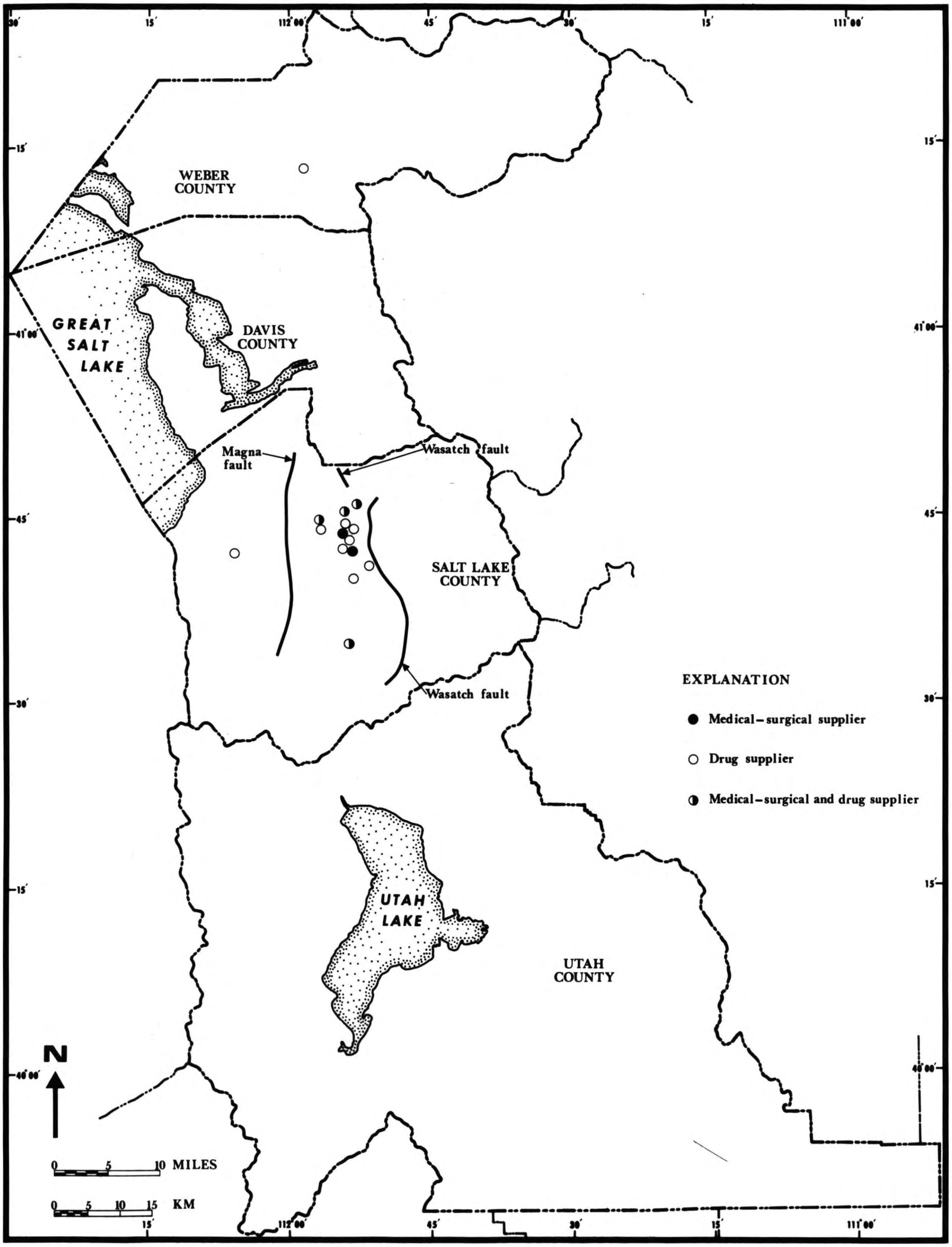

Figure 34.--Wholesale drug and hospital suppliers. (One dot may represent more than one facility. Shown fault breakage is assumed for planning purposes.)

Table 24.--Retail drug and pharmacy locations

[Source: Utah Dept. of Business Regulation List, March 1975]

County	Total number
Weber	36
Davis	17
Salt Lake	140
Utah	39
Total	232

The losses of medical supplies require the analysis of two factors: (1) loss as the result of drugs falling from their shelves, and (2) building collapse on drug stocks (or buildings damaged to the extent that use and occupancy of the facilities are seriously restricted).

Retail medical supplies

Reliable data on losses from 90 pharmacies experiencing the 1971 San Fernando shock provided the information listed below. These losses include the results of rare instances of building damage to drug stocks plus the usual losses caused by falling from shelves.

1. Relationship between Modified Mercalli intensity and dollar loss to drug stocks:

Modified Mercalli IX	23 percent loss to drug stock
Modified Mercalli VIII	12 percent loss to drug stock
Modified Mercalli VII	7 percent loss to drug stock

2. Average length of time that pharmacy was closed when building damage or collapse was not a significant factor:

Modified Mercalli IX	3.7 hours
Modified Mercalli VIII and under	2 hours

The data listed above can be used directly in the study areas having the same Modified Mercalli intensities, based on the reasonable assumption that the average construction for drug stores does not differ significantly in the four-county study area from that in San Fernando.

The 1971 San Fernando shock occurred before pharmacies were open, and personnel had opportunities to take care of personal problems before reporting for work. In many cases, the delay in opening pharmacies located in the lower intensity zones appeared to be a function of general confusion and the time lag of personnel arrival, as well as the cleaning up of fallen shelf stock. Several downtown stores opened a number of hours late, even though reported stock losses were zero and the buildings were not damaged.

In the analysis summarized by table 25, the number of retail drug stores and pharmacies in intensity zones VII, VIII, and IX were tabulated by county for the postulated earthquakes and multiplied by the loss percentages given above for each of the three zones. The percentage-loss

Table 25.--Losses to retail drug and pharmacies (in percent)

[Increase percentage by 5 percent during inclement weather]

County	Magnitude of postulated earthquakes: Wasatch fault Magnitude = 7.5 or Magna fault Magnitude = 7.5
Weber	10
Davis	25
Salt Lake	25
Utah	15
Average	20

figure for each county was then computed by dividing the sum obtained for each county by the total number of retail drug stores and pharmacies within the county.

The percentage losses in table 25 do not reflect possible additional losses due to inclement weather, when water could leak through damaged roofs, walls, and windows. Losses listed in table 25 should be increased by 5 percent if inclement weather is assumed(that is, 20 percent becomes 25 percent).

Magnitude 7.5 on the Wasatch fault--expected damage patterns.--Higher-than-average drug losses will occur in Salt Lake and Davis Counties due to high-intensity ground shaking. Serious transportation difficulties caused by surface faulting are not anticipated in the delivery of critical drugs to the heavily shaken areas from other communities within the study area. Some difficulties will be encountered in transporting critical drugs to outlets in suburbs located east of the zone of faulting. These difficulties could last for one week pending temporary repairs and re-routing of traffic.

Magnitude 7.5 on the Magna fault--expected damage patterns.--Losses to retail drug supplies will be the same as for the Wasatch fault event. No transportation difficulties due to surface faulting are anticipated.

Wholesale-drug and medical-surgical supply houses

The percentage-loss figures for the 90 pharmacies in the 1971 San Fernando shock were also used as a basis for estimating losses to wholesale-drug and medical-surgical supply houses. The susceptibility of retail drugs to earthquake losses is considered to be greater than that of wholesale drugs, due to the fact that large portions (50-90 percent) of the wholesale drugs are stored in original cartons. However, this is partially offset by wholesale drugs being stored in relatively high stacks and unbraced racks in larger warehouse-type structures, where partial roof collapses as a result of earthquakes are more common.

The percentage losses shown in table 26 were computed using the same methodology as was applied in computing losses to retail drug stores and pharmacies. These losses should be increased by 5 percent when assuming inclement weather (that is, 25 percent becomes 30 percent).

Table 26.--Losses to stock in wholesale drug and medical-surgical supply houses (in percent)

[Of the 26 buildings in the study area, 25 are located in Salt Lake County]

County	Magnitude of postulated earthquakes: Wasatch fault, Magnitude = 7.5	or	Magnitude of postulated earthquakes: Magna fault, Magnitude = 7.5
Weber	10		
Davis	0		
Salt Lake	25		
Utah	0		
Weighted average	25		

Magnitude 7.5 on the Wasatch fault--expected damage patterns.--All but one of the wholesale-drug and medical-surgical supply houses are located in Salt Lake County, where intense ground shaking is expected. For planning purposes, 25 percent of wholesale supplies will be lost (see table 26). Air delivery of certain items in short supply from outside the study area may be necessary.

Magnitude 7.5 on the Magna fault--expected damage patterns.--Effects will be essentially similar to those of the Wasatch fault event.

Mortuary services

In a major disaster, private mortuary companies would be called upon to provide emergency services. Cooperative agreements have been established between companies and the local Offices of Emergency Services to provide adequate care for the large number of fatalities that may be anticipated in a major disaster.

The ability of a mortuary to remain functional following an earthquake was the basis for analysis in this section. This includes damage to the building and to equipment. The same serviceability conditions then would apply to mortuary services as to ambulance services following a severe earthquake. A vehicle will be nonfunctioning if housed in a building that collapses or whose exit is blocked in any way.

Data collection

The State of Utah licenses funeral establishments, and a 1975 computer printout was obtained from the Utah State Department of Business Regulations, Department of Registration, Salt Lake City, of this listing. The Utah Funeral Directors and Embalmers Association provided a list of member mortuaries in the study area, and a listing of mortuaries for the four-county study area can also be found in the yellow pages of the Salt Lake, Ogden, and Provo telephone directories.

Construction data and certain operational details were collected on 7 of 42 mortuaries in the four-county study area. Five of these were field inspected. The collected data included the following: location, year built, type of construction, number of fatalities that can be processed on an emergency basis, type and sensitivity of equipment, number of stories, area (ft.^{2}), accessibility, number of vehicles, and type and construction of building housing the vehicle.

The number and distribution by county of the mortuaries and construction types of those where data were collected are given in table 27. The location of mortuaries in the study area is shown on figure 35.

Analysis

The seven mortuary buildings that were surveyed were built before earthquake design became mandatory in the study area. The sampling is believed to be representative of the whole, and older two-story homes are frequently used as mortuaries. These older buildings, located in

Table 27.--Mortuaries

[Sources: State of Utah Department of Business Regulations; Utah Funeral Directors and Embalmers Association list of members]

County	Total number	Type of construction of mortuaries inspected					
		Wood frame	Masonry	Concrete	Steel	Mixed	Total inspected
Weber-----------	5	2	1	0	0	0	3
Davis ---------	5	0	1	0	0	0	1
Salt Lake-----	17	0	2	0	0	0	2
Utah ---------	15	0	1	0	0	0	1
Totals----	42	2	5	0	0	0	7

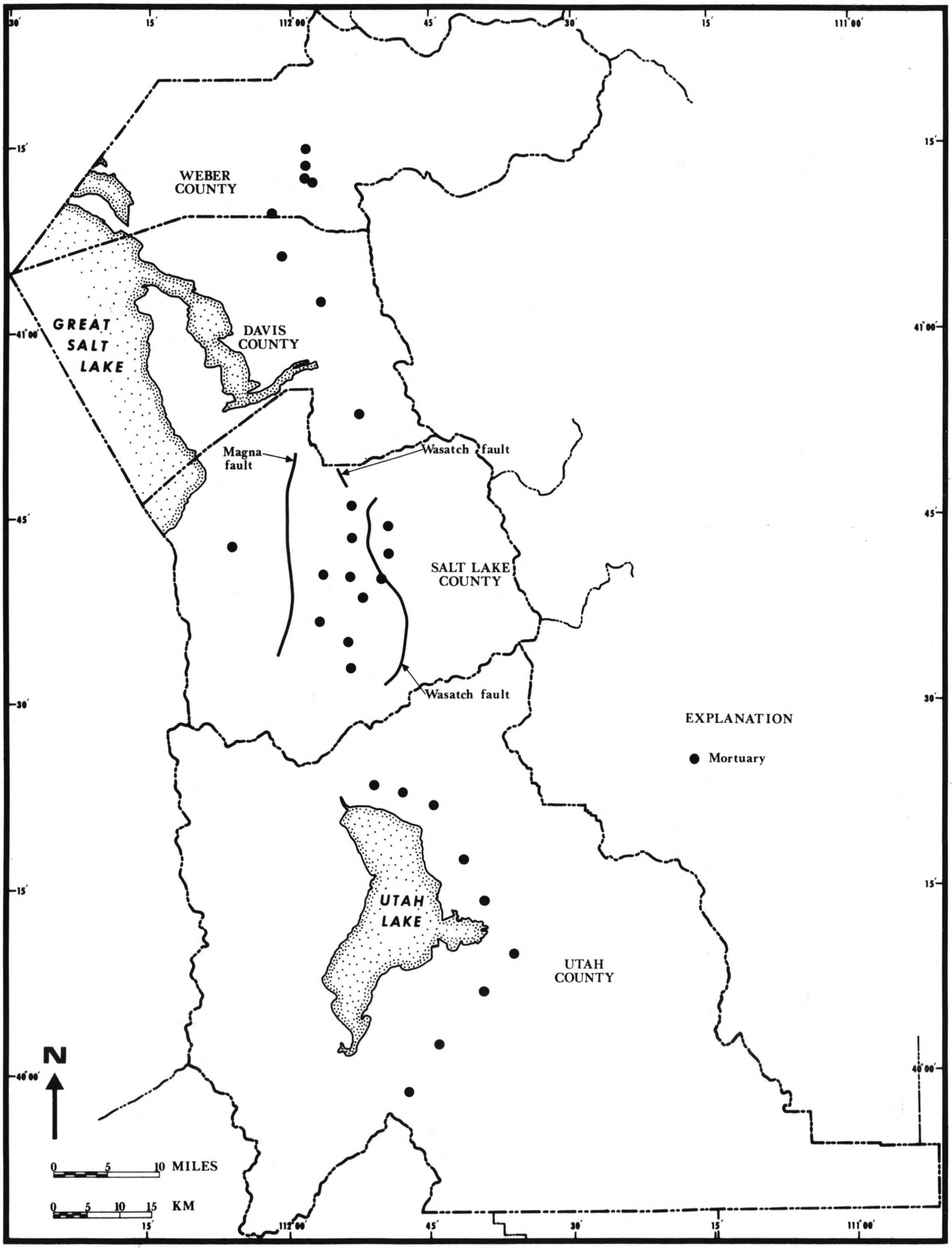

Figure 35.--Mortuaries. (One dot may represent more than one facility. Shown fault breakage is assumed for planning purposes.)

high-intensity zones in Salt Lake and Davis Counties, would suffer significant damage in either postulated earthquake (see table 28). Some heavily damaged buildings might still be useable as temporary morgues.

Temporary morgues might have to be established, both at mortuaries and at the site of a collapsed building; and these, combined with hospital morgues and those mortuaries that would still be functional, could accommodate immediate needs.

The only sensitive equipment in the mortuary is the embalming pump. This could be damaged by collapse of all or part of the building. Most mortuaries (about 90 percent) have electrically operated pumps. These would be inoperable if electrical power were suspended. One of the mortuaries surveyed has gravity-flow pumping equipment, and it can be assumed that a few other mortuaries in the study area, particularly the older establishments, still have this type of equipment, even though electrical pumps may be in daily use. Embalming fluid is stored in glass and plastic bottles on shelves and on the floor. It can be assumed that at least 50 percent of these supplies would be destroyed in intensity zone IX. There would be some damage to caskets, although this would probably be only about a 10-percent loss in intensity zone IX. The number of fatalities that can be processed in one day varied from about 5 for a small mortuary to 50 for a large mortuary. To take an inventory of all mortuary capabilities in the study area was beyond the scope of this report.

Most mortuary services park their hearses inside the building or in a garage, where they are more susceptible to being rendered nonfunctional in an earthquake, so it is likely that many of the fatalities will have to be transferred to mortuaries or temporary morgues by some means other than hearses.

Hearses can serve as ambulances to transport the injured to hospitals. Cots would be provided in the vehicles, but there would probably be no life-saving apparatus available. Damage to hearses from building collapse would of course inhibit this ambulance capability. About one-half of the mortuary services are located in densely populated areas where street access would be restricted in a time of disaster; the other half are located in residential or suburban areas with easy access.

Table 28.--Mortuaries made nonfunctional due to earthquake damage to buildings

Wasatch fault, magnitude = 7.5 or Magna fault, magnitude = 7.5			
County	Number		Percent of total
Weber ------------------	2		50
Davis ------------------	4		80
Salt Lake ------------	13		80
Utah ------------------	8		50
Total-------------	27	Average------	65

Magnitude 7.5 on the Wasatch fault--expected damage patterns.--
Those mortuaries in the heavily shaken areas of Salt Lake and Davis Counties would suffer significant damage. For the postulated event with the epicenter in Salt Lake, about 80 percent would be nonfunctional. (See table 28.) For planning purposes, it should be assumed that the same percentage of hearses would be nonfunctional due to blocked roadways, jammed doors, and building or garage collapse. In Weber and Utah Counties, only about 50 percent of the mortuaries and hearses would be nonfunctional, because they are in areas of lower shaking intensity. Some temporary morgues would probably have to be established, and vehicles other than hearses would be required to transport some of the fatalities.

Magnitude 7.5 on the Magna fault--expected damage patterns.--
Effects would be similar to those of the Wasatch fault event.

Other medical resources--

blood banks

Blood banks in the four-county study area would play a major role in disasters where large numbers of casualties result. The capability of local blood banks to adequately supply major disaster needs in these cases is insufficient, and nationwide resources would be required.

However, the discussion in this report is limited to the potential damage to the 16 hospital and 2 nonhospital blood banks (table 29), all of which are located within the four-county study area shown in figure 36 . A total of 33 blood banks exist in Utah, and the study area contains about 50 percent of those in the State.

The ARC (American Red Cross) Intermountain Center in Salt Lake City is the only nonhospital facility at which whole blood is drawn and processed for later use. After processing, part of the supply is kept at the blood bank itself, and the rest is stored at the various hospitals in the area. According to the ARC in Salt Lake, about 33 percent of their blood supply is kept at that blood center in order to handle an emergency. Blood is stored, according to type, in 1 pint (0.47 liters) plastic bags that are set in cartons and stored on shelves in a refrigerator. The other nonhospital facility in the study area is engaged in removal and storage of plasma only, and once each week sends all of its supply to a laboratory in California.

The ARC center in Salt Lake supplies about 37 percent of the blood for hospitals in the four-county study area. The individual hospital blood banks supply the remainder.

Data collection

Authoritative information concerning the blood banks in the study area was received from the 1973 directory listing, "Blood Banking and Transfusion Facilities and Services," published by the American Medical Association, and from the ARC Intermountain Center in Salt Lake City.

A field inspection was made of the ARC Intermountain Center and of the other nonhospital plasma-operation facility, and they were reviewed for the following information: equipment and supplies, storage methods used, year built, foundation type, number of stories, refrigeration capability, capacity in blood units, construction type, size of

Table 29.--Blood banks and their registered capacities

[Sources:"Blood Banking and Transfusion Facilities and Services," American Medical Association, 1973; and American Red Cross, Intermountain Center, Salt Lake City, Utah]

County	American Red Cross		Private		Hospitals		Total	
	Number of banks	Annual blood unit capacity (pints)	Number of banks	Annual blood unit capacity (pints)	Number of banks	Annual blood unit capacity (pints)	Number of banks	Annual blood unit capacity (pints)
Weber-----------	0	0	0	0	3	13,342	3	13,342
Davis ---------	0	0	0	0	2	unknown	2	unknown
Salt Lake-----	1	24,100	1	1/ 0	8	23,374	10	47,474
Utah---------	0	0	0	0	3	3,912	3	3,912
Totals-----	1	24,100	1	0	16	40,628	18	64,728

1/Plasma operations only.

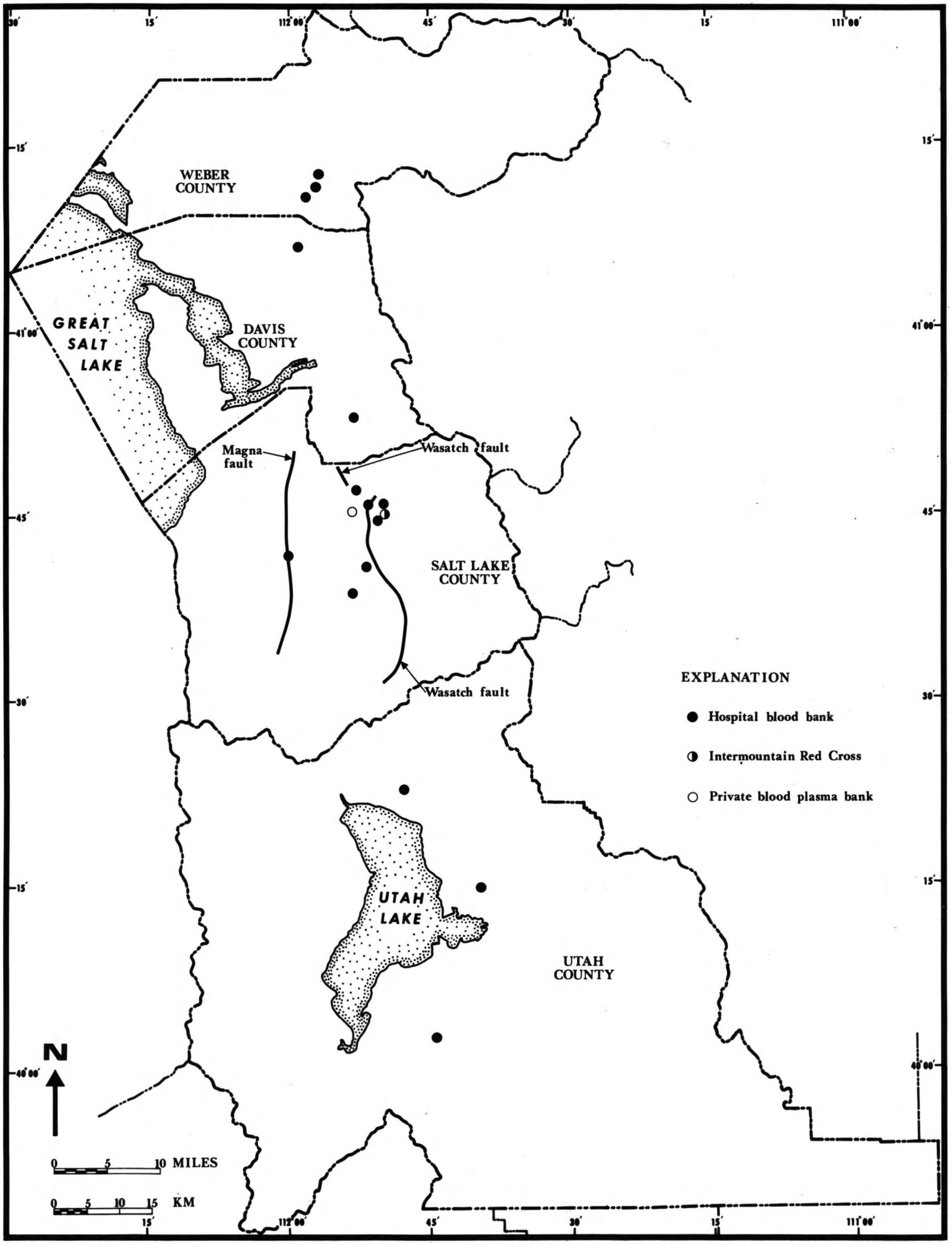

Figure 36.--Blood Banks. (One dot may represent more than one facility. Shown fault breakage is assumed for planning purposes.)

building, type of lateral bracing, accessibility for mobile units, emergency (auxiliary) generators, and emergency plans and systems.

The ARC operation in Salt Lake has two mobile units and receives approximately 80 percent of its supply from mobile-unit operations in outlying areas and from local organizations.

The ARC blood bank has an emergency generator for supplying electric power vital to keeping the refrigeration units in operation, thereby preserving blood supply in storage in the event of electric-power failure. However, the mobile units can be used for 24-hour refrigerated storage of about 1,000 blood units, providing that they have been fully refrigerated prior to the earthquake.

Analysis

Both of the nonhospital blood banks in the study area are located in buildings having metal or wood frames, floors, and roof systems. This type of structure is quite earthquake resistive, although the buildings under study were built before 1961 and were not specifically designed to resist earthquake forces.

Blood banks located in hospitals will be greatly affected by the overall earthquake performance of those hospitals, in addition to whatever happens within the blood banks. For example, a structurally damaged hospital requiring evacuation will have a nonfunctioning blood bank should one exist within the structure. Thus, the expected performance of the 16 blood banks located in hospitals will be largely based on the data used in the discussion of "Hospitals" found earlier in this report (p. 94-109). The discussion on equipment damage in the instances of building survival applies in both cases.

The building analysis was based on field inspections of the two nonhospital facilities and on construction data files for the hospitals that contain blood banks; these hospital files were discussed under the section on Hospitals. The degree of property damage was determined as a function of isoseismal zones, using the known earthquake resistance of each building. Table 30 indicates the number of blood banks that

Table 30.--Number and percent of blood banks rendered nonfunctional due to building damage

	Wasatch fault, magnitude = 7.5				Magna fault, magnitude = 7.5			
County	Non-hospital	Percent	Hospital	Percent	Non-hospital	Percent	Hospital	Percent
Weber	0	0	1	40	0	0	1	30
Davis	0	0	1	45	0	0	1	40
Salt Lake	1	35	5	50	1	35	5	55
Utah	0	0	2	53	0	0	2	53
Totals	1		9		1		9	

may be nonfunctional due to earthquake damage to buildings. Banks that can continue to function will do so at a reduced capacity due to damage to equipment and lack of electrical power and utilities, as discussed earlier.

Damage to unanchored and delicate equipment on tables and shelves will be substantial where intensities are high, because the equipment will fall to the floor and, in many cases, it will become inoperable. Damage to automatic processing equipment will require that the work performed by these machines be done manually, thereby possibly reducing production by as much as 80-90 percent in the larger centers that have automatic equipment. Lack of electrical power and utilities will also curtail operations and endanger refrigerated stocks. Although the ARC has emergency electrical generators, experience in past earthquakes has shown that generators frequently become inoperable due to lack of adequate anchorage of the units and of batteries and fuel supplies. Loss of refrigeration due to loss of electrical power is expected in high-intensity areas. In these cases, mobile units must be used to the limit of their capabilities. The stored blood in nonbreakable plastic containers will fall from shelves, and some loss is inevitable from lack of refrigeration.

Magnitude 7.5 on the Wasatch fault--expected damage patterns.--For planning purposes, one of the nonhospital blood banks and nine of the hospital blood banks should be considered nonfunctional. Five of these nonfunctional hospital blood banks are located in Salt Lake County, where the Mercalli Intensity is IX. The ARC Center in Salt Lake City is located about 1.33 miles (2.1 km) east and uphill from the postulated surface fault rupture. There could be some difficulty in transporting blood supplies from the ARC to hospitals west of the fault. The ARC should remain functional but at a reduced capacity of about 50 percent of normal, due to damage to equipment.

Magnitude 7.5 on the Magna fault--expected damage patterns.--Damage from this event should be similar except that transportation of blood from the ARC to hospitals in the area will not be curtailed due to faulting. One hospital blood bank located in Granger is within one-half mile (0.8 km) of the postulated surface fault rupture and should be considered nonfunctional for planning purposes.

Other medical resources--

hospital reserve disaster inventory (HRDI) modules

Emergency medical supplies in package module form are known as HRDI (Hospital Reserve Disaster Inventory Modules) and were prepositioned and stockpiled in existing major hospital buildings in the four-county study area. The concept of the HRDI unit is based on a 30-days' supply of emergency medical resources for each bed unit; that is, a 50-bed HRDI Module represents 1,500 patient days of care, whereas a 100-bed Module would service 3,000 patient days. The medical supplies in the HRDI stockpile had expiration-date limitations; therefore they had to be periodically inspected and a variety of the materials had to be rotated and replaced. Medical supplies which constituted the HRDI Module were only to be used in the event that an incident or potential situation would tax the local hospital facilities beyond the normal emergency capacity required to respond to a disaster.

In 1973 the Department of Health, Education, and Welfare informed the State of Utah that the HRDI program would be phased out. Subsequently the State instructed the hospital consignees of the HRDI Modules to assume ownership and to use the modules as part of their own supply. At this writing, it can be assumed for planning purposes that these HRDI Modules cannot be included as a viable resource in postearthquake recovery. Accordingly, no damage analyses were made.

Other medical resources--

clinical laboratories

Data collection

The Utah State Division of Health, Salt Lake City, maintains a list of Utah clinical laboratories by county. As of April 1975, there were 51 clinical laboratories in the four-county study area. Of the 51 total, 18 are located in hospitals and 33 are separate, nonhospital facilities. The Division of Health also has a voluntary program whereby laboratories can be approved to perform certain medical tests and then be placed on an approved list. Inasmuch as the application for approval is by request of a laboratory and there is no required certification, no distinction has been made in this study between approved and nonapproved clinical laboratories.

A physical "on site" inspection was conducted of six nonhospital clinical laboratories within the study area. Three laboratories were visited in Salt Lake County, and one building was visited in each of the remaining three counties. This resulted in a comparison of facilities in the more heavily populated Salt Lake County with those in the less populated counties of Weber, Davis, and Utah.

The field inspections obtained the following information on the buildings in which the clinical laboratories are located: location, year built, type of construction, sensitivity of equipment, number of stories, area (sq. ft.), accessibility, and storage of equipment.

The number and distribution by county of the laboratories are given in table 31 and figure 37 . Table 32 gives a summary of data on type of structure and construction dates.

Analysis

For purposes of analysis clinical laboratories are divided into those located in hospitals and those located to serve the adjacent neighborhood through doctors' offices located in the area.

The problems of a clinical laboratory located in a hospital will be greatly affected by the overall earthquake performance of that hospital, in addition to whatever happens within the laboratory. For example, a

Table 31.--Clinical laboratories

[Source: "Approved Laboratories," from Bureau of Laboratories, Utah State Division of Health, May 15, 1975]

County	Hospital labs	Nonhospital labs Total	Nonhospital labs Field inspected	Total
Weber ------------	4	3	1	7
Davis ------------	1/ 2	6	1	1/ 8
Salt Lake --------	8	17	3	25
Utah -------------	4	7	1	11
Total ------	18	33	6	51

1/ Includes Layton Community Hospital which is under construction

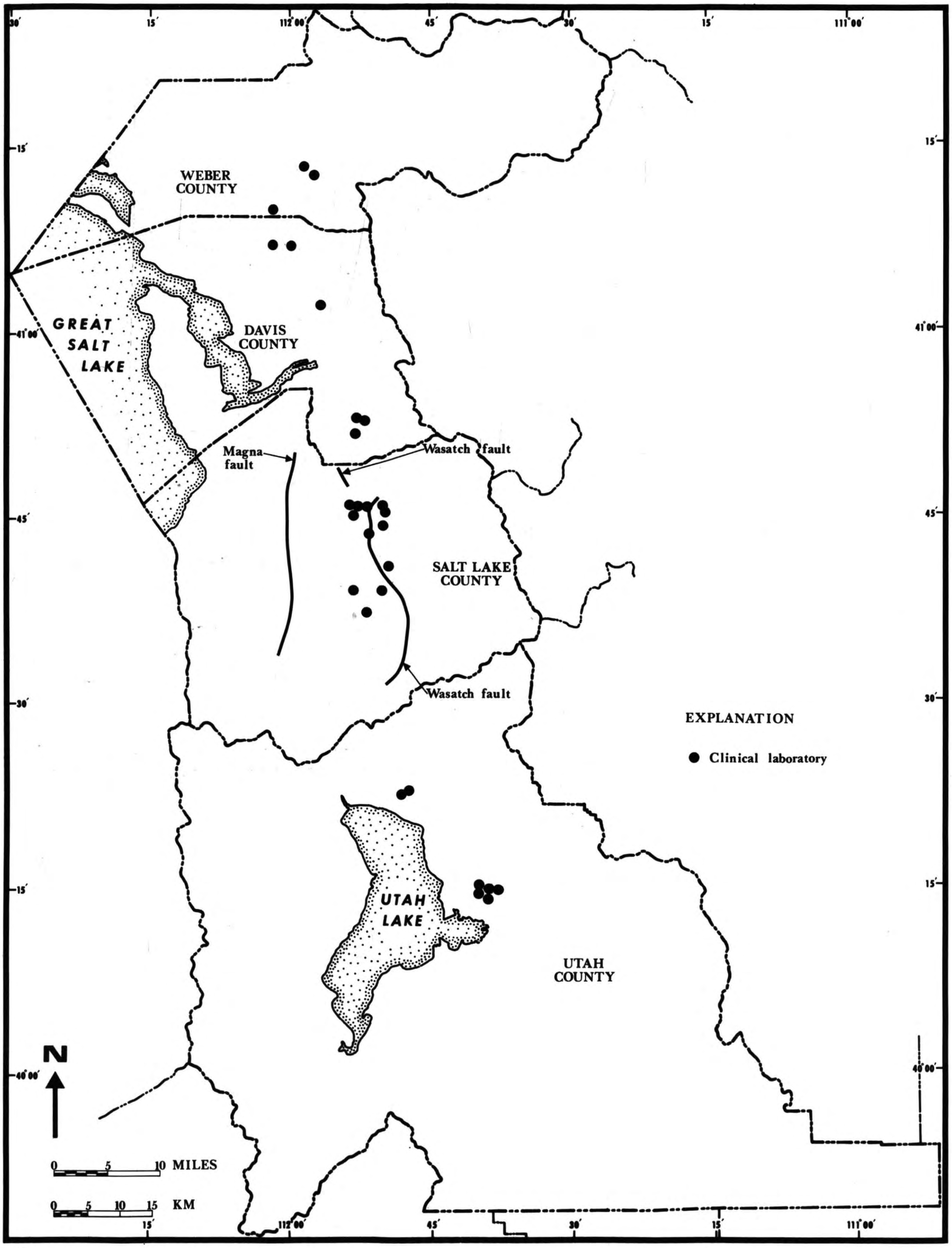

Figure 37.--Non-hospital clinical laboratories. (One dot may represent more than one facility. Shown fault breakage is assumed for planning purposes.)

Table 32.--Field inspected nonhospital clinical laboratories

[Construction information]

County	Year of Construction	Type of Construction
Salt Lake --------------	1955	Wood roof and floors, concrete bearing walls with brick veneer, 1 story.
Salt Lake -------------	1964	Wood roof and floor, steel frame, masonry nonbearing walls, 1 story.
Salt Lake ------------	1972	3 story, concrete pan joists, reinforced concrete frame, masonry in-fill panels, designed for future expansion to 6 stories.
Weber ----------------	Unknown	Reinforced concrete slab on grade, wood roof, wood frame, masonry walls, 1 story.
Utah-----------------	1970	2 story, concrete slab floors, and roof, concrete frame, exterior walls, concrete, wood, and glass.
Davis---------------	1955 & 1963	1 story wood frame, wood joist roof, masonry veneer exterior walls.

structurally damaged hospital requiring evacuation will have a nonfunctioning clinical laboratory, should one exist within the structure. Thus, the expected performance of the 18 clinical laboratories located in hospitals must be largely based on the discussion of "Hospitals" found elsewhere in this report, except that the discussion on equipment damage in the instances of building survival applies in both cases.

All buildings that contain clinical laboratories and that remain in safe functioning condition will have certain common problems with laboratory equipment and supplies. In Intensity IX areas, microscopes and other equipment will fall from benches, chemicals will be thrown to the floor, and extensive laboratory glassware damage is to be expected. Electric power will generally be out in Intensity IX areas, thereby leading to the spoilage of refrigerated stocks if power remains out for any lengthy period of time. Transportation problems in Intensity IX areas will seriously affect the employees' ability to report for work and also the movements of supplies and materials. This problem is discussed in more detail in Section 6.

Lower earthquake intensities will cause fewer problems, but the loss to equipment and stock will remain a substantial problem even if power supplies do not fail.

The inability of clinical laboratories to function in areas experiencing intensities of IX or greater is serious. However, as long as some microscopes remain in a functioning condition, considerable vital work can continue, but at a significantly reduced pace and scale. For a large clinical laboratory with substantial amounts of labor-saving devices, an Intensity IX event could reasonably result in as much as an 80 percent loss in output effectiveness, even if the building remained sound and the power was not lost. Smaller and less automated laboratories would not experience this efficiency loss due to their more simplistic operations, but this would be partially offset by the lack of usable standby power. Therefore, the building construction will have relatively little influence on the operability of the nonhospital laboratories unless very severe structural damage or collapse occurs.

As shown in table 32, six of the nonhospital laboratories (about

20 percent of the total) were field inspected. The distribution of the inspected laboratories in relationship to the total distribution is reasonable, and it has been assumed for the purposes of this analysis that the sampling is representative of the total.

Table 33 shows the numbers and percentages of nonhospital clinical laboratories likely to be rendered nonfunctional due to earthquake damage to buildings and equipment. The numbers shown are for all nonhospital laboratories in the study area and were arrived at by assuming the type of construction and equipment (based on the six field inspected laboratories), and by locating these laboratories in relation to expected shaking intensities.

Magnitude 7.5 on the Wasatch fault--expected damage patterns.--Table 33 indicates that 80 percent of the nonhospital clinical laboratories will be rendered nonfunctional in Davis and Salt Lake Counties. This high percentage is a result of the clinical laboratories in these two counties being located in intensity area IX.

Two of the laboratories in Utah County are located in intensity area IX. The other laboratories in Utah County and all of those in Weber County are located in intensity area VIII, and forty percent of these facilities would be rendered nonfunctional.

One-half of the total number of nonhospital clinical laboratories in the four-county study area (17 out of 33) are located in Salt Lake County. Of these, 14 would be rendered nonfunctional. When considering the four-county study area, 24 laboratories out of a total of 33, or 73 percent, would be nonfunctional.

Figure 37 shows that the postulated surface break on the Wasatch fault would affect several of the laboratories. Two are directly in the fault zone, and an additional seven are located between one-half mile and one mile from the break, but outside of the fault zone.

The results of the analysis indicate that the study area will suffer severe losses to nonhospital clinical laboratories, and that dependence on laboratories in other areas, even in other states, may be necessary.

Table 33.--Nonhospital clinical laboratories

[Nonfunctional due to earthquake damage. Based on damage to buildings and equipment]

County	Wasatch Fault Magnitude = 7.5 Number	Wasatch Fault Magnitude = 7.5 Percent	Magna Fault Magnitude = 7.5 Number	Magna Fault Magnitude = 7.5 Percent
Weber -------------------	1	40	Same as for Wasatch fault	
Davis -------------------	5	80	--------do.	
Salt Lake ---------------	14	80	--------do.	
Utah --------------------	4	51	--------do.	
Totals ------------	24	73	------- do.	

Magnitude 7.5 on the Magna fault--expected damage patterns.--
The nonhospital clinical laboratories in the four-county study area are located within the same intensity zones for the Magna fault as they are for the Wasatch fault, so damage patterns from shaking would be the same. (See table 33.) There are no clinical laboratories in or near the Magna fault zone, so there could be a smaller total number of buildings damaged due to the Magna fault event than due to the Wasatch fault event.

Other medical resources--

ambulance services

In general, ambulance services in Utah are either those serving the public at large, such as private ambulance services and fire departments, or those identified as "special services" provided by national guard units, military units, state hospital units, state colleges and universities, and private corporations. In case of emergency, however, the closest service of either type could be expected to respond to a call. The listings in this section are confined to the four-county study area.

In surface equipment (or ground equipment) used for ambulance services, the term "ambulance" includes any motor vehicle constructed, arranged, and operated for the purpose of transporting ill, injured, infirm, or otherwise incapacitated persons. If the vehicle functions as an ambulance and is used to respond to emergency situations, the operator of the service must obtain an ambulance license and vehicle identification card.

The "Utah State Ambulance Control Act of 1973" specifies that an ambulance service shall be provided in communities of 40,000 population or greater. The local community is responsible for providing the service, and it will conform to the rules and regulations of the State regarding equipment and vehicles for full-time ambulance services. Volunteer services are exempt.

Some helicopter ambulance service is currently rendered by the Utah Air National Guard, Dugway Proving Grounds, and Hill Air Force Base, but the scope of this service is limited and not primarily designed to provide ambulance service to the public.

Data collection

Identification and location of the ambulance services have been made through the use of the publication, "Survey of Utah Ambulance Services," issued in 1973 by the Bureau of Statistical Services in cooperation with the Bureau of Local Health Services, Division of Health, Utah State Department of Social Services. The mailing addresses and locations of ambulance services are found in the Appendix to this publication. An updating of this list was made by interviews with the director and staff of the Emergency

Medical Services, Utah State Division of Health.

Two important conditions govern the serviceability of ambulance units following earthquakes. The first is the method used in parking the vehicle when it is not in use. The second is its vulnerability in the event of building collapse (either the building that houses the vehicle or the one adjacent to it).

Accordingly, the field inspections conducted of all the ambulance services in the four-county study area differ from those conducted for other building categories in that diverse sets of data had to be collected. The building in which the ambulance is garaged (or the system used in the parking of the vehicles) was field inspected for the following information: number of vehicles, type of parking facilities, vehicle accessibility, type of garage structure, type of construction of garage, age of building (garage), building materials (garage), vulnerability of adjacent buildings, number of stories (garage), type of service,number of vehicle exits, and location of service.

Data was collected on general ambulance groups serving the public, including fire departments, and those identified with the "special services" provided by specific and particular organizations, such as military units, private corporations, colleges, and so forth. It did not include data on "medicabs" or similar vehicular services designed for the "nonemergency" transportation of the infirm or handicapped.

The number and distribution of public-service ambulance groups, as well as of the special-service ambulance groups, are given in table 34 and figure 38. Field inspections were made of 5 out of a total of 29 facilities in the four counties. Some ambulance services, such as the Salt Lake County Fire Department, station ambulances at more than one location; each location is treated in this report as a separate facility.

Analysis

The field inspections of 5 out of 29 facilities in the study area represent a sampling of about 17 percent. These inspected services share certain characteristics that are representative of the total. The majority of ambulances are parked inside, and the garage buildings were all of

Table 34.--Ambulance service groups

[Sources: "Survey of Utah Ambulance Services 1973," Bureau of Statistical Services and Bureau of Local Health Services, Division of Health, Utah State Department of Social Services. Abbreviations: No., Number; NA, not available]

County	Public groups and fire Departments				Special service groups				Total		
	Total services[1]	No. inspected	No. vehicles	No. vehicles w/ 2-way radio	Total services	No. inspected	No. vehicles	No. vehicles w/ 2-way radio	Total services	No. inspected	No. vehicles w/ 2-way radio
Weber ---------	3	1	10	10	1	0	NA	NA	4	1	10
Davis --------	1	1	2	2	1	0	8	8	2	1	10
Salt Lake -----	8	2	14	14	4	0	7	7	12	2	21
Utah----------	9	1	16	16	2	0	3	3	11	1	19
Totals--	21	5	42	42	8	0	18	18	29	5	60

1/Additional ambulance locations for any one service are counted.

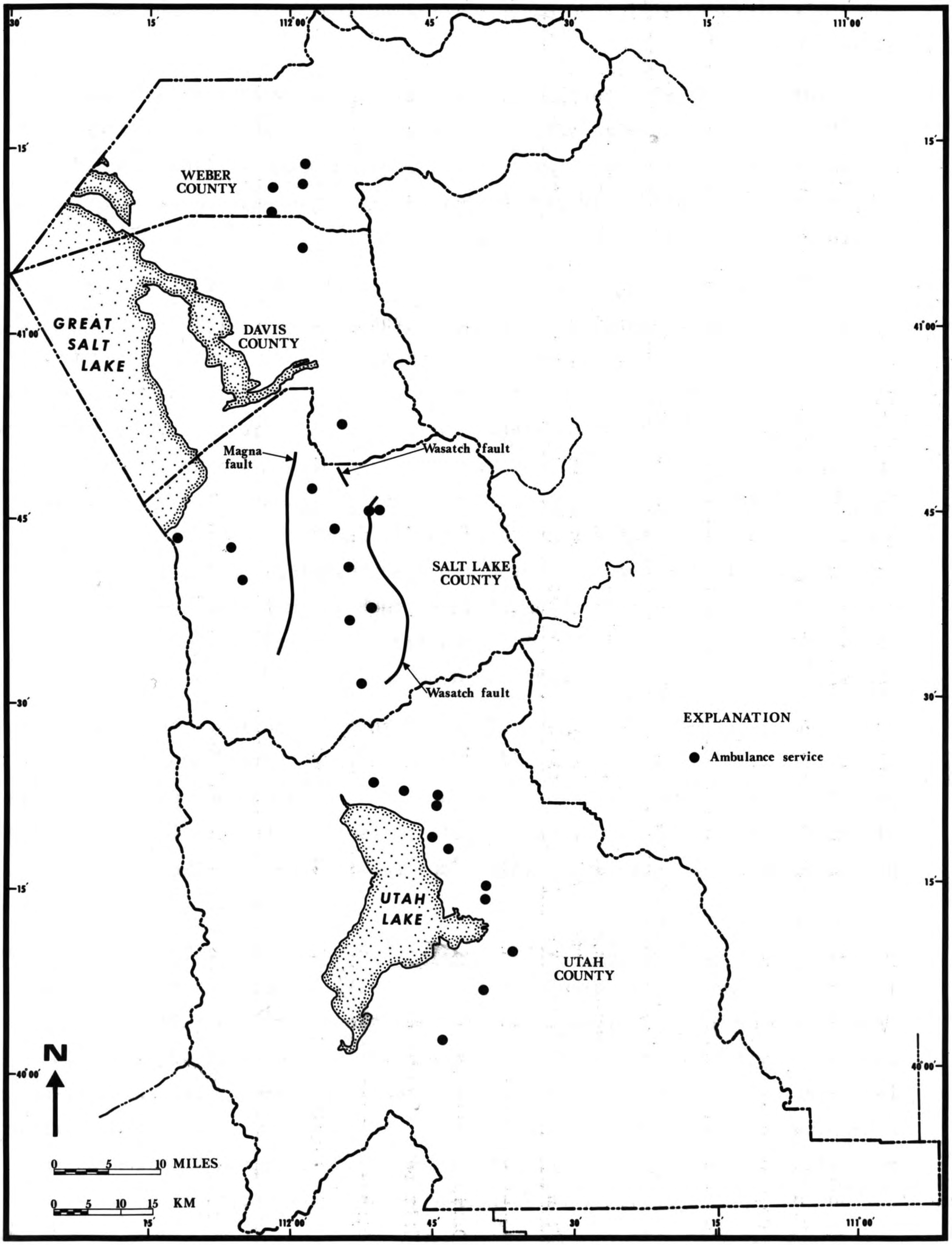

Figure 38.--Ambulance Services. (Shown fault breakage is assumed for planning purposes.)

one- or two-story reinforced masonry construction, built between 1957 and 1971.

For services with outside parking, experience with past earthquakes has shown that the problem areas (or service impairments) are typified by building debris in the streets, landslides on roadways, and other roadway obstructions, with only rare direct damage to ambulances from buildings located at or near ambulance parking.

Ambulance services that park their vehicles indoors face the added potential hazards of building collapse on the ambulance or nonfunctioning overhead doors. Of the facilities inspected, however, only one was built prior to 1963, the approximate time when designing for earthquake resistance became mandatory in the study area. Therefore, the majority of the structures housing ambulances should perform well, even in strong intensity areas, as they have some degree of earthquake resistance built into them. Although nearly 20 percent of these structures may be damaged, it is likely that most of the vehicles can be removed from the buildings in functional condition. Structural collapse on ambulances, such as that which occurred at the Olive View Hospital in the 1971 San Fernando earthquake, is still a possibility, but this occurrence would be rare.

The estimated total number of impairments to ambulance services is shown in table 35. As the sampling indicates that it is common practice to park vehicles inside, the figures in table 35 are based on expected behavior of the structures that house the vehicles. As indicated previously, vehicles parked outside are less likely to be impaired in an earthquake than those indoors.

Magnitude 7.5 on the Wasatch fault--expected damage patterns.--Approximately 17 percent of the ambulance services will be rendered nonfunctional by this earthquake. The greatest damage to these services will be in Salt Lake and Davis Counties,as all ambulance buildings in these areas are in intensity area IX. One ambulance service has a permanent parking place at a hospital located within the fault zone. Another service is located within one mile (1.6 km) of the fault. (See figure 38.) Figure 38 indicates that all but one of the services in Salt Lake County may be cut off from areas

Table 35.--Ambulance service impairment

County	Services parked inside[1]	Services not functional[2] Number of services	Percent of total services
Weber	4	1	15
Davis	2	0	20
Salt Lake	12	2	20
Utah	11	2	15
Total	29	5	17

1/ Based on 100 percent of all services in study area that have ambulances parked inside of buildings

2/ Figures are the same for an earthquake on either fault.

east of the fault due to damage to transportation systems caused by severe ground shaking and surface fault rupture.

Magnitude 7.5 on the Magna fault--expected damage patterns.--The impact of this event will be similar to that from an earthquake on the Wasatch fault (17 percent of services nonfunctional), except that areas are less likely to be cut off completely from ambulance services since the postulated fault rupture occurs about 7 miles (11 km) west of the city center and does not affect major transportation routes in the city.

Other medical resources--

nursing homes

In terms of medical health facilities, nursing homes in the four-county study area include the following: nursing homes, convalescent hospitals, sanitariums, extended care facilities, rehabilitation centers, and homes for the aged.

It should be noted that nursing homes differ from hospitals in that nursing homes do not generally contain all the facilities, equipment, and accommodations usually found in a major hospital building, such as X-ray equipment, surgery or operating rooms, fully functioning clinical laboratories, special examining rooms, and so forth. All nursing homes in the State of Utah must apply for certification and licensing through the Department of Health.

Not included in this nursing home category are major hospitals and clinical laboratories referred to in other sections in this report. Also not included are other facilities licensed by the State of Utah, such as day centers, home health agencies, alcoholism hospitals, clinics, mental retardation facilities, and long-term accommodations. Some nursing home facilities may be quite large; for example, there are 19 nursing homes in the four-county study area with a capacity of 70 beds or more (table 36).

The main source of data was the Standards and Licensure Section, Bureau of Medical Care Services, Division of Health, Utah State Department of Social Services, which publishes a directory of "Licensed Nursing Homes," September 1, 1974.

Information regarding definitions and licensure requirements for nursing homes was found in the "Code of Nursing Home Rules and Regulations," published by the Utah State Department of Health.

A complete list of licensed nursing homes in the four-county study area by number of beds and number of facilities is found in table 36. Figure 39 shows the geographic distribution by county of those nursing homes with 70 beds or more.

Table 36.--Nursing homes

[From a publication "Licensed Nursing Homes," Standards and Licensure Section, Bureau of Medical Care Services, Division of Health, Utah State Department of Social Services]

County	Bed capacity of nursing homes 10-40 beds	40-70 beds	70-100 beds	100 or more beds	Total Number of Facilities	Total Bed Capacity
Weber	3	3	2	0	8	382
Davis	3	0	0	1	4	162
Salt Lake	48	10	5	6	69	2,739
Utah	9	7	3	1/ 2	21	1/ 1,661
Totals	63	20	10	9	102	4,944

1/ Includes Utah State Training Schools Intermediate and Comprehensive facilities.

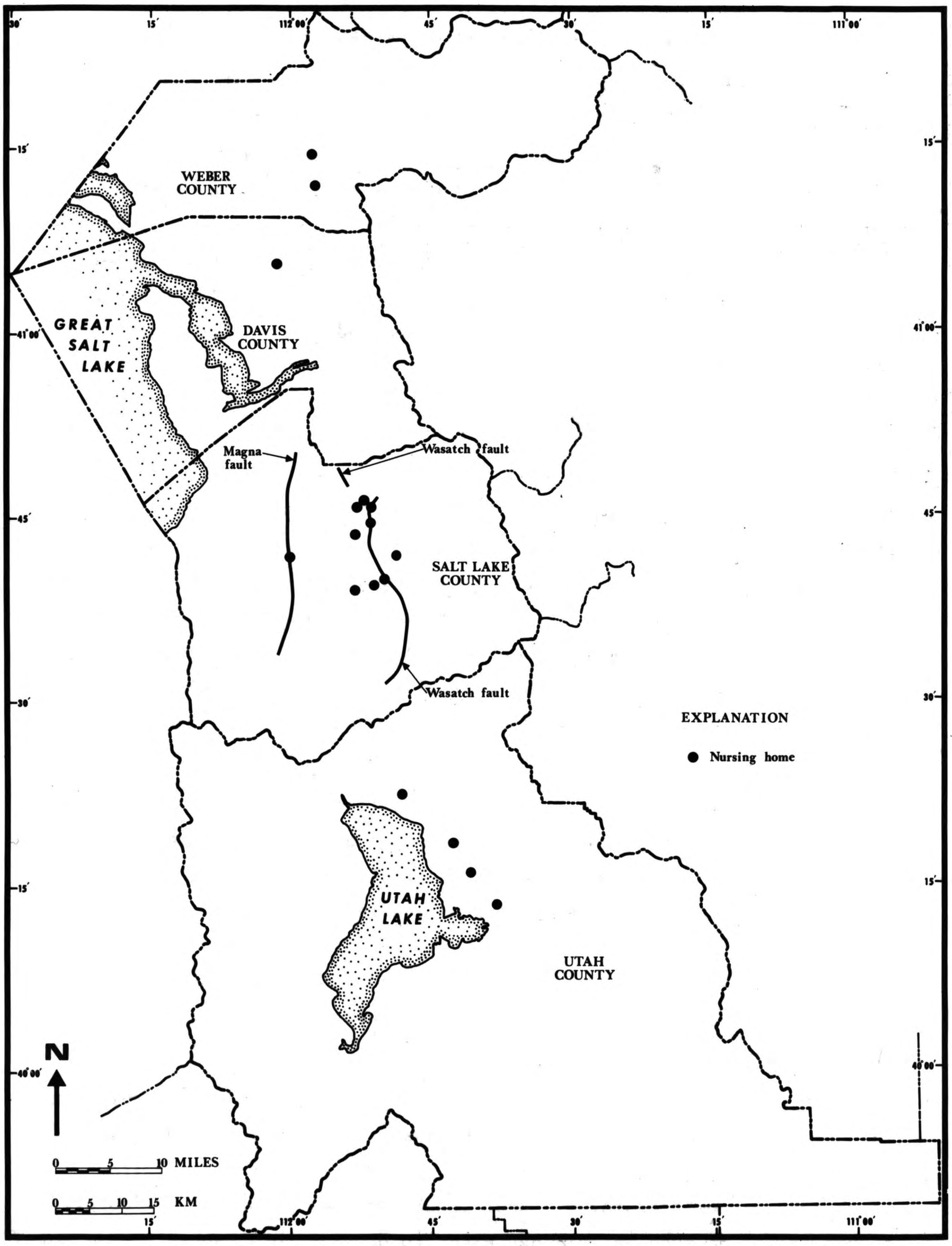

Figure 39.--Nursing homes with more than 70 beds. (One dot may represent more than one facility. Shown fault breakage is assumed for planning purposes.)

SECTION 5: ESTIMATED CASUALTIES AND HOMELESS

Deaths and injuries excluding dam failure

Deaths and injuries resulting from the postulated earthquakes in the four-county study area will be due principally to failures of manmade facilities, such as buildings. Whereas earthquake-induced landslides and snow avalanches may cause loss of life during spring and winter seasons, the type of landslide that led to the loss of 25,000 to 30,000 lives after the Peruvian earthquake of 1970 is unlikely but not impossible. Many housing developments are located on the western foothills of the Wasatch Range between Ogden and Provo. These developments could be vulnerable to earthquake-induced landslides and rockslides.

Data collection

Historical record

Table 6 of this report is a listing of earthquakes in the United States having relevance to this study. Excluded was the 1872 Owens Valley earthquake in which 23 persons out of a population of 250-300 were killed in Lone Pine, Calif. This exclusion was made on the basis of nonrelevant construction--adobe and stone houses, usually without any kind of mortar. Foreign earthquakes normally have minimal relevance, owing to construction or other differences, and were therefore also excluded from the list, although specific events are considered elsewhere in the text.

Documentation of death and injuries is less clearly stated in earthquake reports than is the damage to buildings and other property. Deaths caused by heart attack may or may not be included, and texts leave the matter unclear in most cases. Injuries leading to death may be included under injuries or under deaths. The dividing line between "serious injury" and "injury" is rarely stated in reports, and the given data are often incomplete. Whether or not emotional cases were included is usually not stated, although some of these cases would have required medical attention.

Table 37 is a listing of deaths and injuries per 100,000 population for selected American earthquakes. Earthquakes with life loss of less than eight were excluded from the listing, and the 1872 Owens Valley earthquake was omitted for reasons already stated. Possibly the cutoff figure should be much larger than eight to provide an acceptable base for extrapolation.

Table 37.--Death and injury ratios, selected U.S. earthquakes

[Source: A Study of Earthquake Losses in the Los Angeles, California Area, NOAA, 1973]

Earthquake	Date	Time of occurrence 2/	Deaths per 100,000 population	Injuries per 100,000 population
Charleston, S.C.	Aug. 31, 1886	9:51 p.m.	45 outright; 113 total	----no record----
San Francisco, Calif.	April 18, 1906	5:12 a.m.	124	104 serious
Santa Rosa, Calif.	April 18, 1906	5:12 a.m.	116	69 serious
San Jose, Calif.	April 18, 1906	5:12 a.m.	80	38 serious
Santa Barbara, Calif.	June 29, 1925	6:42 a.m.	45	119
Long Beach, Calif.	March 10, 1933	5:54 p.m.	26	1,300
Imperial Valley, Calif.	May 18, 1940	8:37 p.m.	18	40
Olympia, Wash.	April 13, 1949	11:56 a.m.	1	5 serious
Kern County, Calif.	July 21, 1952	4:52 a.m.	500	----no record----
Bakersfield, Calif.	Aug. 22, 1952	3:41 p.m.	3	47
Anchorage, Alaska	March 27, 1964	5:36 p.m.	9	315
Seattle-Tacoma, Wash.	April 29, 1965	7:29 a.m.	1.5	3
San Fernando, Calif.	Feb. 9, 1971	6:01 a.m.	64 total 1/	180 serious

1/52 deaths in V.A. Hospital.

2/Local time.

The effect of a single major collapse can strongly affect the losses per 100,000 population; see, for example, the variations in table 37 when the deaths at the Veterans Administration Hospital from the 1971 San Fernando shock were included.

Table 37 is a useful guideline when applied with judgment and in the context of the time of day, appropriate comparative construction, and appropriate Modified Mercalli intensities. It must be clearly understood that information contained in this table cannot be used directly without consideration of the foregoing qualifications. For one example, the hazardous unreinforced brick-bearing-wall buildings are slowly being phased out in the study area, although large numbers of them still exist. This means that data from past earthquakes (such as 1933, Long Beach) may be of decreasing importance. However, the current trend to rehabilitate and reoccupy older buildings has, in the past 5 years, slowed the removal rate of this building type and has, at the same time, increased the occupancy.

Building inventory

For realistic usage, the death and injury ratios in table 37 must be modified on the basis of a hazard evaluation of the construction types found in the study area. In turn, these modified ratios must be multiplied by the daytime and also the nighttime populations in the areas being examined.

Data on multistory construction were gathered for portions of Salt Lake City, Ogden, and Provo and listed in table 38 by number of buildings and by story-height groupings. The areas within each city were selected on the basis of their relatively high population concentrations, relatively congested building areas, and potentially higher-than-average disaster effects; the boundaries of these areas are shown in figure 40. The selected construction types of multistory buildings were concrete steel frame, brick, and mixed construction.

The basic data were obtained from Sanborn map volumes. This material is proprietary and is used principally by the insurance industry. Access to the volumes was provided by the Insurance Services of Utah.

Table 38.--Multistory building inventory for selected congested areas

[Source: Data from Sanborn maps volumes; Insurance Services of Utah, updated by field inspection]

Construction material	Number of stories	Number of buildings		
		Salt Lake	Ogden	Provo 2/
Concrete----------------	4-8	16	0	0
	9-13	3	1	0
	14 up	2	0	0
Steel frame-------------	4-8	2	2	0
	9-13	3	0	0
	14 up	5	0	0
Brick 1/------------------	4-8	18	1	0
	9-13	2	0	0
	14 up	0	0	0
Mixed construction	4-8	10	1	0
	9-13	4	1	0
Totals----------------------------		65	6	0

1/Reinforced and nonreinforced brick walls.

2/No buildings in selected congested area of Provo were four stories or over.

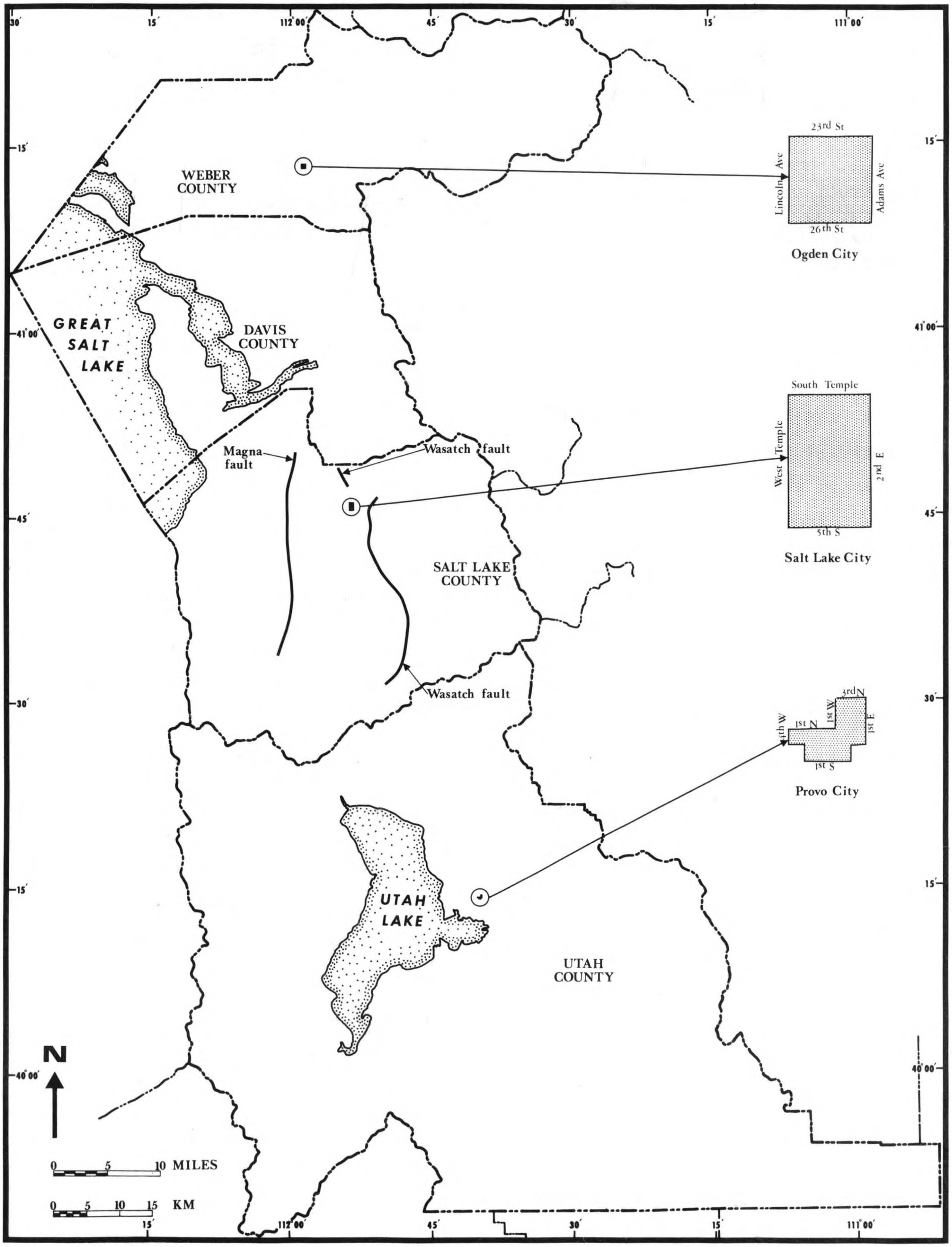

Figure 40.--Selected congested areas containing large buildings in Ogden, Salt Lake City, and Provo. (Shown fault breakage is assumed for planning purposes.)

Heavy loss of life from earthquakes in the United States is usually associated with brick buildings, and, therefore, special attention has been paid to this construction type in the building inventory.

In the study area, 1961 is the dividing line between earthquake-resistive brick structures and nonresistive brick structures. This year was selected because of the adoption of the earthquake sections of the Uniform Building Code in the area, which resulted in changes in the current architectural and structural treatment for buildings. These latter changes include tilt-up concrete, curtain-wall facings, and precast facings. Additionally, life-loss statistics may be segregated into those related to building collapse (deaths within the building) and those related to parapet and appendage failure (deaths on sidewalks, on roadways, and in alleys).

Table 39 is a listing of all non-earthquake-resistive brick masonry buildings, regardless of height, in the selected congested areas of the cities of Salt Lake, Ogden, and Provo; also included is the total lineal footage of street frontage, not including alleys, for this building type. This lineal footage becomes the basis for estimates of the number of casualties from parapets and other masonry appendages that may fall on sidewalks and streets.

The count of brick buildings within the selected congested areas of the cities of Salt Lake, Ogden, and Provo may vary substantially, depending upon the building definition that is used. Numerous structures in the old city areas are a series of interconnected "party wall" buildings; in such cases, multiple-occupancy and separately designated buildings were counted as one in the table, unless the party wall was parapeted above the roof line. Table 40 shows peak population in congested areas.

At the present time, no major community in the Salt Lake study area has ordinances covering parapet removal. It is therefore assumed that all old non-earthquake-resistive brick buildings within the congested areas of Salt Lake City, Ogden, and Provo have parapets that will be responsible for casualties. The number of such buildings and their lineal street frontage are given in table 39 and can be used for estimating casualty calculations.

Table 39.--Non-earthquake-resistive brick masonry buildings and their street frontages in selected congested areas of Salt Lake, Ogden, and Provo (Nonreinforced brick buildings constructed prior to 1961)

[Source: Data from Sanborn map volumes; Insurance Services of Utah, updated by field inspection]

City	Sanborn Map volume	Number of buildings	Street frontage lineal feet
Salt Lake---------------	2	101	9,170
	1	20	3,035
	3	115	11,683
Totals---------------------------------		236	23,888
Ogden-------------------	1	257	11,850
Provo------------------	1	149	6,240

Table 40.--Population in selected congested areas

[Source: Data from Salt Lake, Weber, and Utah Counties Community Shelter Plans; and Block Statistics, Bureau of Census, 1970]

City	Area	Resident population	Peak population
Salt Lake--------	Census Tract 22	983	89,581
Ogden-----------	Tract 11 (9-block area)	614	13,250
Provo-----------	Tract 24 (part of 12-block area)	228	9,000

Dwelling data

Within the four-county study area, those dwellings erected prior to 1965 were of predominantly brick and concrete-masonry construction. The rest were of wood-frame construction. Since 1965 most of the single-dwelling units are of wood-frame construction using a single brick veneer. This could be classified as wood-frame construction, which is considered inherently safe. Buildings containing many housing units, such as apartment buildings, are often of fire-resistive construction or of mixed construction using either unit masonry or reinforced concrete. These multiple-unit structures are often much more vulnerable to earthquake damage than is a single-family wood-frame dwelling.

The 1970 census provides, in a generalized way, one convenient method for relating the population to the type of housing in the urbanized areas of the four counties. Table 41 shows dwelling and population data for all urbanized areas in the four-county study area.

According to the 1970 census, the population of the urbanized area is 627,546, whereas the total population of the entire four-county study area is 821,689. Although some of the suburban areas may not be accurately represented through the use of these urbanized-area data, the error is not significant in number and not otherwise significant because suburban and rural areas tend to have fewer earthquake problems. Estimated 1974 population figures are found in table 1.

Day-night population shifts

Information on day-night population distributions is of substantial importance with respect to potential casualties, and accurate statistics for analysis purposes are most difficult to obtain. At night, much of the population has shifted from congested areas usually associated with the higher-than-average hazard to the relatively safe single-family dwellings.

Salt Lake, Weber, and Utah Counties have prepared data showing resident population and peak daytime population within the selected congested areas of Salt Lake, Ogden, and Provo. These are to be found

Table 41.--Selected dwelling and population data for urbanized areas in four-county study area

[Source: Data from Block Statistics, Bureau of Census, 1970

Note: Total population of four-county urbanized area (1970) 627,546

Total population of four-county study area (1970) 821,689

Estimated total population of four-county study area (1974) 902,000]

		Year-round dwellings by number of units				
County	Area 1/	1 unit	2-9 units	10 or more units	Total units	Population in urbanized areas
Weber	Ogden	15,951	5,725	2,009	23,685	69,478
	Other	10,415	1,809	78	12,302	46,817
	Totals	26,366	7,534	2,087	35,987	116,295
Davis	All areas	14,125	2,988	232	17,345	69,882
Salt Lake	Salt Lake	36,274	20,164	9,215	65,653	175,885
	Other	36,931	5,801	1,510	44,242	164,794
	Totals	73,205	25,965	10,725	109,895	340,679
Utah	Provo	6,898	5,167	975	13,040	53,131
	Other	10,154	2,364	181	12,699	47,559
	Totals	17,052	7,531	1,156	25,739	100,690
Grand Totals		130,748	44,018	14,200	188,966	627,546

1/"Other" denotes urbanized communities of more than 2,500 population.

in the "Community Shelter Plans" for these areas. These show data for the year 1970 using the resident population for that period and an estimated figure projected to 1975. The population shift for Davis County was estimated on the basis of percentages for the other three counties. However, the population of Davis County is only about 12 percent of the total of the four-county study area. Additionally, the aggregate day-night population shifts are substantially less than for the congested areas of Salt Lake, Ogden, and Provo. Therefore, detailed population-shift data for Davis County will have comparatively little effect on the overall casualty calculations.

Analysis

As has been stated, casualty estimates are determined by population distributions as related to construction types, earthquake intensity, and special geologic or foundation conditions. In turn, these overall figures must be adjusted to suit specialized factors such as freeway casualties and special occupancy casualties, including those from schools, hospitals, and other buildings with high occupancy ratios.

A large portion of the population in the one-unit structures is housed in wood-frame and wood-frame brick-veneer dwellings, which have had a minimum of earthquake casualties and for which substantial favorable-experience data exist. The balance of the one-unit structures are of brick and block-masonry construction with wood-frame interior partitions, which will reduce earthquake casualties to levels near that of the wood-frame dwellings. The population in the two-to-nine-unit structures will have a somewhat higher risk, whereas a significant portion of the population in the structures having more than nine units will be at the highest risk level.

In all of the discussion that follows, casualty figures are restricted to the four-county study area. In the event of a magnitude-7.5 earthquake on either the Wasatch or Magna faults, there will be additional casualties outside the four-county study area, although the population of such areas is minor and the casualties are estimated to be low.

Nighttime casualties (2:30 a.m.)

Estimates of nighttime casualties are based on the fact that the populace is essentially in its dwellings at that hour. A reasonable death ratio for persons in single-family dwellings in the hardest hit areas (MMI IX) is 12 deaths per 100,000.

Often structures containing two to nine units are more than one story in height, and frequently they are of a construction type that is not as safe as wood frame or frame brick veneer; as a result a higher death ratio is expected. The death ratio for structures with 10 or more units includes the long-period effects on high-rise structures; namely, that high-rise buildings are proportionately more affected at larger distances from the epicenter than are low structures.

In general, the calculation methodology followed that used for the Los Angeles and San Francisco studies,because of the similarity between these cities and cities in the Salt Lake study area with respect to types of construction and types of expected damage to this construction. The calculations showed that the average death ratio for the four-county study area was 28 per 100,000 population for a magnitude-7.5 earthquake on the Wasatch fault and 23 per 100,000 population for a magnitude-7.5 earthquake on the Magna fault. Obviously, the average death ratio for any location within the four-county area varies with the construction types, foundation conditions, and distance from the epicenter.

The many uncertainties regarding the number of casualties and the nature and gravity of injuries made the development of statistics from previous records of very doubtful value. A ratio of four serious injuries to one death was assumed for planning purposes, with serious injuries defined as those requiring hospitalization, however brief. The ratio of 30 injuries to 1 death was assumed for nonserious injuries. The summary results of the calculations are shown in table 42.

Daytime casualties (2:00 p.m.)

The life-hazard problem is more complicated and less subject to reliable analysis for daytime earthquakes than for those occurring at night. Many of the 902,000 persons in the four-county area will be at

Table 42.--Deaths at three times of day in the four-county study area for two postulated earthquakes [1/]

County	Wasatch fault, magnitude = 7.5 Deaths			Magna fault, magnitude = 7.5 Deaths		
	2:30 a.m.	2:00 p.m.	4:30 p.m.	2:30 a.m.	2:00 p.m.	4:30 p.m.
Weber ---------------	27	260	315	21	246	304
Davis----------------	18	185	129	17	181	128
Salt Lake------------	176	1,572	1,271	148	1,355	1,233
Utah-----------------	29	249	215	24	212	207
Totals------------	250	2,266	1,930	210	1,994	1,872

1/For planning purposes, a ratio of four injuries to one death was assumed, with serious injuries defined as those requiring hospitalization, however brief. The ratio of 30 injuries to 1 death was assumed for nonserious injuries.

work in structures that are not as safe as their residences. The others will still be at home, in shopping areas of not much greater hazard than their single-family homes, in schools, in moderately safe industrial plants, in office buildings of various quality, and the like. Some will be on the streets in the more hazardous areas. At 2:00 p.m., the streets will not be as crowded as during the commuting hours.

The daytime-casualty calculations may be broken into the following categories:

1. Persons experiencing no more than average nighttime earthquake hazards;
2. Persons in the congested areas where the hazard is the highest;
3. Persons in intermediate hazard areas; and
4. Special hazards (schools, freeways, hospitals, fire).

For the four-county study area, 40 percent of the population, or about 328,680 persons, may reasonably be estimated to have about the same general hazard as that of the nighttime population. The process of determining the geographic distribution of deaths by proportion from the nighttime figures then becomes simple.

Data on selected congested areas are given in tables 38 and 40 , and some of their geographic locations are shown in figure 40. By no means do the foregoing include all of the congested areas, but they do place the necessary emphasis on the older business areas where construction is poorer and resulting loss of life will be heaviest. Clearly, the city of Salt Lake dominates the multistory-building categories and congested-population figures.

As one basis for analysis, the death ratio in Anchorage in the 1964 Alaskan earthquake can be used. Table 37 indicates that the ratio was 9:100,000 for this earthquake, which occurred late in the day on Good Friday. Based on extensive building investigations made after the 1964 shock, 100 deaths would have been reasonable if the hour had been earlier and if the buildings under construction had been completed. Metropolitan Anchorage had a population of 100,000 at the time of the earthquake, with about 50,000 within the city limits. If the population in homes, in schools, and in low wood-frame buildings were discounted, then the downtown population at the time of the estimated 100 deaths would be estimated to have been not more than about 20,000. This would give a death ratio of 500:100,000.

Another approach may be used. Using the ratio of three major building collapses in Anchorgge per 20,000 congested-area population, a proportional figure developed for Salt Lake would be $3 \times \frac{89,600}{20,000}$ or 13 equivalent major building collapses.

A death ratio of 480 deaths to 100,000 population at MMI IX, the experience of Caracas, Venezuela, was reviewed. Most of the 12 high-rise buildings that collapsed there in the 1967 earthquake were modern earthquake-resistive structures designed to meet about one-half of the standards required for Salt Lake City buildings. The average death rate was roughly 40 deaths per building, or 480 deaths, at earthquake forces possibly equal to those expected at maximum conditions in Salt Lake City.

Deaths from unanchored parapets and building appendages must be added to deaths from the collapse of buildings to determine the total estimated deaths in a congested area. One death per unbraced building was considered to be a reasonable upper limit for planning purposes.

Last, the figures in table 42 for 2:00 p.m. include special factors such as freeway collapse, high-rise building fires, school and hospital collapses, and similar items not covered by the death-ratio figures.

Daytime casualties (4:30 p.m.)

The deaths at 4:30 p.m. will be similar in number to those at 2:00 p.m., except that many of the persons who were in offices and in other places of employment will now be on the streets. The total population in the congested areas at 4:30 p.m. may be substantially less than that at 2:00 p.m.; however, the street population will be greater, resulting in increased possibility of casualties from parapet and appendage hazard and from freeway collapse. One mitigating factor on overall casualties is the fact that schools are generally closed before 4:30 p.m., and most children have returned to single-unit dwellings. In Salt Lake City hospitals, casualties were found to be lower at 4:30 p.m., because many employees had returned home.

Dams

Dams in many parts of the world have failed during earthquakes. In the United States, the earthen Sheffield Dam failed in the 1925 Santa Barbara earthquake. The earthen Hebgen Lake Dam was damaged but remained serviceable after the August 17, 1959, Montana earthquake, despite its being overtopped several times and there being a major fault scarp less than 1,000 feet (305 m) from the spillway. The partial failure of the Lower San Fernando Dam in the 1971 San Fernando earthquake required the evacuation of 80,000 downstream inhabitants.

On the other hand, several dams performed quite well in the 1906 San Francisco earthquake. The 95-foot (29-m)-high Pilarcitos Dam, located less than 2 miles (3.2 km) from the San Andreas fault, was constructed in 1864-66 and has an earthen puddle core; it was not damaged. In 1906, a 7-foot (2-m) right-lateral offset on the San Andreas fault went through a knoll that formed an abutment for the two sections of the San Andreas Dam. This 93-foot (28-m)-high earthen-puddle-core dam, constructed in 1868-70, was uninjured. The Lower Crystal Spring Dam is a concrete dam and is located within a few hundred feet of the 1906 fault breakage; it survived the 1906 earthquake without injury.

The near-catastrophic failure of the Lower San Fernando Dam in the 1971 San Fernando earthquake has resulted in a complete review by the State of California of the earthquake-design criteria for dams and in the upgrading of these criteria where necessary. Certain suspect type of dams, such as older, earthfill dams, are being given special study, and corrective work is currently in progress on some of these earthen dams.

An excellent summary of the problems relating to dam adequacy is given in the report of the Earthquake Task Force "B" to the Los Angeles County Board of Supervisors, as follows:

> "The San Fernando earthquake of February 9, 1971, demonstrated that ground accelerations can occur which are significantly higher than most engineers, seismologists or geologists would have anticipated and which are considerably in excess of those customarily used for the design of dams... (p.4)
>
> "The term 'modern standards of safety' merits special attention because of the impact of the February

9, 1971 earthquake. The principles which were almost universally accepted for establishing seismic safety of dams prior to the earthquake have now been demonstrated to be largely inadequate, and new principles must now be established. (p. 5)

"The next step will be the identification of those dams which do not satisfy these newly emerging principles. This can be done only by individual study of each dam. While it is possible to identify types of dams which should be given first priority in analyses, detailed case-by-case engineering investigations are needed to provide reliable results. Such investigations will not be simple; the present methods of analysis have now been demonstrated to be nonrepresentative and thus undependable..." (p.5)

Data collection

A complete list of all dams of 50 acre-feet and greater capacity within the four-county study area was obtained from an "Inventory of Dams in the United States," prepared by the U.S. Army Corps of Engineers, Sacramento District. This inventory gives pertinent design and capacity data.

Information relating to dams owned by the Bureau of Reclamation, U.S. Department of the Interior, was obtained from the Region-4 office in Salt Lake City. Copies of the following reports were made available: Weber Basin Project, Ogden River Project, and Provo River Project. A list of Weber Basin reservoirs was also provided.

Design details of the Mountain Dell Dam near Salt Lake City was obtained from the Salt Lake City Water Department.

U.S. Geological Survey maps showing all dams in the study area were used as a basis for inundation maps approximating areas of damaging flow and flooding flow which might result from the sudden failure of three critical dams; they were prepared for the planning purposes of this report.

Analysis

About 18 dams exist in or near the four-county study area. Many of these dams are small, and their failures as a result of an earthquake would not be catastrophic.

A list of nine major dams that affect the study area is given in table 43. This table also gives other important information relating to the construction and capacity of each dam. These dams are plotted on figure 41.

Three of these dams were selected for special study and assumed failure for planning purposes. They are Pineview Dam, Echo Dam, and Deer Creek Dam. These particular dams were selected because of their large reservoir capacities, types of construction, dates of construction, and large downstream populations.

All three dams were built between 1930-41 and are of earthfill construction. Dams this old or older and of earthfill construction are suspect during an earthquake. The Lower San Fernando Dam, which partially failed in the 1971 earthquake, was an earthfill dam built around 1915 using the hydraulic-fill method of construction. This method involves sluicing earth and rock from the reservoir bottom and nearby hills into a pond in the dam area and draining off the excess water. In contrast, modern practice calls for careful placing of all earth materials in lifts by rolled compaction under conditions of controlled moisture content and density. All of the earthfill dams listed in table 43, including the three selected for study, have been constructed using rolled compaction methods rather than hydraulic-fill methods.

Life loss and homeless--The number of important dams is small compared to the number of buildings in the study area. However, the rapid failure of any one of the larger dams would lead to catastrophic results to the downstream population. One possible conservative approach is to assume failure of all dams having even a small element of suspicion and to assume that the failure would occur in a catastrophic manner. ("Failure in a catastrophic manner" means in a very rapid and almost instantaneous manner, thereby not allowing downstream evacuation.) Using these extreme but credible assumptions, it can be assumed for planning purposes that a magnitude-7.5 shock on the Wasatch fault could result in the failures of six or more dams. A magnitude-7.5 shock on the Magna fault would be less critical, due to its location at a greater distance from all of the dams in the study area. However, for the purposes of this report, both events should be considered as possible causes of dam failure and, in keeping with the somewhat greater hazard

Table 43.--Major dams affecting the study area having a capacity greater than 3,000 acre feet

[Source: U.S. Army Corps of Engineers; Bureau of Reclamation, U.S. Department of the Interior; Salt Lake City Water Department]

Dam	Counties affected	Type of dam	Year built	Capacity (acre feet)2/	Height (ft.) above stream 3/
Pineview	Weber	earthfill	1937	116,000	89
Causey	Weber	earthfill	1966	8,730	193
Echo	Weber Davis	earthfill	1931	73,900	110
Wanship	Weber Davis	earthfill	1957	62,120	156
Lost Creek	Weber Davis	earthfill	1966	22,510	187
East Canyon	Weber Davis	concrete arch	1966	58,400	195
Mountain Dell1/	Salt Lake	concrete multi-arch	1916	3,224	140
Deer Creek	Utah	earthfill	1941	161,000	150
Mona	Utah	earthfill	1895	21,000	31

1/Design details from the Salt Lake City Water Department.

2/Acre feet x 1233.6 = meters ^{3}

3/Feet x 0.3048 = meters

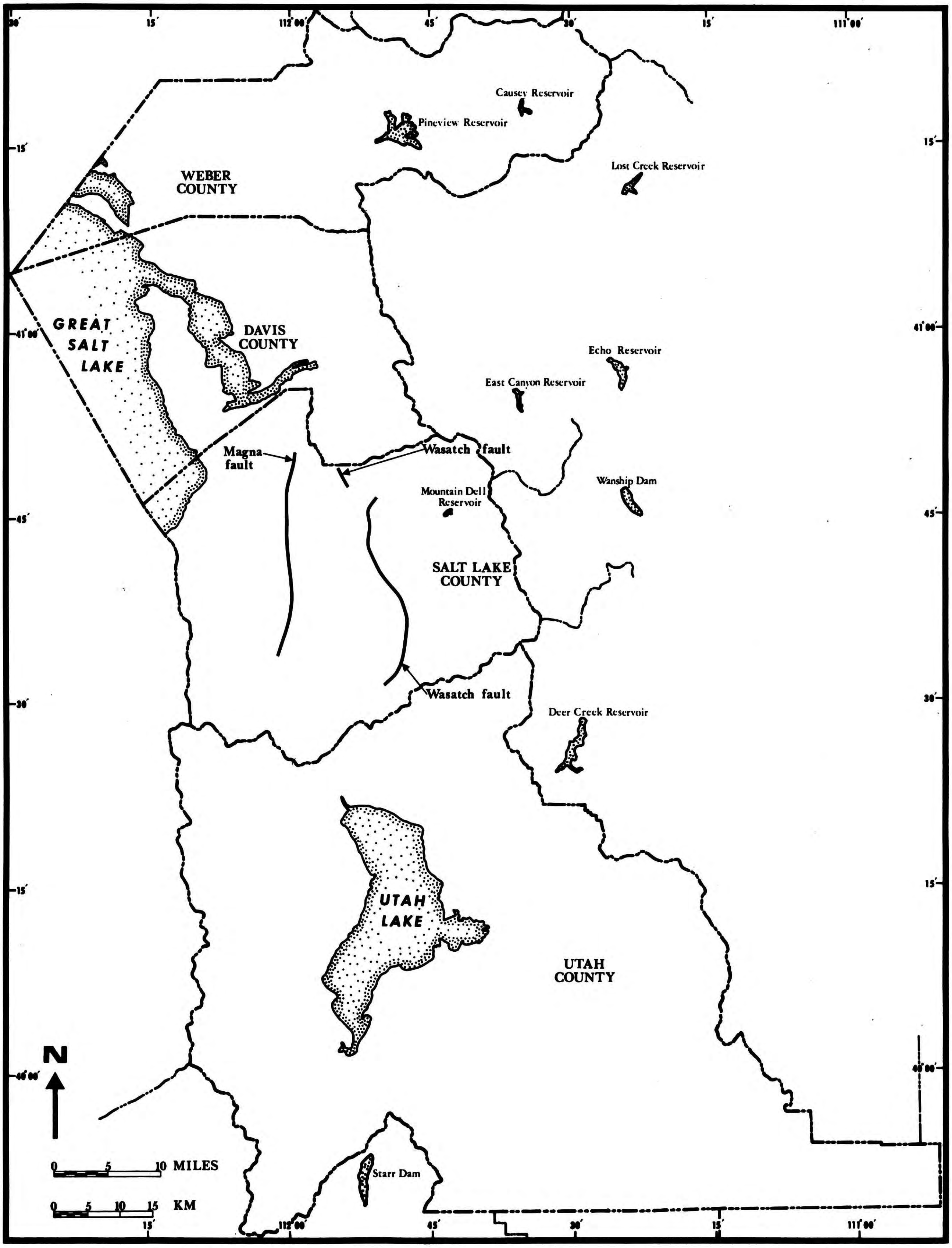

Figure 41.--Major dams and reservoirs with capacities greater than 3,000 acre-feet. (Shown fault breakage is assumed for planning purposes.)

from older, earthfill dams, only the three dams already listed will be considered as being able to fail in a catastrophic, or near catastrophic, manner.

The number of probable deaths and homeless victims from sudden failure of each of the three dams selected for this study have been listed in table 44.

Table 44.--Deaths and homeless from dam failure

Dam	Deaths	Homeless	Location of homeless/deaths
Deer Creek	11,900	14,800	Orem and Provo
Echo	2,900	1,000	Ogden, So. Weber
Pineview	8,000	7,200	Ogden

All of the foregoing figures represent the worst conditions, which, for planning purposes, assume total sudden failure of the listed dams. The estimated numbers of deaths are based on generalized assumptions regarding inundation areas.

Assumed failure for planning purposes--In the event of a 7.5-magnitude shock on either the Wasatch or Magna faults, the possible failure of one of the three dams listed in table 44 should be anticipated. It should be noted that dam failure for any one of these three dams is postulated on the basis of ground shaking and not as a result of surface faulting where the ground rupture would pass through the dam itself.

Homeless

Data collection

The principal sources of data on population statistics, dwelling information, urbanized data, poor soil, and possible landslide areas were found in the following documents for the four-county study area:

1. "Block Statistics, Ogden, Utah Urbanized Area," HC(3)-250, 1970, U.S. Bureau of Census.
2. "Block Statistics, Provo-Orem, Utah Urbanized Area," HC(3)-251, 1970, U.S. Bureau of Census.
3. "Block Statistics, Salt Lake City, Utah Urbanized Area," HC(3)-252, 1970, U.S. Bureau of Census.
4. "Detailed Housing Characteristics," HC(1)B46, 1972, U.S. Bureau of Census.
5. U.S. Department of Agriculture, Soil Conservation Service Soil Survey, Weber-Davis Area, Utah, July, 1968; Salt Lake Area, April 1974; Utah County, January 1972.

The following information was obtained when available: single-family-dwelling units, multiple-dwelling units, densely populated areas, population by county, location of poor-soil areas, and location of possible landslide areas.

The urban regions in the four-county study area are shown in figure 42.

Analysis

Data on the past performance of single-family wood-frame dwellings in earthquakes are summarized in an ESSA (Environmental Science Services Administration) report to HUD (Housing and Urban Development, 1969). In addition, a detailed study on dwelling performance in the 1971 San Fernando shock is available (Steinbrugge and others, 1971). These sources identify the dollar losses to wood-frame dwellings but do not state at what damage level the houses were evacuated. Indeed, there probably was no consistent practice in this regard; in some earthquakes, social needs were sometimes confused with safety requirements when it came to building condemnations. For the purposes of this report, wood-frame dwellings suffering 50 percent or greater loss are considered to be

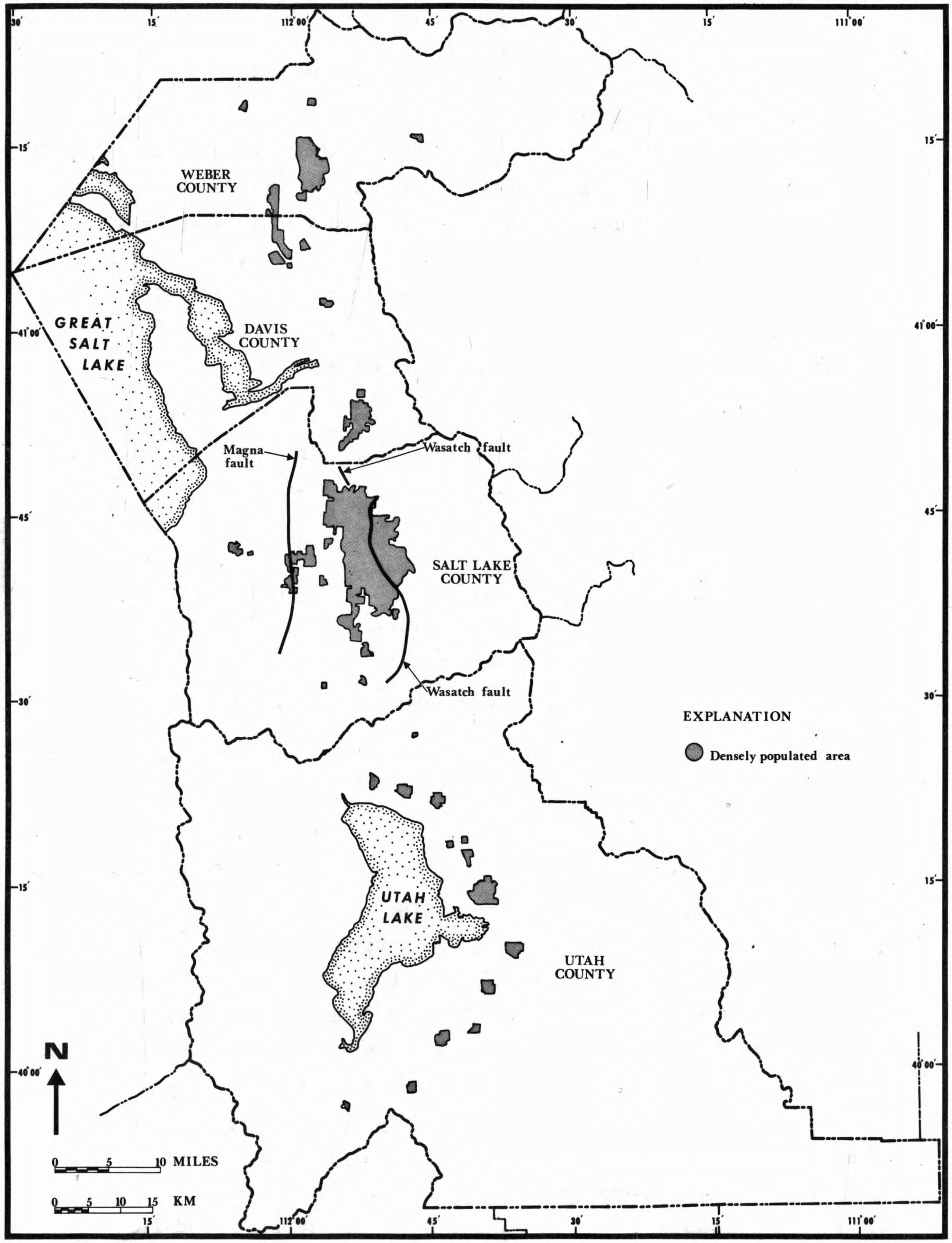

Figure 42.--Densely populated areas. (Shown fault breakage is assumed for planning purposes.)

uninhabitable, as the utilities are usually inoperative, doors will not open or close, and the buildings often have substantial structural damage. On this basis, the backup data used from the detailed study of the San Fernando earthquake may be summarized as follows:

1. For pre-1940 dwellings in MMI-IX zones, 2 percent of the wood-frame dwellings had 50 percent loss or more; and

2. For post-1940 dwellings in MMI-IX zones, 0.3 percent of the wood-frame dwellings had 50 percent loss or greater. In the 1933 Long Beach earthquake, 1 percent of the wood-frame dwellings in the city of Compton had 50 percent loss or greater.

It is estimated that slightly over 50 percent of single-family houses in the four-county study area are of solid-masonry-wall construction. This includes most older houses which used either two or more courses of brick or a combination of cinder block and brick with sand-lime mortar and with no steel reinforcing. Floors and roofs were constructed with wood joists that were not anchored to the walls. Newer construction (after 1950) used hollow-concrete block walls with some steel reinforcing in grouted cells and brick veneer.

During the past 10 years about 90 percent of new houses in the study area have been built using a wood frame with brick veneer. Floors and roofs have plywood sheathing on wood joists and some form of anchorage to the walls has been provided.

This newer wood-frame construction has probably been designed to resist at least moderate (zone 2) earthquake forces inasmuch as the UBC (Uniform Building Code) has required design for these forces in the study area beginning in 1961. The 1970 edition of the UBC required design for strong (zone 3) earthquake forces in the study area. Most cities and counties in Utah have adopted the UBC and require that buildings be constructed according to its provisions.

Past earthquake experience has shown that single-family houses built with unreinforced masonry walls have suffered more structural damage from the effects of an earthquake than have houses with the lighter, more flexible wood-frame construction. This is particularly true of older masonry buildings where sand-lime mortar was used and where there has been no attempt to anchor the floors and roof to the walls.

The data on numbers of homeless for the 1971 San Fernando earthquake and for the Long Beach earthquake provide a reasonable basis for determining numbers of homeless in the Salt Lake study area for Mercalli Intensity IX. However, the percentage of homeless to total population in the Salt Lake study area may be somewhat greater than that in Southern California because of the relatively larger number of solid-masonry-wall houses in Utah. This fact has been applied in the methodology for the Salt Lake study.

In San Fernando a portion of the damage to structures was related to surface rupture. This would also be true for damage to structures in the Salt Lake study area because for planning purposes, a zone of deformation due to surface faulting has been assumed to extend one-quarter mile (0.40 km) in width for the length of both the Wasatch and Magna faults, as shown on the various maps in this report.

Multiple-unit dwellings, such as apartment houses, vary in kind of construction materials, often depending upon location within a fire zone. Construction also varies by occupancy and building type, as defined by respective municipal agencies. Multiple-unit structures located in the high density, urbanized sections are often multistory and are constructed of heavier mass materials than wood frame. On the other hand, wood-frame multiple units are more common elsewhere, in the areas characterized as lower density zones (both urban and suburban). This follows from building code provisions that commonly limit wood-frame construction to three stories in height; any structure having a greater number of stories may generally be classified as having a structural system of heavy timber, masonry, concrete, or steel. Multiple-unit structures constitute an average of 10 percent of dwelling units in the four-county study area.

Communities in the Salt Lake study area lack large areas of high-density, high-rise multiple-unit dwellings. However, they have an increasing proportion of wood-frame multiple units, many built as speculative ventures, with limited quality control in construction.

The season of year would have an effect on the homeless population. This was previously discussed in the "Introduction" to this report.

Freezing and subfreezing temperatures can be expected in the four-county study area during the months of November through March. These low temperatures have been known to continue for many days and even for periods of one or two weeks. Daytime temperatures may rise to values above freezing but nighttime temperatures drop again to below freezing. During this period, the loss of natural gas and electric power for heating would result in difficult living conditions for most people and impossible conditions for some (very young, aged, ill and so forth). Following the San Fernando earthquake of 1971 some families were forced to evacuate structurally unsafe homes. This event occurred on February 9, and rather than leave their home and relocate in a temporary shelter, many people preferred to camp in their back yards. This was possible because of the mild winter climate in Southern California. It would normally be impossible to do the same in the Salt Lake City area in February. Even if a home were not damaged but lacked electric power and natural gas it could be uninhabitable for people who were not prepared with warm clothing and coal or wood for use in a functioning fireplace. Electric power and natural gas outages could be widespread following an earthquake (see "Public Utilities") not only from damage to main lines but from damage to individual customer lines where they enter the house. It might take several weeks to repair and reconnect all such broken lines in a large populated area such as Ogden, Salt Lake City, or Provo.

The percent homeless to total population in the Salt Lake study area could therefore be far greater than that in Southern California following a destructive earthquake in the winter. The percent homeless to total population would be about the same for Utah and California during the summer months except for the increase in homeless percentages in the Salt Lake City area because of masonry house construction.

Another planning factor that was also mentioned in the "Introduction" is the isolation of the four-county study area when compared to Los Angeles or San Francisco where large populated communities with great resources are in close proximity to these cities and could house and feed a homeless population. The closest large city to the Salt Lake study area is Denver, Colo. located 400 miles away. Homeless people would be forced to remain in the area and rely on housing resources within the area.

The availability of housing facilities at Hill Air Force Base might offer a temporary solution to the problem of caring for a homeless population. See the discussion of Hill AFB under "Federal Buildings" in the "Public Structures" section of the report.

For planning purposes the numbers of homeless people listed in table 45 should be doubled if one of the postulated earthquake events occurs in the winter.

The calculations used to derive the values shown in table 45 include the comparative numbers of single-family dwellings and multi-unit structures of various construction types. The geologic hazards of landslide and poor-ground conditions were included as factors in the analysis. Extensive areas of steep sidehills, where many houses have been built during the past 10 years, create much landslide potential. These factors have not affected large numbers of homes or people in the past but have become more of an exposure element with population growth in the study area.

"Long-term homeless" is defined as being homeless for one week or longer. Long-term homeless also includes families remaining on the premises (indoors or out), but with loss of public utilities and (or) building damage to make the structures uninhabitable under nonemergency conditions.

For numbers of homeless from dam failure, see the previous section, "Dam Failure," in this report.

Magnitude 7.5 on the Wasatch fault--expected damage patterns.--Referring to table 45,it can be seen that numbers of homeless due to vibration damage is the same for both postulated events. This is because intensities in the heavily populated areas are approximately the same for both events. The Wasatch fault event would result in a larger number of total homeless than would the Magna fault event for two reasons: first, the postulated surface rupture results in a zone of deformation

Table 45.--Long-term homeless resulting from postulated earthquake disaster, exclusive of losses from dam failure or fire

Wasatch fault, magnitude = 7.5

Homeless population

County	Vibrations	Geologic hazards				Total
		land- slides +	poor soil +	fault zone	= total	
Weber-------------	1,134	(114 +	95 +	0)	= 209	1,343
Davis-------------	2,410	(225 +	76 +	0)	= 301	2,711
Salt Lake---------	13,456	(1,500 +	1,035 +	6,000)	= 8,535	22,000
Utah--------------	2,705	(678 +	132 +	0)	= 810	3,515
Totals----------	19,714	(2,517 +	1,338 +	6,000)	= 9,855	29,569

Magna fault, magnitude = 7.5

Homeless population

County	Vibrations	Geologic hazards				Total
		land- slides +	poor soil +	fault zone	= total	
Weber-------------	1,134	(114 +	95 +	0)	= 209	1,343
Davis-------------	2,410	(225 +	76 +	0)	= 301	2,711
Salt Lake---------	13,465	(1,130 +	1,380 +	2,000)	= 4,510	17,975
Utah--------------	2,705	(678 +	132 +	0)	= 810	3,515
Totals----------	19,714	2,147 +	1,683 +	2,000)	= 5,830	25,544

due to faulting that covers an area in Salt Lake County of 2.84 square miles (7.4 km^2). This zone occurs in heavily populated (24,000 people) residential areas. If one-fourth of this population were forced to evacuate their homes, this would result in 6,000 homeless. Second, the location of the postulated Wasatch fault rupture is near the foothills in the north and east residential areas of Salt Lake County, and many new houses have been built on the hillsides. This creates a potential for damage to these houses from earthquake-induced landslides. For example, the Olympus Cove development in Salt Lake County is situated directly beneath the granite face of Mount Olympus, which is nearly 10,000 feet (3,048 m) in elevation. Approximately 6,000 people live in this development. An additional 3,500 people live in housing developments along the base of the steep Wasatch Range between Parleys Canyon and Draper. The estimated number of homeless from landslides caused by the postulated Wasatch fault event could be as high as 1,500 people in Salt Lake County. The majority of housing developments in the other three counties are also closer to the foothills than they are to the poor-soil areas near the center of the valley. As a result, homeless related to landslides exceeds homeless related to poor-soil areas by nearly 1,200 people.

Magnitude 7.5 on the Magna fault--expected damage patterns.--Whereas the Wasatch fault event affects a relatively large population because of surface faulting and landslides, the Magna fault event could produce a homeless population of 1,380 due to poor-soil effects in Salt Lake County. This number of homeless is greater than the homeless population resulting from landslides caused by the Magna event. The postulated surface rupture associated with the Magna fault occurs in the west part of the Salt Lake Valley, where there is considerable swampland and alkaline flatlands. Most of the west valley areas in the other three counties are sparsely populated and contain large poor-soil areas. The postulated fault rupture extends through the community of Kearns in Salt Lake County, affecting about 17,000 people. Eight thousand would be located in the zone of deformation due to faulting, and about 2,000 could be homeless.

SECTION 6: EFFECTS ON VITAL PUBLIC NEEDS

The basis for selecting certain subject areas for damage analysis in this section was outlined in the "Introduction" on page 5 . Once the immediate needs of medical treatment, shelter from the elements, and water for human consumption and fire fighting are met, attention will focus on restoration of areas that affect the public safety and welfare. These would include certain vital government services housed in public structures, communication and transportation systems, essential public utilities, food supply, and debris removal. School buildings could be used to temporarily house and feed the homeless population. The subject of fire following an earthquake is considered in this section because it is a potential danger to be faced during the period immediately following the earthquake, and possibly during a period of several days after the event.

Public structures

Data collection

For the purpose of this study, public structures are defined as those buildings under jurisdiction of government at one of four levels: municipal, county, state, or federal. Only public buildings in the four-county study area that are considered vital after an earthquake are covered in this study; these buildings house administration centers, communication centers, law enforcement facilities, fire stations, and major repair and storage facilities. Wherever possible, the following data were collected: location, year built, type of construction, number of stories, type of facility, soils condition, area or size(ft.^{2}), type of materials, foundation type, emergency power facilities, occupancy capacity. The following sources provided the described data on municipally owned buildings in the four-county study area:

1. Cities of Ogden, Bountiful, Salt Lake, Orem, and Provo.	Lists of city buildings, including police and fire departments, with some construction information.
2. Emergency services for counties of Weber, Davis, Salt Lake, and Utah.	Lists of police and fire stations for all cities in study area.

3.	Insurance Services Office of Utah	Copies of fire rate survey sheets giving construction data.
4.	U.S. Army Corps of Engineers Civil Defense Support	Copies of DCPA "All Effects Data Collection Forms," giving construction data for Weber County.

Figure 43 shows locations of municipally owned fire stations and police stations for all cities in the four-county study area. This figure also shows locations of administration buildings and major repair and storage buildings owned by the cities of Ogden, Bountiful, Salt Lake, Orem, and Provo. Table 46 is a summary of municipally owned buildings covered in this report.

Each of the four counties provided lists of county-owned and county-leased facilities. Construction information was obtained from the counties, from Insurance Services Office of Utah, and from U.S. Army Corps of Engineers Civil Defense Support. Figure 44 shows locations of major administration facilities, sheriffs' offices, emergency services, fire stations, and major repair and storage facilities. Table 47 summarizes the number of county-owned buildings covered in this report.

Information on state-owned and state-leased buildings in the four-county area was obtained from the Utah State Building Board, Salt Lake City. Construction data were also obtained from the Insurances Services Office of Utah. Figure 45 shows the location of major state buildings in the four-county study area, and table 48 gives the number of major administration buildings, state highway patrol buildings, and national guard armories.

Information on federally owned buildings was made available through the Salt Lake City office of the General Services Administration. Construction information and other detailed material were obtained from the "Building Description Report" of various dates from January 1, 1973, to September 30, 1974. An on-site inspection of Hill Air Force Base was conducted in order to determine which buildings might remain functional as a resource and might therefore, be used to temporarily house and feed a homeless population from the study area following a major earthquake. Information on post office buildings in the four-county study area was furnished by the Salt Lake City District Office of the U.S. Postal Service on the buildings under its jurisdiction. Figure 46 shows the location of the federal and the major U.S.

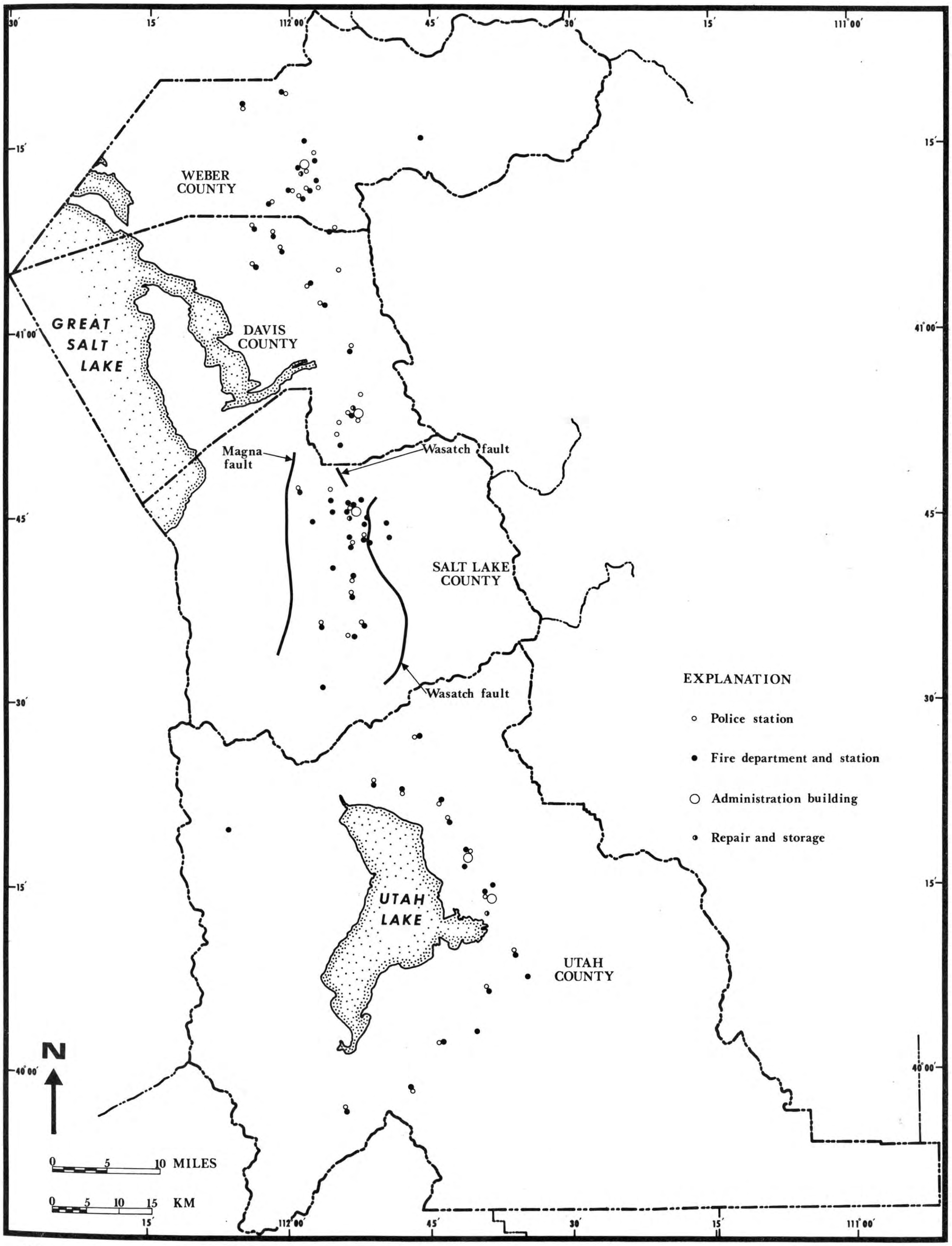

Figure 43.--Municipal buildings of vital public need. (One dot may represent more than one facility. Shown fault breakage is assumed for planning purposes.)

Table 46.--Essential city buildings

City	County	Administration buildings	Major repair and storage	Police buildings	Fire stations
Ogden --------------	Weber	2	1	1	5
Other cities -------	--do--	[1] -	-	8	6
Bountiful ---------	Davis	2	1	1	1
Other cities -------	--do--	-	-	12	9
Salt Lake ----------	Salt Lake	3	2	3	14
Other cities -------	--do--	-	-	7	9
Provo-Orem ---------	Utah	6	1	2	4
Other cities -------	--do--	-	-	9	13
Totals		13	5	43	61

[1] Administration and major repair and storage buildings were tabulated only for the cities of Ogden, Bountiful, Salt Lake, and Provo-Orem. The - symbol indicates information not tabulated.

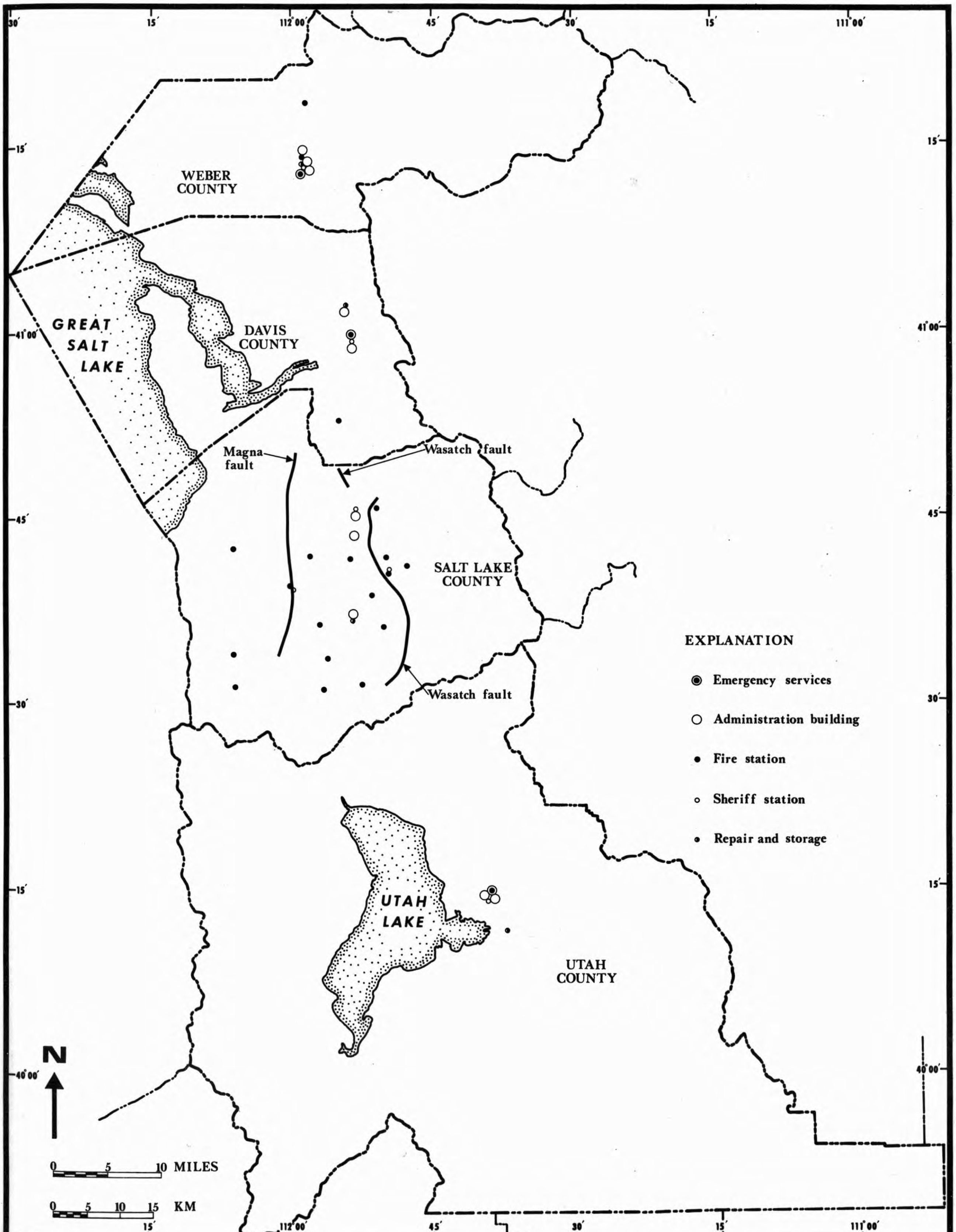

Figure 44.--County buildings of vital public need. (One dot may represent more than one facility. Shown fault breakage is assumed for planning purposes.)

Table 47.--Essential county buildings

County	Administration buildings	Sheriffs' buildings	Emergency services	Fire stations	Major repair and storage
Weber	3	1	1	2	1
Davis	2	1	1	1	1
Salt Lake	5	3	1	15	1
Utah	2	1	1	0	1
Totals	12	6	4	18	4

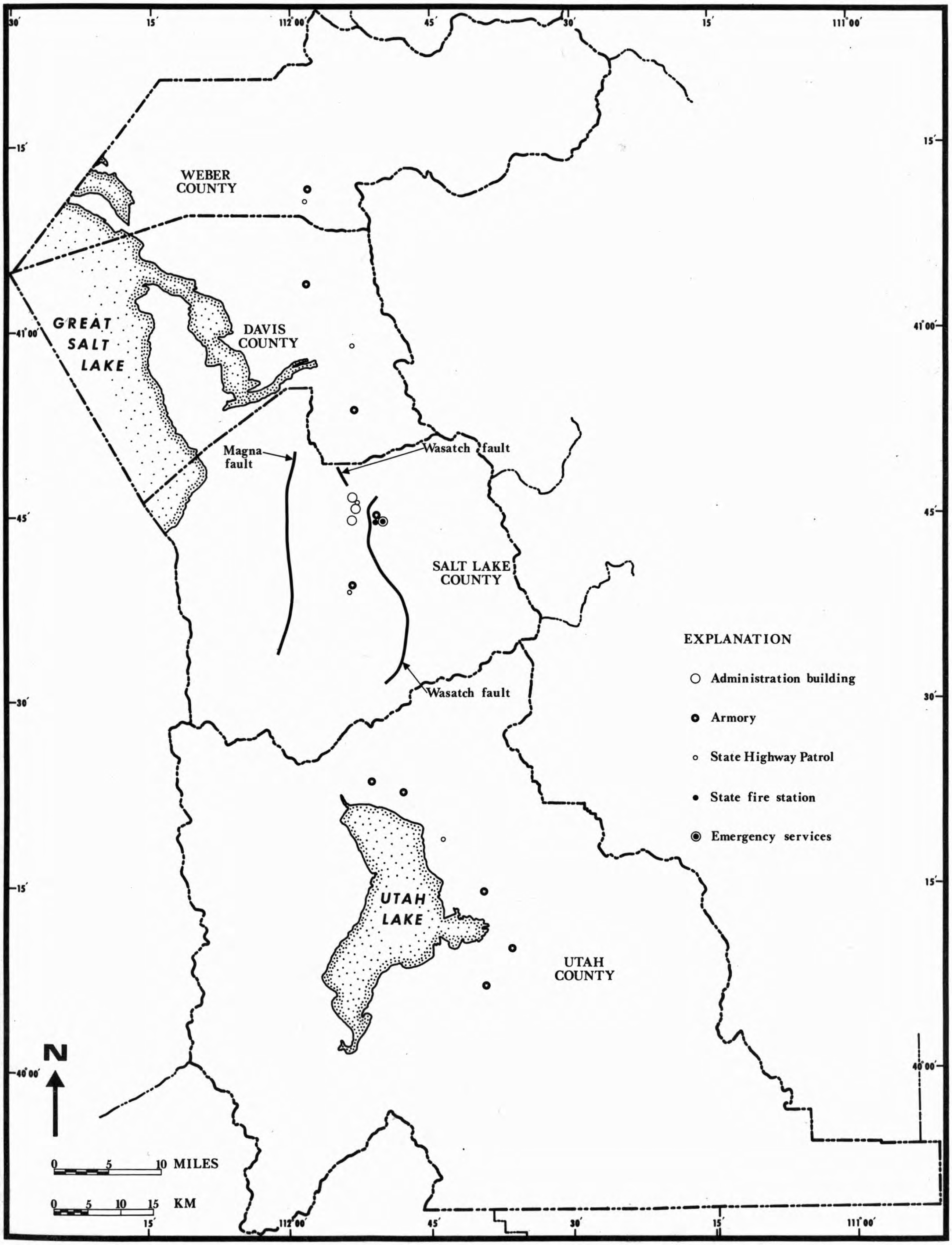

Figure 45.--State buildings of vital public need. (One dot may represent more than one facility. Shown fault breakage is assumed for planning purposes.)

Table 48.--Distribution of essential state buildings

County	Administration	Highway Patrol	National Guard armories
Weber	0	1	1
Davis	0	1	2
Salt Lake	1/ 9	2	4
Utah	0	1	5
Totals	9	5	12

1/Includes State Office of Emergency Services

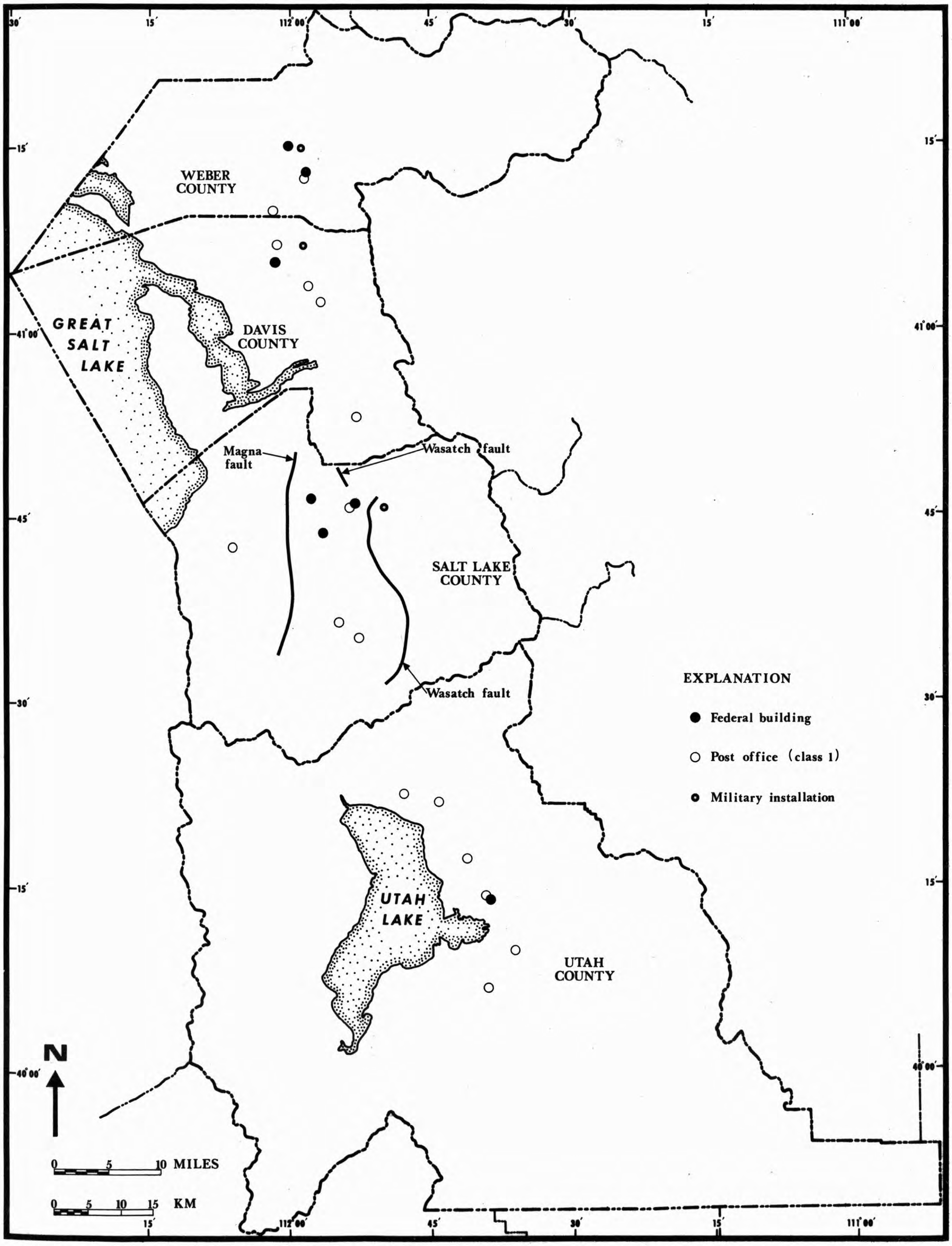

Figure 46.--Federal buildings of vital public need. (One dot may represent more than one facility. Shown fault breakage is assumed for planning purposes.)

Postal Service buildings (Class 1), while table 49 gives this information in tabular form.

Analysis

General

Most of these facilities are operated by personnel who are trained to function in emergencies. However, severe building damage and collapse could render a facility unusable; failures of communication systems due to power failure and overloading could seriously hamper operations. In addition, emergency functions could be significantly affected by personnel being unable to get to work due to blocked streets and crippled public transportation; by personnel casualties; by lack of electrical power and water; and by lack of mobility due to blocked streets and freeways.

Some of these facilities have emergency electrical generators; however, experience in California has shown that many of these generators will be out of service due to inadequate anchorage of equipment and batteries and to damaged fuel supplies.

A problem peculiar to fire stations is the jamming of the large doors due to racking of the structure. This problem can be expected even in one- and two-story wood-frame stations, which usually suffer little earthquake damage. Power-operated doors will have to be opened manually when electrical power fails.

In recent years, high-rise construction has generated considerable public concern regarding its collapse potential in earthquakes, which is significant inasmuch as some public buildings fit into this high-rise category. However, a review of the experience in the 1906 San Francisco earthquake, discussed in Section 3 of this report, shows that of the 17 multistory steel-frame structures in existence in 1906 none collapsed, and where damage occurred, it was repairable. In the February 9, 1971, San Fernando earthquake, several multistory reinforced concrete buildings in the hardest hit area were severely damaged, and one partially collapsed. High-rise buildings in the downtown Los Angeles area did not suffer significant structural damage, but the older ones had considerable nonstructural damage. It should be noted that the estimated intensity in the downtown Los Angeles area was only about VII. Over 800 elevators

Table 49.--Major federal and U.S. post office buildings and(or) facilities

County	Federal building/facility	Post offices (class 1)
Weber	[1] 4	2
Davis	[2] 2	4
Salt Lake	[3] 5	4
Utah	2	6
Totals	13	16

[1] Includes the Defense Depot, Ogden, with many buildings.

[2] Includes the Clearfield Depot and Hill Air Force Base. Both have many buildings.

[3] The FAA building at the Salt Lake Municipal Airport is equipped with emergency electrical power.

were rendered inoperable as a result of the February 9, 1971, earthquake.

The following sections discuss buildings in the following order: city, county, state, federal, and post offices. Following post offices, table 61 lists, by county, those public buildings that should have been designed to resist at least some degree of earthquake forces (built after 1961), and which for planning purposes, will survive and could be used for emergency operations. The locations are plotted on figure 47.

City buildings

Because earthquake-related problems are generally more severe in the larger cities, this discussion is limited primarily to the five cities of Ogden, Bountiful, Salt Lake, Provo, and Orem. Police and fire stations in the other cities are usually located in small, one-story buildings, which are similar to substations in the five larger cities. In the four-county study area, major police departments and the communication centers for their operations are housed either in a municipal administration building or in a combined city-county administration building. Thus, the communication centers serve both the police and the administrators responding to disaster. Limited data were obtained on emergency electrical generators in city buildings, but it is known that the Metropolitan Hall of Justice in Salt Lake City has emergency power and that most police and fire stations have battery-, gasoline-, or diesel-powered generators for emergency use. Also, most police and fire vehicles have mobile radios that are not dependent on commercial electrical power.

The City and County Building in Salt Lake City is highly vulnerable to earthquakes owing to its age and type of construction. Some strengthening of the structure is being done in conjunction with restoration, but serious damage or partial collapse is likely in a strong-intensity earthquake. Another large city administration building in the same area was designed for earthquakes of moderate intensity (earthquake zone 2). Serious nonstructural damage can be expected in multistory portions of the complex in the event of a strong-intensity earthquake, but chances of collapse are remote.

The city buildings in Bountiful were built after 1960 and should have been designed for moderate earthquake forces. However, in the event of a strong earthquake in Salt Lake City, these buildings could be severely damaged.

The city administration offices in Ogden are housed in older, non-earthquake-resistant structures; the Provo and Orem city offices are located in newer buildings designed for earthquakes. The earthquake intensity is not expected to be as great in either Ogden or Provo if the epicenter occurs in Salt Lake City, so the threat of damage to city offices is not as serious in these two cities. For all of the cities that were studied, police stations (not located in the administration buildings) and fire stations are usually housed in small one-story buildings, of wood frame or block construction, and are inherently quite earthquake resistant. However, most of these buildings were designed for only moderate earthquakes. Repair and storage facilities were found to be located in larger one-story buildings, which are less earthquake resistant.

Table 50 shows the number of city-owned buildings built prior to 1961, before earthquake design was required; the number built between 1961 and 1969, designed for moderate earthquake forces; and the number built in 1970 and later, designed to be earthquake resistant. About 20 percent of administration buildings and 30 percent of police and fire stations were constructed in 1970 and later, when buildings were required to be designed for strong earthquake forces. About one-half of the city buildings were constructed between 1961 and 1969 and were designed to resist only moderate earthquake forces (zone 2). There could be 50-60 percent nonfunctional buildings of this era from a strong-intensity earthquake and for planning purposes, at least one collapse.

Magnitude 7.5 on the Wasatch fault--expected damage patterns.--Referring to tables 50 and 51, most of the functional losses to city facilities can be attributed to buildings built prior to 1961. Losses are not as high in Weber and Utah Counties, because of their distance from the postulated epicenters.

Functional losses in city fire stations will be high in Salt Lake and Davis Counties owing to the large proportion of masonry structures in high-intensity zones. Most of these buildings were only designed for moderate earthquake forces (zone 2). This, combined with the rupture

Table 50.--Construction dates of city buildings

[Dates furnished by respective cities and by insurance rating forms. NA, date of construction not available]

City	Administration			Police			Fire			Repair-Storage		
	Pre-1961	61-69	70-75	Pre-1961	61-69	70-75	Pre-1961	61-69	70-75	Pre-1961	61-69	70-75
Ogden ---------	[1] 2	0	0	1	0	0	1	3	NA	0	1	0
Bountiful------	1	1	0	0	1	0	0	1	0	0	1	0
Salt Lake------	[2] 1	2	0	NA	2	NA	1	2	3	NA	NA	NA
Provo-Orem-----	1	NA	2	0	0	2	1	2	1	0	1	0
Totals----	5	3	2	1	3	2	3	8	4	0	3	0

[1] City and county building built in 1935; annex building built in 1922.

[2] City and county building built in 1894.

Table 51.--City buildings nonfunctioning due to earthquake damage

Wasatch fault, magnitude = 7.5 or Magna fault, magnitude = 7.5

City	Administration buildings		Major repair and storage facilities		[1]County	Police stations		Fire stations	
	Number	Percent of total	Number	Percent of total		Number	Percent of total	Number	Percent of total
Ogden----------	1	45	1	60	Weber	4	45	4	35
Bountiful------	2	90	0	20	Davis	8	60	6	55
Salt Lake------	2	66	1	50	Salt Lake	6	55	14	60
Provo-Orem----	2	35	0	20	Utah	7	60	9	55
Totals---	7		2			25		33	

[1]Includes city-owned police and fire stations for all cities in the four-county study area.

of waterlines that cross the fault, will gravely hamper fire-fighting efforts west of the fault after an earthquake.

The fire station in the Sugarhouse area of Salt Lake City is within the zone of deformation due to the postulated surface fault rupture and should be considered nonfunctional for planning purposes. Structural data were available for main police stations located in major administration buildings in the five cities. For the sub-stations in these cities and for police stations in the smaller cities, these data were generally not available; but it has been assumed in table 50 that building construction of police stations is similar to that of fire stations, and construction information on the major city fire stations was available.

As was discussed previously, impairment of administration facilities in the four-county study area will be largely due to the presence of old non-earthquake-resistant buildings.

For planning purposes, impaired use is expected to last for at least 1 month for 50 percent of the nonfunctional buildings listed in table 51. In winter, this impairment could last for 45 to 60 days, depending on damage to the heating plant and to windows in the buildings.

Magnitude 7.5 on the Magna fault--expected damage patterns.--Damage patterns are expected to be similar, with two exceptions: First, serious disruption of city water supplies is not likely to occur, because major water-supply lines providing water for Salt Lake City do not cross the Magna fault. Second, city buildings at the Salt Lake Airport (police, fire, control tower, airport administration, and so forth) are about one mile (1.60 km) from the postulated Magna fault. The predominant soil at the airport is poorly drained clay with alternating layers of silt and sand. Ground water is within 2 feet (0.61 m) of the surface. Many structures are built on compacted fill. The terminal buildings have pile foundations. Earthquake experience in California for buildings constructed in similar poor-soil areas has shown that high amplification of ground motion occurs during an earthquake, resulting in severe damage to even new, well-designed structures.

County buildings

Construction data were obtained for some of the county buildings listed in table 52. Weber, Salt Lake, and Utah Counties share some

Table 52.--Construction dates of county buildings

[NA, date of construction not available]

County	Administration			Sheriff			Emergency service			Fire stations			Repair-storage		
	Pre-1961	61-69	70-75	Pre-1961	61-69	70-75	Pre-1961	61-69	70-75	Pre-1961	61-69	70-75	Pre-1961	61-69	70-75
Weber---------	[2] 2	NA	NA	1	0	0	NA	NA	NA	0	2	0	0	1	0
Davis[1] -----	1	1	0	1	0	0	1	0	0	0	1	0	NA	NA	NA
Salt Lake ----	[3] 2	2	NA	NA	1	NA	0	1	0	9	3	2	NA	NA	NA
Utah ---------	NA	NA	NA	NA	NA	NA	NA	NA	NA	0	0	0	0	1	0
Totals---	5	3	NA	2	1	NA	1	1	NA	9	6	2	NA	2	NA

1/County administration, sheriff, and emergency services located in county courthouse building.

2/City and county building built 1935.

3/City and county building built 1894.

administrative buildings with the cities of Ogden, Salt Lake, and Provo. For example, county-sheriff headquarters for the three counties mentioned are located in municipal buildings and city-county complexes. Therefore, the listing and analysis of these combined city-county facilities were included again in this section. For a discussion of the combined city and county building facilities in Salt Lake, Ogden, and Provo, see page 198. No information was available on emergency generators, except as noted for the Salt Lake Metropolitan Hall of Justice in the discussion of city buildings.

Outside of Salt Lake County, the great majority of fire stations are volunteer units and fall under the jurisdiction of the cities and small towns. In Salt Lake County, however, there are 15 county fire stations, 9 of which were built prior to 1961. Available dates of construction for county buildings are shown on table 52.The offices of emergency services in each of the four counties are located in so-called "hardened" sites in basement areas of county administration and municipal buildings, which are intended to provide protection from nuclear explosions and fallout. These important communications and operations centers should have a high degree of protection from earthquake damage as well, even though the building above ground may be nonfunctional.

Magnitude 7.5 on the Wasatch fault--expected damage patterns.--Most major Salt Lake County offices are housed in old buildings, and disruption of activities will be great in a major earthquake. Damage to county administration facilities in the other three counties is likely to be less both because of newer construction and milder intensities predicated on the basis of the epicenter location in Salt Lake or near Magna. The estimated numbers of nonfunctioning buildings are tabulated in table 53. For planning purposes, impaired use is expected to last for 1 month for 50 percent of the nonfunctional buildings listed in the table.

For planning purposes, 8 of the 15 Salt Lake County fire stations will be nonfunctional. Much of this again is due to older nonearthquake-resistant construction and high intensities. Many water-supply lines will be ruptured where they cross the Wasatch fault. This will inhibit the efforts of county fire units west of the fault.

Table 53.--County buildings nonfunctioning because of earthquake damage

Wasatch fault, magnitude = 7.5 or Magna fault, magnitude = 7.5

County	Administration buildings		Sheriff		Emergency services		Fire stations		Repair-storage	
	Number	Percent of total	Number	Percent of total	Number	Percent of total	Number	Percent of total	Number	Percent of total
Weber	1	45	0	50	0	20	1	30	0	50
Davis	1	55	1	60	0	20	1	90	1	90
Salt Lake	4	85	2	60	0	10	8	55	1	50
Utah	1	50	1	50	0	20	0	0	1	90
Totals	7		4		0		10		3	

Magnitude 7.5 on the Magna fault--expected damage patterns.--Damage should be similar to that occurring from the Wasatch-fault event, except that water supply will probably not be disrupted.

A county fire station and sheriff's office, both in the Kearns area of Salt Lake County, are within the zone of deformation due to surface faulting and should be considered nonfunctional for planning purposes.

State buildings

All of the major state administration offices are located in Salt Lake City. Most of the essential state offices are located in either the State Capitol Building or in the State Office Building directly behind the Capitol. The State Office of Emergency Services is located in a National Guard armory in Salt Lake City. These buildings house major administration, highway patrol, highway department, water resources, and communication facilities. The State leases space in six other buildings in Salt Lake City for health services, social services, education, data processing, and employment security. All of the above buildings are located in Mercalli Intensity Area IX from either of the postulated earthquakes.

Table 54 lists nine buildings housing major state administration offices for which construction data were obtained. Most highway patrol buildings are small, one-story, bearing-wall buildings. The main headquarters, which is an important communications center, is located in the State Office Building. National Guard armories are two-story bearing-wall buildings containing large inside drill areas. The locations of administration, highway patrol, and National Guard facilities are plotted in figure 45.

If the nine major administration facilities are analyzed as a group, the percentage of buildings rendered nonfunctional would be 50 percent, or five buildings for either postulated earthquake. See table 55 This high percentage reflects the fact that four state facilities are housed in buildings that were not designed for earthquake forces. Some of these older buildings are expected to be nonfunctional in the postulated earthquakes owing to structural and nonstructural building and equipment damage. The State Office Building was built in 1960, just

Table 54.--Dates of construction and description of buildings housing major State administration offices

Facility	Year built	Number of stories	Frame and materials of construction
State Capitol	1913	4	Reinforced concrete frame, floor, roof, and walls, concrete dome.
State Office Building	1960	6	Steel frame, floors and roof are concrete slabs on steel deck, precast concrete walls.
Health services (Federated Securities Bldg.)	1909	4+ Penthouse	Reinforced concrete frame, floor, roof, nonreinforced brick panel walls.
Social services (Empire Building)	1959	4	Reinforced concrete frame, prestressed concrete TT, block and brick panel walls.
State Board of Education (University Club Building)	1964	24	Reinforced concrete frame, floors, roof, light-weight panel walls.
Systems Planning (S.L. Board of Education Building)	unknown	2	Old building; steel frame, wood floors and roof. New building reinforced concrete. 1/
Computer Control Center (Chancellor Building)	1974	3	Reinforced concrete frame and floors, brick and block panel walls.
Department of Employment Security (D.E.S. Building)	1970	5	Reinforced concrete frames and floors, steel roof, block and brick panel walls.
Office of Emergency Services (National Guard Armory Building)	1958	2	Office area: concrete floor and roof, concrete-bearing walls.

1/ Data processing in new building

Table 55.--Buildings housing major State offices that will be nonfunctioning because of earthquake damage

Wasatch fault, magnitude = 7.5 or Magna fault, magnitude = 7.5

County	Administration buildings		Highway patrol		National Guard armories	
	Number	Percent of total	Number	Percent of total	Number	Percent of total
Weber	0	0	0	20	0	50
Davis	0	0	0	20	1	50
Salt Lake	5	50	1	40	2	50
Utah	0	0	0	20	2	50
Totals	5		1		5	

prior to adoption of earthquake-design requirements for buildings in the study area, and, as far as is known, was not designed to resist earthquake forces.

The only emergency electrical power for State facilities is in the State Office Building, which has emergency power for the highway-patrol communications center located in that building; and all highway patrol offices and armories have emergency-power capabilities.

Magnitude 7.5 on the Wasatch fault--expected damage patterns.-- It has been mentioned that 50 percent of the State buildings surveyed are expected to be nonfunctional owing to building and equipment damage. Some will likely have to be abandoned for many days, pending inspections and temporary repairs. The high percentage reflects the facts that most state buildings surveyed are in a high earthquake-intensity zone, and that several important buildings have no specific earthquake-design features.

For planning purposes, impaired use is expected to last for at least 1 month for 50 percent of the damaged buildings listed in table 55.

Magnitude 7.5 on the Magna fault--expected damage patterns.-- This shock should have the same impact on state buildings as the Wasatch fault event.

Federally owned buildings
(excluding post offices)

The detailed information gathered from federal sources pertains only to the larger federally owned buildings, excluding military, leased and small structures. (The analysis of Hill Air Force Base was included but analysis of Defense Depot, Ogden, and other military installations is beyond the scope of this report; and leased building data could not be developed in the time available). No field inspections of major federal buildings in the four-county study area were necessary.

Major federal buildings are located in all four counties (table 56). The Clearfield Depot facility in Davis County consists of 21 large, one-story wood-frame warehouses, several other miscellaneous buildings, and one large one-story wood-frame administration building. All of these buildings were constructed during World War II. Except for Hill AFB, the remainder of the major federal buildings in the study area house administration facilities and, considering their dates of construction (table 56), it is likely that 7 of the 11 major federal buildings for which construction data were obtained were not designed for earthquake forces.

Only one of the buildings, the FAA (Federal Aviation Administration) Air Route Traffic Control Center, has emergency power. Both Clearfield Depot and Hill AFB have emergency power available to their facilities.

Hill Air Force Base covers a large area and contains many different types of buildings, including airplane hangars, test and repair facilities, administration buildings, power plants, and living facilities for military personnel on the base.

In the case of a great earthquake, where thousands of people were homeless in the study area, some of the living facilities at the base could be used as a resource to house and feed the homeless population. These facilities include Capehart single family housing, Wherry fourplex housing, airmen's dormitories, visiting officers' quarters, and visiting airmen's quarters. Other buildings that might serve as an emergency shelter are the gymnasium, chapel, library, officers' club, service club, and new NCO club. Table 57 lists these facilities with dates and types of construction. Most of the buildings at Hill AFB are heated from central steam heating plants. An inspection of a typical plant showed that boilers, switching units, and other large equipment were not anchored to the structure and could move and become nonfunctional. All buildings heated by steam, however, have a heating-oil backup system, which could operate for 1 month based on the normal oil reserve maintained at the base. Family housing is heated by natural gas supplied by Mountain Fuel Company. These facilities have no standby heating-oil system, and so in winter the use of this housing as a temporary resource for homeless people would be of questionable value. The airmen's dormitories and older barracks living quarters are also heated by natural gas but are on a different rate basis and have a standby heating-oil system. (See also "Public Utilities," "Natural Gas.")

For planning purposes, access to Hill AFB following an earthquake would be by either the south or southwest gates, which should be clear.

Table 56.--Dates of construction and description of major federal buildings

Facility	Location: City	Location: County	Year built	Number of stories	Frame and materials of construction
Federal Building	Ogden	Weber	1965	6	Reinforced concrete frame, floors, and roof, precast concrete panel walls.
Forest Service Building	Ogden	Weber	1933	8	Reinforced concrete frame, floors, and roof, masonry panel walls.
IRS Service Center	Ogden	Weber	1966	1	Steel frame and roof system, masonry panel walls.
Clearfield Depot	Clearfield	Davis	1942	1	21 warehouse buildings, wood frame and roof, concrete slab floors.
Federal Building	Salt Lake	Salt Lake	1964	9	Concrete frame, floors, roof, precast concrete panel walls.
Federal Building annex	Salt Lake	Salt Lake	1920	4	Wood frame, floors, and roof, masonry walls.
U.S. Courthouse and Post Office	Salt Lake	Salt Lake	1930	5	Steel frame, reinforced concrete floors and roof, masonry and cast stone walls.
Federal Administration Building	Salt Lake	Salt Lake	1943	2	Masonry-bearing walls, wood floor and roof.
FAA Air Route Traffic Control Center	Salt Lake	Salt Lake	1951	1	Timber frame, concrete slab, wood roof, masonry walls.
Federal Building	Provo	Utah	1938	3	Concrete frame, floor, roof, cast stone panel walls.
Social Security Administration	Provo	Utah	1972	1	Steel frame, concrete floor and roof, masonry walls.

Table 57.--Resource housing at Hill Air Force Base

Facility	Year built	Number of levels	Number of units	Total people	Frame	Walls	Floor/ roof
Capehart housing----	1963	1	Total for family housing = 1,130	Total for family housing = 3,000	Wood	Brick veneer	Wood.
New single-family housing-----------	1975	1			--do--	--do--	Do.
Wherry housing------	1953	2			--do--	Wood	Do.
Airmen's dormitories	1955	3	4	479	Concrete	Block and brick veneer	Concrete
Visiting officers' quarters --------	1941	2	6	115	Wood	Wood and some brick	Wood.
Visiting airmen's quarters --------	1941	2	3	138	--do--	--do--	Do.
Officers' club-----	1941	1	1	unknown	--do--	--do--	Do.
Gymnasium----------	1965	1	1	--do--	Concrete	Block and brick	Concrete/TT.
Chapel-------------	1970	1	1	--do--	Wood	--do--	Concrete/wood and steel.
Library------------	1970	1	1	--do--	Wall bearing	--do--	Concrete/steel.
Service club--------	unknown	1	1	--do--	Steel	--do--	Do.
New NCO club-------	1975	2	1	--do--	unknown	unknown	unknown.

Access to the base via the west, Roy, and north gates could be blocked due to collapse of overpasses at these locations.

Magnitude 7.5 on the Wasatch fault--expected damage patterns.--Sixty percent of federal buildings in Salt Lake County would be nonfunctional due to the postulated Wasatch fault event (table 58). This would be a result of high shaking intensity (Mercalli Intensity IX) and the fact that four of the five buildings were not designed specifically for earthquake forces. (Three of those buildings were built prior to 1950). The main Federal Office Building in Salt Lake City was designed for earthquake forces and should suffer only moderate damage to the structure.

For an epicenter in Salt Lake City, the federal buildings in Weber and Utah Counties were in zones of lower shaking intensity than those in the other counties. Hill AFB (Davis County) is in intensity zone IX and numbers of resource housing expected to be nonfunctional at the base are shown in table 59.

For planning purposes, it is expected that all of the major federally owned administration buildings over one story in height will be closed for 1 day, 50 percent for over 1 week, and 25 percent for over 1 month. This closure will be due to lack of utilities, lack of operable elevators, opening delays due to inspections to determine the extent of structural damage, (if any), and the inability of employees to commute to these buildings because of debris and damage in the congested areas of the cities.

Magnitude 7.5 on the Magna fault--expected damage patterns.--Results will be similar.

Post office buildings

Building construction data were gathered on all of the Class-1 post offices in the four-county study area. No information was gathered regarding emergency electrical generators in postal facilities.

Nearly all of the buildings surveyed were of one-story masonry construction; the two main factors affecting the functioning of these facilities following an earthquake, therefore, were the year built and the expected intensity at each facility location. Older buildings not

Table 58.--Major federal buildings and(or) facilities nonfunctional due to damage to buildings and equipment

Wasatch fault, magnitude = 7.5 or Magna fault, magnitude = 7.5

County	Number	Percent of total
Weber ------------------	1	30
Davis ------------------	0	20
Salt Lake --------------	3	60
Utah -------------------	1	30
Total--------------	5	

Table 59.--Resource housing at Hill Air Force Base nonfunctional due to earthquake damage

Facility	Wasatch fault, magnitude = 7.5 or Magna fault, magnitude = 7.5 Number		Percent of total
Permanent housing:			
Capehart, Wherry, and new single-family housing----------------	113		10
Airmen's dormitories ---------	1		20
Visiting officers' and visiting airmen's quarters----	2		20
Subtotal, nonfunctional permanent housing--------	116		
Possible temporary housing:			
Officers' club------------------			1/ 20
Service club ------------------			20
NCO club ----------------------			20
Subtotal, nonfunctional temporary housing-------	1	Average percent	20
Total, all housing--------	117		

1/ These figures represent percent nonfunctional for an average building of this date and type of construction (table 57) subjected to Mercalli Intensity IX.

designed for earthquake forces and buildings using heavy precast-concrete roof systems would not perform as well as newer buildings or buildings with lighter roof systems.

Magnitude 7.5 on the Wasatch fault--expected damage patterns.--
The nonfunctional postal facilities are summarized by county in table 60. For planning purposes, it should be assumed that 50 percent of the inoperable services will be at least partially functioning within 48 hours, and 90 percent of the remainder in 30 days.

Magnitude 7.5 on the Magna fault--expected damage patterns.--
Except for slight variations in Utah County due to shifted intensity zones, expected damage for a Magna event is the same.

Table 60.--Class-1 post office buildings nonfunctioning due to earthquake damage

County	Wasatch fault, magnitude = 7.5 or Magna fault, magnitude = 7.5 Number	Percent
Weber	1	85
Davis	2	40
Salt Lake	2	50
Utah	3	50
Total	8	

Table 61.--Public buildings remaining functional and which could be used for emergency operations following an earthquake (built 1962 and later)

[Letter code: A , Administration; P, Police;F, Fire;R, Repair and Storage; E, Emergency services; PO, Post Office]

County	City buildings	County buildings	State buildings	Federal buildings
Weber --------------	3F	2F	0	2A 1PO
Davis -------------	6F	1A 1F	0	1PO
Salt Lake ---------	2A,P 1P 5F	2A,P,E 5F	3A 1F	1A 2PO
Utah -------------	2A, P 3F 1R	1R	0	1A 1PO
Totals -----	23	12	4	9

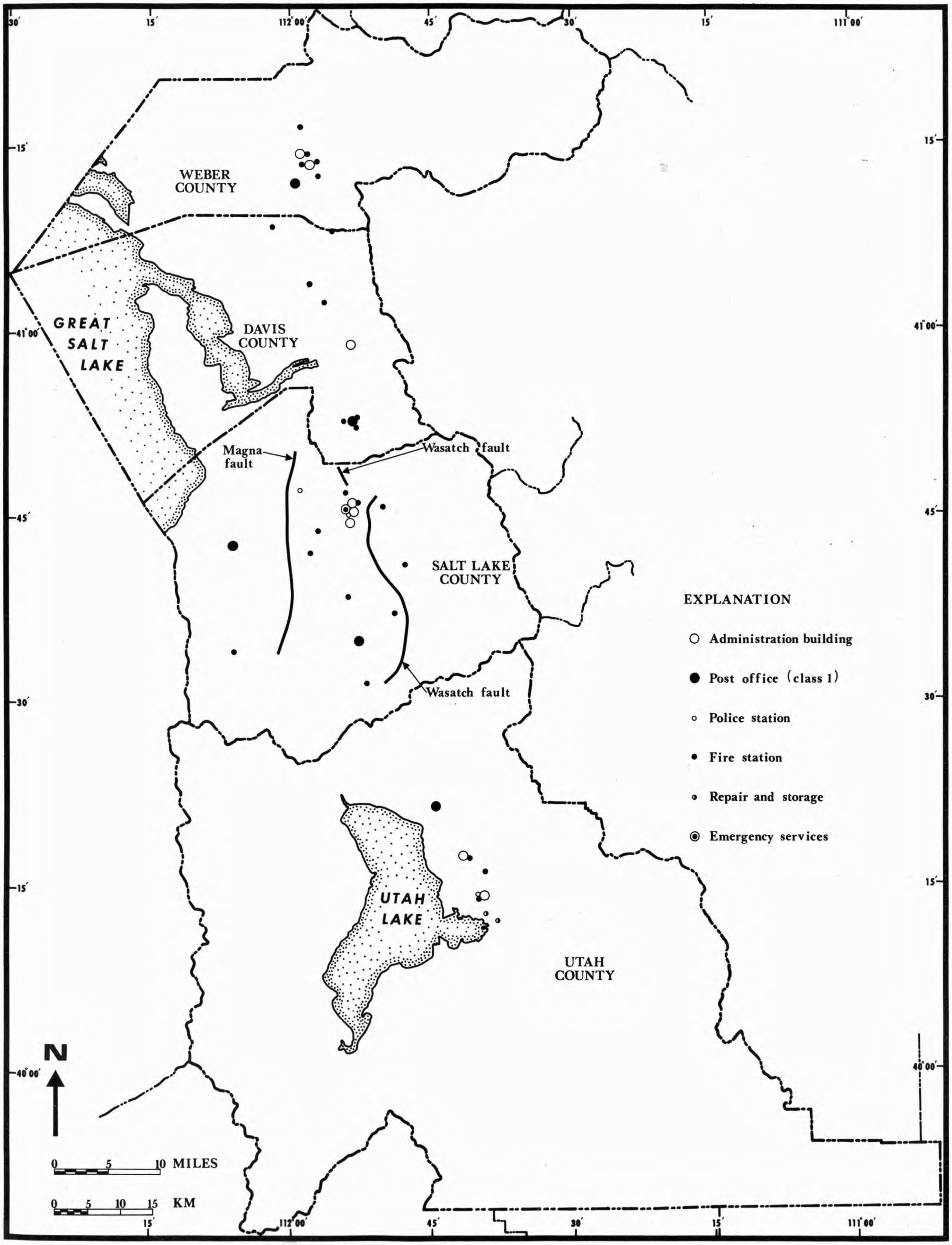

Figure 47.--Vital public buildings built 1962 and later. (One dot may represent more than one facility. Shown fault breakage is assumed for planning purposes.)

Communications

Introduction

In the four-county study area, communications may take many forms. Among the most widespread are printed or written, electronic (radio and television), verbal, and visual. The use of a particular medium is dictated by a variety of factors, including time constraints, type of information, producer and user requirements and operations, demand,level of detail needed, and others. For instance, emergency communications (fire, police, and ambulance) have critical but short-term value, whereas others, such as magazines, serve different purposes and have a longer time value.

The San Fernando earthquake caused failures of communications, which thus limited contact between certain critical locations and agencies responsible for emergency relief. This resulted in delays in assignment and use of available volunteers and materials and in transmittal of adequate emergency information to the public. Emphasis in this report has been given to the communication types that are vital to emergency services and to minimal maintenance of community life in the days immediately after the disaster. Therefore, greatest emphasis has been given to radio, television, and telephone communications, with some attention to other means.

It is obvious that post office facilities will be severely damaged when located in older non-earthquake-resistive structures that are in high-intensity zones. Additionally, it is obvious that post office facilities located in the congested portions of the study area, for example, may be inoperative while the region is sealed off for damage evaluation. (Post office facilities are discussed in the section on "Public Buildings".)

Newspapers are important in that they give the public much of the detail that cannot be carried by radio or television. Electric power outages, misalignment of sophisticated printing equipment or direct damage to it, and commuting problems for employees will cause delays in the publishing process. It is reasonable to assume, for planning purposes, that newspapers will have to rely on presses located outside the urban areas of the study area for at least 1 week.

Data collection

Data were collected for the entire four-county study area from several sources rather than from one central agency. Among those consulted for information were Mountain Bell Telephone Company and various radio and television stations.

Information was collected that permitted the plotting of the locations of commercial radio stations and also of the radio towers within the four-county study area. Additionally, the locations of all television stations and their transmitting towers were plotted. Much of this information is shown in figure 48.

Table 62 indicates the number and distribution of radio and television stations that were field inspected and for which the following construction data were obtained: date of construction, number of stories, construction materials, area (ft^2), emergency electrical generator, mobile units, and number of occupants.

Most of the larger radio stations have remote transmitting stations and towers. Several radio towers are located on top of the Oquirrh Mountains to the immediate west of the Salt Lake Valley, and others are located at various outlying locations in the study area or at the stations themselves. A total of 4 of 11 radio stations inspected indicated that they have emergency electrical power. Nine of the 22 radio stations serving the study area are part of the emergency broadcasting system.

The study area is served by three commercial and two educational VHF television stations. Four of the five facilities also operate radio stations. All five television stations have their transmitting towers located on top of the Oquirrh Mountains. Three of the stations indicated that they have mobile broadcasting units, and at least three have emergency electrical power generators at the studio.

The four-county study area is served by Mountain Bell Telephone Company. Data obtained from the company permitted the location on figure 49 of main trunk lines,microwave sites, and equipment buildings. Information pertaining to construction of the equipment buildings was obtained by written and oral communication with telephone company spokesmen.

Analysis

Radio and television

Damage to radio and television facilities may be divided into that

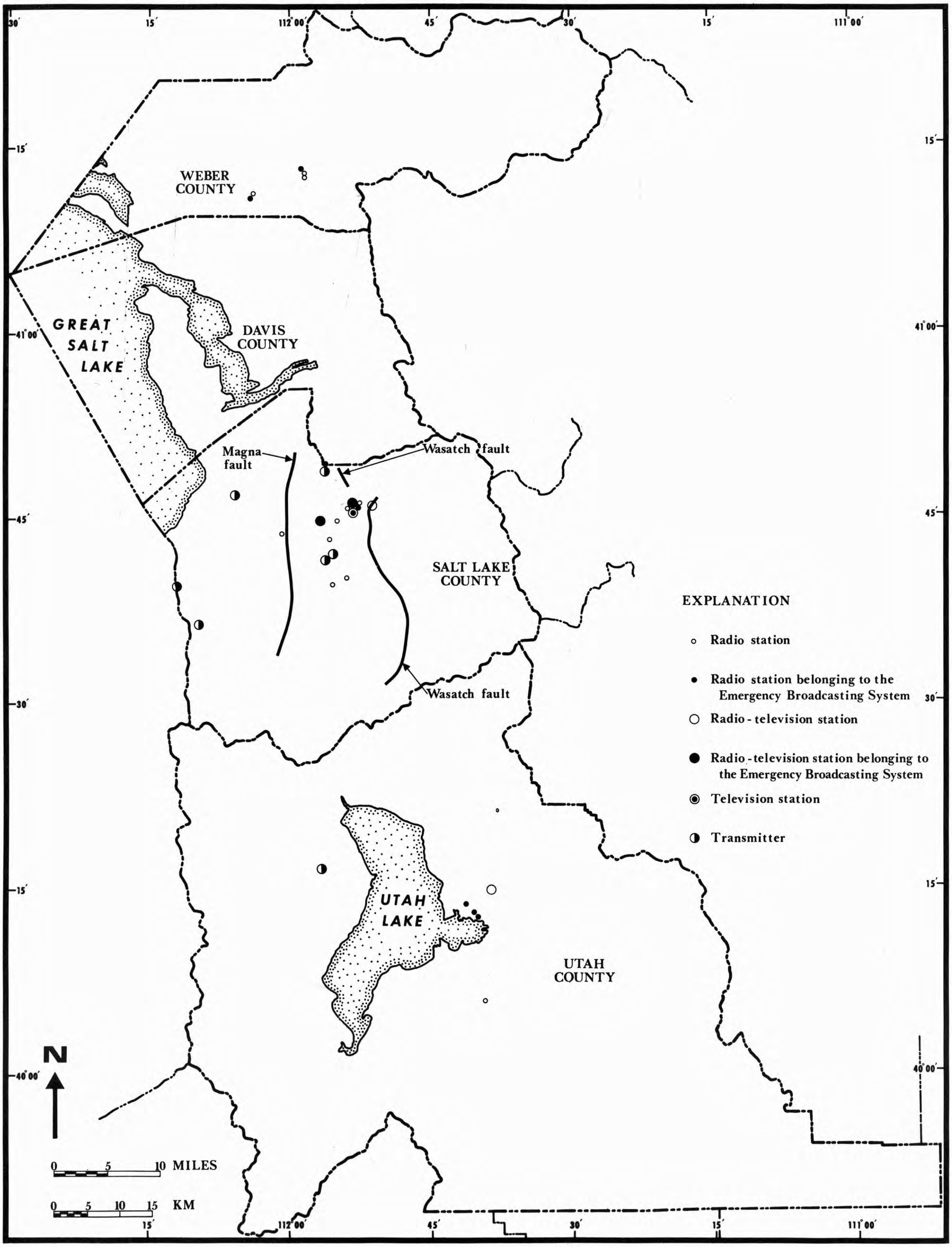

Figure 48.--Major radio and television stations and transmitter towers. (One dot may represent more than one facility. Shown fault breakage is assumed for planning purposes.)

Table 62.--Television and radio stations inspected

County	Radio		Television	
	Pre-1961	Total	Pre-1961	Total
Weber --------------	2	2	0	0
Davis --------------	0	0	0	0
Salt Lake-----------	5	6	3	4
Utah ---------------	2	3	0	1
Totals---------	9	11	3	5

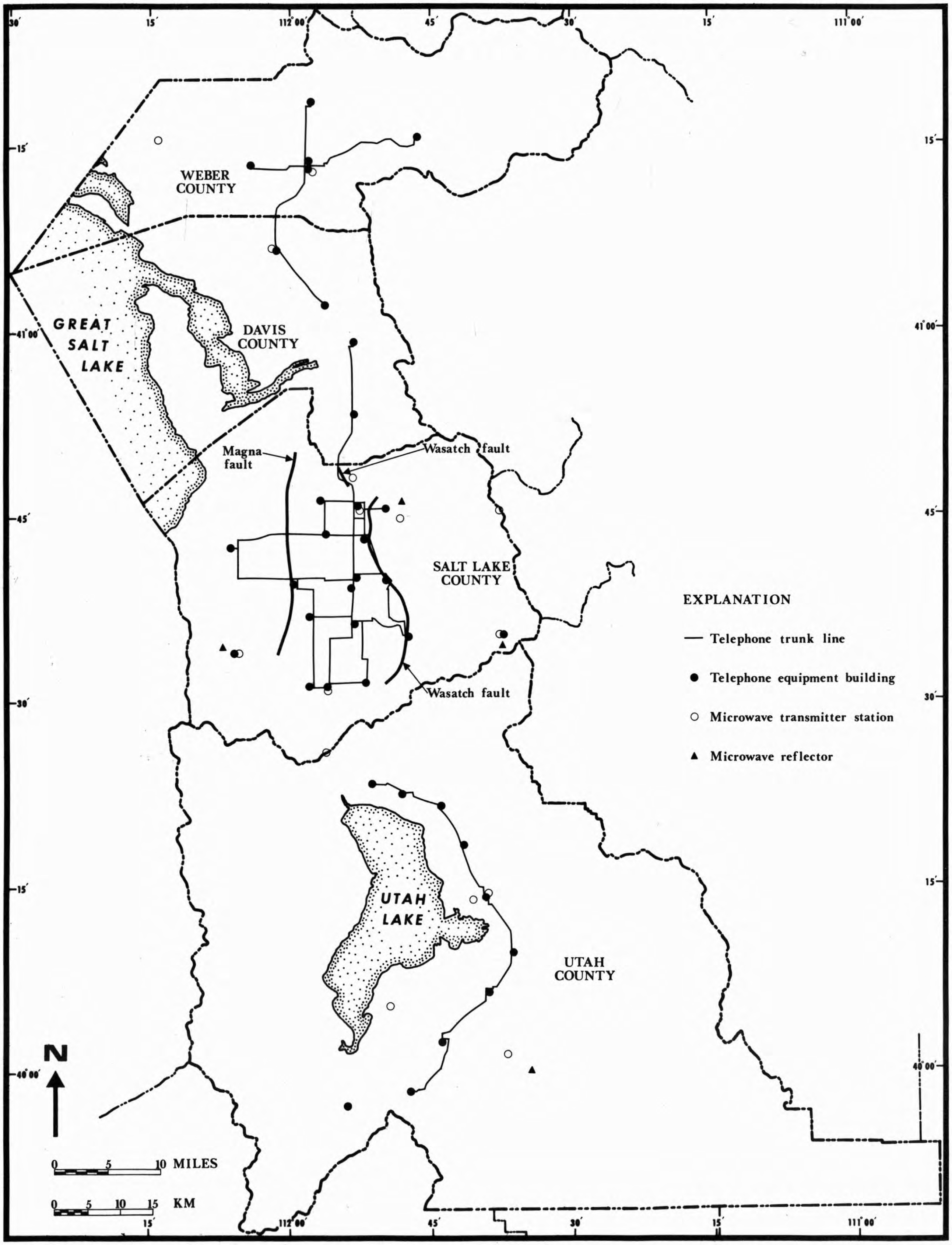

Figure 49.--Approximate location of telephone facilities. (One dot may represent more than one facility. Shown fault breakage is assumed for planning purposes.)

which occurs (1) to the studio building and its equipment, (2) to the lines from the studio to the tower, and (3) to the tower, appurtenant structures, and related facilities.

The geographic distribution of radio and television towers is shown in figure 48, with some radio towers on alluvial soil and some on top of mountains. All television towers are on top of the Oquirrh Mountains, in order to obtain the best line-of-sight benefits for high frequency transmission.

Radio and television towers have certain problems in addition to foundation conditions. The structural design standards are not as conservative as those for buildings, reportedly on the basis that life safety is not involved in the event of tower failure. Tower maintenance is difficult; for example, it is difficult to repaint and otherwise service a high and often swaying tower. Ceramic insulators used in both guyed and unguyed towers are strong and reliable for non-impact-loading conditions, but they may fail in a brittle manner under impact loads such as those that can be expected during earthquakes. Some emergency electric generators have proved to be unreliable in past earthquakes because of inadequate anchorage of equipment and batteries and failures of fuel supplies.

The emergency electric power at the studio for radio and television facilities in the four-county study area consisted primarily of a diesel-powered generator , mounted on springs or shock absorbers with the base anchored by steel bolts to the floor. In some cases the batteries that are used to start the generators in case of power failure were not secured and could be nonfunctional following an earthquake. The fuel supplies for some of the generators were also inadequately secured to resist strong earthquake forces.

The communication equipment that links the broadcast studio with its transmitting tower is usually located on a tall building for line-of-sight operation. Only about 50 percent of the stations indicated that there was emergency power for this equipment.

Emergency electric power at the transmitting tower consisted of a diesel-powered generator with shock absorbers and with the base anchored to a concrete foundation. Most of the generators can be started manually.

With respect to past experience, radio towers survived quite well in the March 22, 1957, San Francisco shock, which had a magnitude of 5.3. The 1964 Alaskan earthquake resulted in stations being off the air due to power failures rather than to equipment or structural failures; however, most facilities were far from the epicenter and center of energy release. The April 13, 1949, Puget Sound earthquake resulted in the buckling of a free-standing radio tower in Seattle. In the February 9, 1971, San Fernando earthquake, failures of electrical power to receivers caused communication black-outs in the heavily damaged area. A television station in Burbank was forced to use its truck-mounted auxiliary transmitter.

Nine of the 11 inspected radio stations in the four-county study area are in buildings of masonry construction built prior to 1961 (table 62). All but one of the inspected radio studies are located in buildings three stories and less in height.

Three of the five television studies are in masonry buildings built prior to 1933. All television studios are in buildings of three stories or less.

The analysis is based on a comparison of the known behavior of similar types of construction in the various intensity zones in past earthquakes with that expected under similar intensities at specific locations in the postulated shocks. In the high-intensity areas, the too-often unanchored equipment will shift and/or overturn, and other equipment will fall from shelves. In order to compute the percent of stations that would likely be inoperable, it was assumed that damage to sensitive equipment peculiar to radio and television stations would double the losses experienced in normal occupancies, except when facilities were located in buildings that were likely to collapse. The results of the analysis are shown in table 63.

Additional impairment, above that shown in table 63, is expected to result from damage to the vital systems of transportation, telephone communication, and public utilities. Casualties among employees will also hamper operations. On the other hand, use of mobile ground and air units

Table 63.--Percent of major radio and television stations inoperable due to damage to buildings, equipment, and towers

Wasatch fault, magnitude = 7.5				Magna fault, magnitude = 7.5			
Radio		Television		Radio		Television	
Studios	Towers	Studios	Towers	Studios	Towers	Studios	Towers
85	15	85	0	85	20	85	15

will help to offset these problems, providing fuel supplies and alternate surface-travel routes are available.

Magnitude 7.5 on the Wasatch fault--expected damage patterns. As can be seen from table 63, damage to radio and television studios is expected to be heavy, as an unusually large number of these facilities were built of unreinforced masonry prior to 1961, the year when seismic design became mandatory in the Uniform Building Code. For planning purposes, 25 percent of the impairments (shown in table 63) to radio and television facilities, located in buildings that do not collapse, should be restored in 24 hours and the remainder in as much as 30 days.

Additional impairments due to damage to vital services and casualties will be most severe in the high-intensity area of Salt Lake County.

Damage to transmission towers located on the Oquirrh Mountains should be minimal, as expected intensities are low. However, ground accessibility may be hampered because of landslides blocking roadways. Helicopters may be required to ferry supplies and employees to the towers.

Magnitude 7.5 on the Magna fault--expected damage patterns.--Damage to radio and television studios and to those transmission towers not located on the Oquirrh Mountains will be similar to that of the Wasatch fault event. Transmission towers located atop the Oquirrh Mountains, however, will be subject to heavier ground-shaking intensities, and more damage to these facilities should be expected. Also, ground accessibility is much more likely to be disrupted due to landsliding.

Special radio and television systems

Fire, police, hospital, school, bus, public utility, and other special-service communication requirements were not specifically field inspected, except in situations where inspection of the buildings was necessary for other purposes.

The problems described for the public radio and television facilities also apply in a general way to these facilities. Even though emergency-service communications may be redundant to varying degrees because of multiple frequencies and alternate base stations, experience has proved that, at best, a considerable number of unanticipated trouble sources will manifest themselves. Those services relying upon a single radio frequency must expect to experience overloading to a nearly impossible degree. However, in view of the large amount of mobile transmitting and receiving equipment, makeshift facilities are possible. Therefore, reliance must be placed on the management ability of those in charge of each special-communication facility to make best use of mobile equipment should his base station be inoperative. For a discussion of hospital communications in the four-county study area, see the "Hospital" section of this report.

Telephone systems

Figure 49 shows the locations of main trunk lines, microwave stations, and equipment buildings. Trunk lines serving Davis County and the southeast sections of Salt Lake County cross the postulated Wasatch fault rupture, and those from Salt Lake City to Magna cross the postulated Magna fault rupture. Trunk-line cables are encased in a polyethylene cover, which is strong and flexible. No additional provisions have been made to protect the cables where they cross the faults. Under non-earthquake conditions, restoration of individual high-density cables can normally be accomplished in a few hours and usually will not exceed 24 hours. The loss of a high-density route and re-routing of traffic over alternate facilities will generally not result in the complete isolation of major communities. Such alternate routing is in daily use. Where major land displacements occur, failure of local underground cables can be expected. Telephone companies continually face similar failures due to construction activities, water penetration, and so forth. Their restoration techniques under non-earthquake conditions allow quick location of failure points and rapid repairs of these failures.

In general, the telephone buildings are designed according to the latest edition of the UBC (Uniform Building Code), and it is expected that the newer (1962 and later) equipment buildings will survive, even though some equipment in them may be damaged. About 75 percent of the telephone equipment buildings in the four-county study area are one and two stories in height and are of reinforced-masonry-bearing wall construction. One-half of these are 10,000 square feet (900 m^2) or less in area. The Salt Lake Main equipment and offices facility consists of three high-rise buildings of reinforced concrete and steel frame construction. These three buildings are on the same corner in downtown Salt Lake City. There is also a large customer service facility, which is a three-story reinforced-concrete-frame building located about two blocks from the Salt Lake Main buildings. Table 64 shows numbers of telephone company buildings by county and indicates the number of buildings constructed before and after 1961, when earthquake design of buildings became a requirement of the UBC for the study area. The table also gives the number of buildings that are one and two stories in height versus the number that are three or more stories.

Most major items of equipment are anchored to the structural floor systems of their buildings and are cross braced at the top. In addition, overhead cable racks are attached to the tops of large items of equipment and provide some lateral support for this equipment. These racks are of braced construction using 1/4-inch x 2-inch steel bar. Equipment anchorage and bracing have been in effect since about 1939 in the study area. Beginning in about 1962, telephone company battery racks have also been braced to prevent the batteries from overturning.

Table 65 shows the number and percent of telephone equipment buildings that could be nonfunctional due to either of the postulated earthquakes. These figures are based on the known behavior of similar buildings in various intensity zones of past earthquakes compared to the expected behavior using the postulated intensities at the specific telephone building sites in the four-county study area. The loss percentages due to building damage were increased by one-half (except for older buildings subject to collapse and buildings in the fault zones) to allow for increased impairment because of damage to telephone equipment within the buildings.

Two types of microwave stations exist in the study area: active repeaters which have a transmitting capability, and passive repeaters which are reflectors only. Both types have been shown on figure 49.

Table 64.--Telephone buildings

[Source: Mountain Bell Telephone Company]

County	Constructed before 1961			Constructed after 1961		
	1 and 2 stories	3 and more stories	Total	1 and 2 stories	3 and more stories	Total
Weber------------------	2	1	3	2	0	2
Davis ------------------	4	0	4	0	0	0
Salt Lake---------------	8	2	10	8	1	9
Utah -------------------	10	0	10	0	0	0
Totals------------	24	3	27	10	1	11

Table 65.--Telephone equipment buildings nonfunctional because of damage to buildings and equipment

County	Wasatch fault, magnitude = 7.5 or Magna fault, magnitude = 7.5 Number	Percent
Weber----------------------	2	40
Davis ---------------------	2	60
Salt Lake------------------	1/12	65
Utah ----------------------	3	30
Total ---------------	19	

1/Two buildings are on the postulated faults.

Nonfunctioning of either type would void the intended communication circuit. In addition to the microwave stations owned by Mountain Bell, three active repeaters within the study area are owned by AT&T (American Telephone and Telegraph). These are long line stations carrying transcontinental communications.

No information was available on earthquake design of microwave stations. However, these stations, including the tower and reflectors, are designed to withstand a wind pressure of 40 pounds per square foot (195 kg/m^2), which corresponds to a wind velocity of about 100 miles per hour (161 km/hr). These stations would therefore possess inherent earthquake resistance.

Magnitude 7.5 on the Wasatch fault--expected damage patterns.--The trunk lines in Salt Lake and Davis Counties cross the postulated Wasatch fault rupture in eight places. (See figure 49.) For planning purposes, these trunk lines are to be considered severed where they cross the fault zone, and telephone service to Davis County and to the southeast areas in Salt Lake County would be impaired.

Table 65 indicates that 19 telephone equipment buildings could be rendered nonfunctional because of damage to buildings and equipment. Twelve of these facilities are in Salt Lake County, where there are a total of 19 equipment buildings and where shaking intensity is expected to be high (MMI=IX). One telephone equipment building is in the fault zone. (See figure 49.)

About 50 percent of the impairments should be corrected within 48 hours, but the remainder could stay uncorrected for an indefinite period.

Magnitude 7.5 on the Magna fault--expected damage patterns.--As indicated on figure 49, trunk lines cross the postulated Magna fault rupture in two places and are considered to be severed. Therefore, the Magna fault event would be significantly less damaging to trunk lines than the Wasatch fault event would be. Telephone service to the Magna area and to the Kearns area west of the fault would be impaired.

Telephone equipment buildings would experience the same shaking intensities from the Magna fault event as from the Wasatch fault event, and numbers and percent of nonfunctional buildings would be the same. One telephone equipment building in Kearns is in the fault zone. (See figure 49.)

Transportation

This report reviews all types of transportation facilities vital to the efficient functioning of the four-county study area, as follows: railroads, major highways, bridges and interchanges, mass public transportation, and airports.

Data collection

Railroads

The Wasatch Front area is served by four major rail systems: Rio Grande, Union Pacific, Southern Pacific, and Western Pacific Railroads. Amtrak offers daily passenger service to Chicago and San Francisco from Ogden, and the Rio Grande provides tri-weekly passenger service from Salt Lake City and Provo to Denver. Freight to and from the East is handled by the Rio Grande and the Union Pacific; to and from the West, by Southern Pacific and Western Pacific. The Union Pacific carries freight to and from the Wasatch Front area and both the Northwest and the Southwest coast areas.

Detailed information was obtained on each of the routes, the bridges, yards , stations, and control centers. Whenever possible, the following specific information was collected on bridges: identification and location of facility, total length, materials of construction, number of tracks, and year put into use. Field inspection of each major trackage and bridge was made to identify possible hazards. Fig. 50 shows the routes of the major rail lines, and table 66 gives the distributions of bridges throughout the study area. It will be noted that comparatively very few bridges exist in the study area and that they are short and simple structures. There are, however, several highway structures that pass over railroad lines, and these were looked at under the "Highway" category.

Highways, freeways, and bridges and overpasses

Major highway and freeway routes that connect centers of population and carry large volumes of traffic were selected for consideration in the study. These are shown in figure 51. Construction information on the bridges and overpasses on these routes was obtained for each structure from the Utah State Department of Highways.

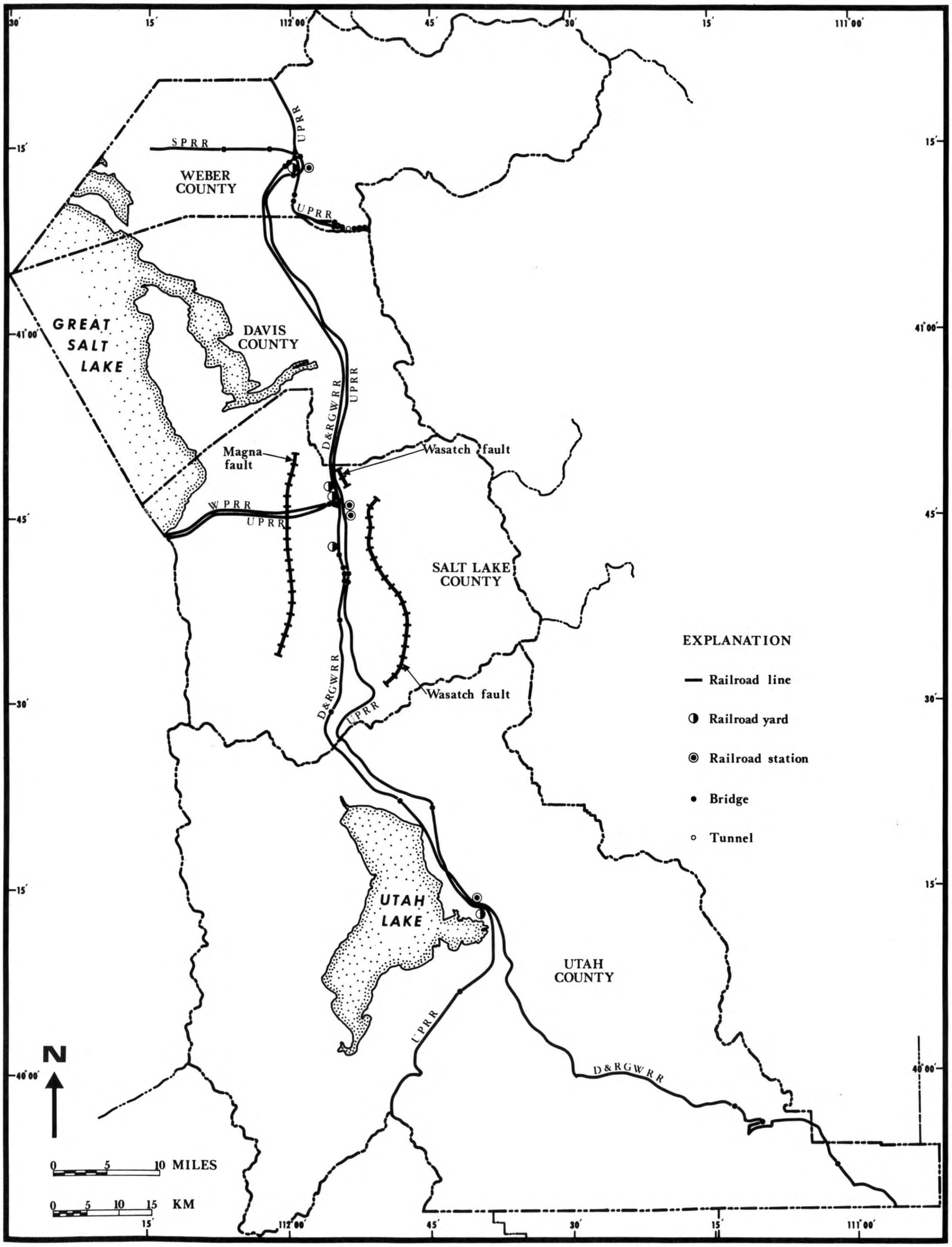

Figure 50.--Major railroad lines and facilities. (Shown fault breakage is assumed for planning purposes.)

Table 66.--Mainline railroad bridges located in the four-county study area

County	Bridges
Weber	15
Davis	0
Salt Lake	9
Utah	6
Total	30

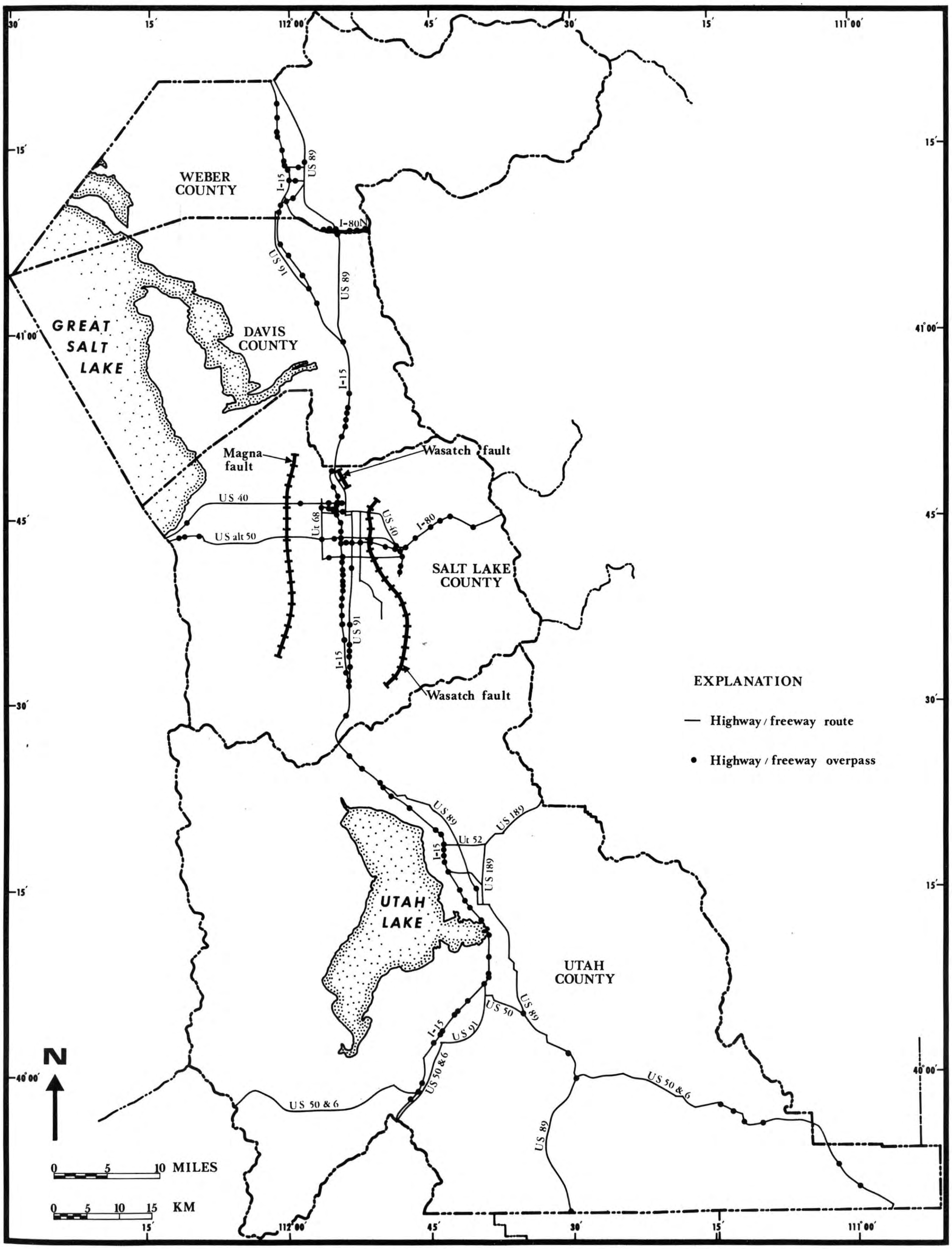

Figure 51.--Selected highway routes, bridges, and overpasses. (Shown fault breakage is assumed for planning purposes.)

The information obtained for each structure included the following: location, identification, route number, length, type and materials of construction, date completed, and specifications used in the design. Table 67 summarizes these. Each structure, except typical overpasses recently completed on the interstate system, was examined in the field.

Mass transportation

Information on the operation of the publicly owned and operated Utah Transit Authority, which furnishes bus transportation for the populated areas of Weber, Davis, and Salt Lake Counties, was received from that organization. Also, the operations of Continental Trailways and Greyhound Lines, which connect the cities in the study area with out-of-state cities, were studied.

Airports

Information was obtained for each of the airports in the study area from airport owners and operators. Table 68 is a summary of airfields by classification and location. Of particular concern are the only major commercial airport, the Salt Lake International, located just west of Salt Lake City, and the only major military airport, at Hill Air Force Base just south of Ogden.

The following information was obtained for each airport: location and access routes, year built, control-tower construction and materials, terminal-building construction and materials, runway layout and soils, fuel storage and fuel pipelines, and traffic statistics. Figure 52 indicates the locations and distribution of airports in the four counties. Table 69 is a summary of the volume of cargo and passenger traffic at the most important commercial airports. Frequently, general aviation flights are not recorded as passenger or air-freight-cargo flights, and so it is extremely difficult to place a numerical count on either total tonnage or on passenger volume.

Analysis

Railroads

From experiences of large U.S. earthquakes, we learn that

Table 67.--Number of highway overpasses and bridges on selected highway routes in the four-county area

[Limited to routes shown on figure 51, not including structures on off-on ramps]

County	Number of overpasses and bridges
Weber	23
Davis	12
Salt Lake	64
Utah	41
Total	140

Table 68.--Inventory of airfields in the four-county study area

County	General Description				
	Commercial			Military	
	Major	Municipal	Minor	Major	Minor
Weber------------	0	1	0	1	0
Davis -----------	0	0	2	0	0
Salt Lake--------	1	1	0	0	1
Utah ------------	0	1	3	0	0
Totals----	1	3	5	1	1

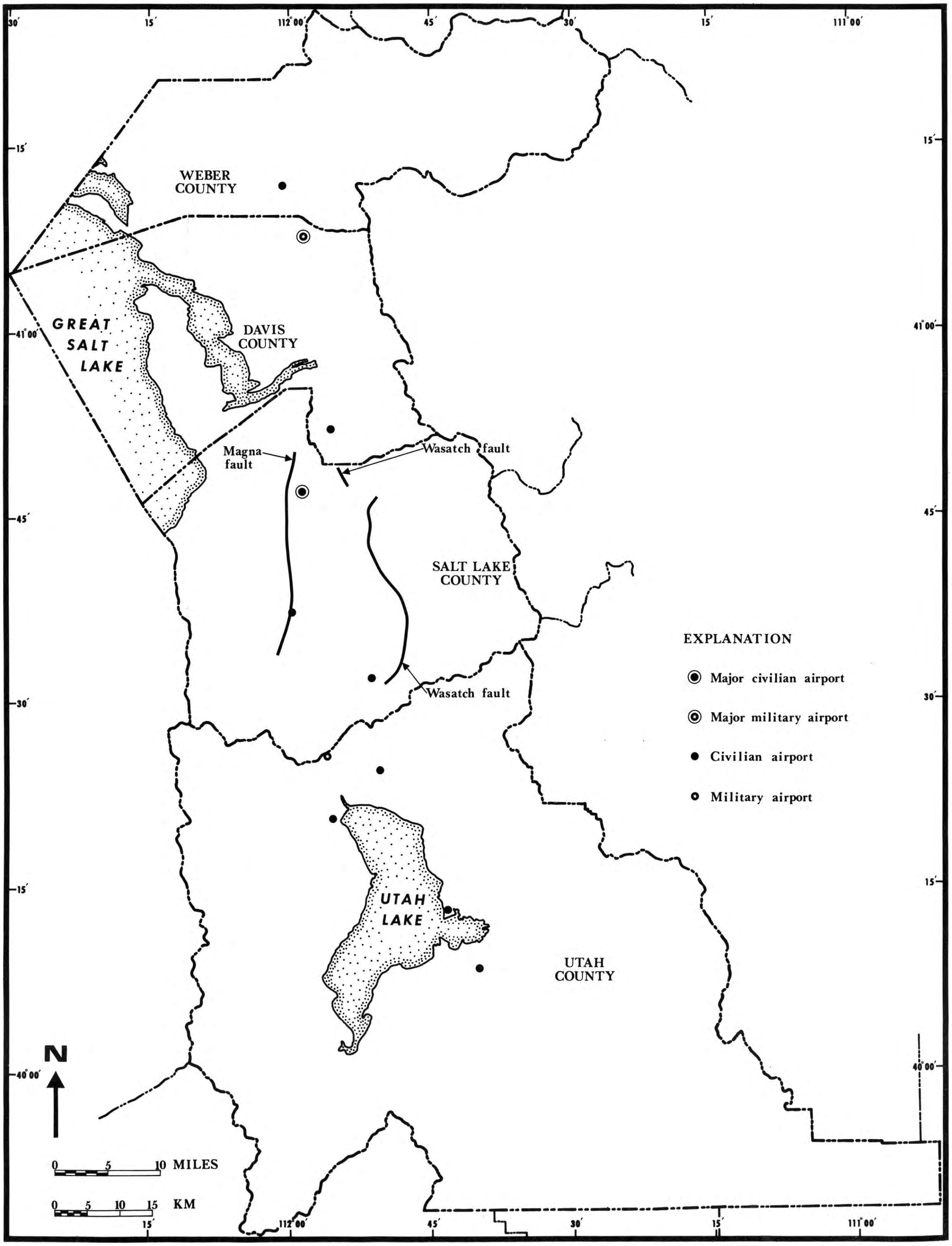

Figure 52.--Airports. (Shown fault breakage is assumed for planning purposes.)

Table 69.--Traffic volume of airports in the four-county area

[Developed from information from airport managers, oral and written communication, 1975]

Airport	Total for the year 1974: Air freight cargo (in tons)	Total for the year 1974: Passenger traffic volume
Salt Lake Int'l-------------	22,192	2,778,507
Salt Lake No. 2-------------	not available	12,100
Ogden Municipal-------------	not available	288,000
Provo Municipal-------------	400	121,000

railroads have fared extremely well and that those damages that have occurred have been repaired quickly by an industry organized to handle emergencies. Except for highway overpass collapses on tracks and moveable bridge damage, problems have usually occurred owing to structurally poor ground. Experience gained in the 1964 Alaska earthquake is excellent in regard to damage in areas of poor ground. Reference should be made to McCulloch and Bonilla (1970).

The poor-ground areas of Utah, which are of concern to railroads occur mainly in the marshy sections to the east of Great Salt Lake and of Utah Lake and in the slide-prone canyons through which the railroads going east out of the study area must pass. Ground conditions become more critical during the wet seasons. Experience indicates that fills over poor ground or ground affected by faulting will experience unequal settlement and cracking at bridge approaches and elsewhere. This requires the repair of subgrade and realignment of track after an earthquake. In the canyons to the east, steep cuts exist, which experience shows may become unstable due to earthquake shaking;resulting slides may cause extensive blockage of tracks, the removal of which becomes difficult due to the rough terrain.

Table 66 summarizes the numbers and distribution of railway bridges in the study area. It may be noted that they are not as numerous (or as long) as those on the Pacific Coast, nor is any bridge a complex structure readily susceptible to damage.

The railroad passenger terminals at Salt Lake City, Ogden, and Provo are old buildings. The Rio Grande terminal at Salt Lake City suffered moderate damage in the Cache Valley earthquake of 1962. It is expected that the terminals at Salt Lake City and Ogden will suffer damage and probable temporary closure owing to either postulated earthquake.

For planning purposes, it is expected that from either earthquake only one bridge will be seriously damaged, this occurring in the high-intensity area of Salt Lake County. The traffic on one of the main north-south railway lines is also expected to be blocked for 5 days due to a highway-overpass collapse. Both of these lines will experience moderate differential soil settlement on the marshy ground in both

Davis and Utah Counties. Either event will cause landslides and extensive ground settlement to the railways going east up the canyons from Ogden and going south of Provo.

From the Magna earthquake event, it is also expected that railways going west out of Salt Lake City and Ogden will experience serious vertical and horizontal misalignment due to earthquake forces on poor wet ground near and over Great Salt Lake and at the postulated Magna fault.

For planning purposes, 50 percent of the railways in each direction should be considered closed for repairs for 30 days.

Highways

Damage to the highway system may be placed in one of two categories: earth failure caused by landslide, movement of structurally poor ground, or fault movement; and damage to bridges and overpasses.

Rockslides blocked many roads in the San Gabriel Mountains as a result of the February 9, 1971, San Fernando earthquake. In the Utah study area, almost every canyon leading east into the mountains experiences some landslide activity. Usually, but not always, these landslides occur in the spring of the year, and cause little damage. However, from these it is easy to predict that major slides may be triggered by an earthquake of large intensity. The results of these slides will be the more serious, because their narrow canyon locations preclude the rapid construction of a bypass and their physical volumes preclude quick removal.

During earthquakes, manmade highway embankments and deep fills often settle with respect to nearby rock or firmer soils. This relative movement is called differential settlement. It often occurs at approaches to bridges or overpasses, where pavement on deep fills may settle, in terms of inches or even feet, away from the surface of the bridge deck. Many bridges in the study area indicate this differential settlement, even without the earthquake. These usually are aggravated nuisance problems that can be quickly repaired, although these problems will slow up traffic or stop it until repairs are made. Major slides may also occur in these high fills, resulting in loss of some traffic lanes or temporary loss of the use of the highway. Where a highway crosses a fault,displacement of the pavement and subgrade obviously will occur, and here even temporary repairs could be difficult.

After either postulated earthquake, slides are expected on both I-80n going east out of Ogden and I-80 going east out of Salt Lake City. Because of the difficulty of digging out, both should be considered closed for 30 days. Portions of I-15 paralleling Utah Lake and Great Salt Lake in Davis County will suffer differential settlement, which could be repaired, at least temporarily, rather quickly. Many streets passing through the commercial sections of the communities of Salt Lake and Davis Counties will likely be blocked by debris from buildings, fallen wires, and pavement damage. Also, some residential streets on the upper bench areas of Salt Lake and Davis Counties will be blocked by landslides,particularly if the quake occurs during the wet season.

After the Salt Lake event, moderate damage to pavements is expected to the following routes where they cross the Wasatch fault:

I-80n southeast of Ogden
US 40 in Salt Lake City - 5th South
Alt. US 40-50 in Salt Lake City - 21st South
I-80 in Salt Lake City
State Highway 171 in Salt Lake City - 33rd South
US 189 east of Provo
US 6-50 east of Spanish Fork

Similar pavement damage will occur on all Salt Lake City streets that cross or closely parallel the fault. For planning purposes, the portion of Salt Lake City east of the fault should be considered to be isolated from the remainder for several hours during which time temporary access can be accomplished.

After the Magna event, extensive pavement damage from strong surface faulting is expected where US 40 and Alt. US 40-50 cross the postulated Magna fault. Similar pavement damage will occur on streets crossing the fault in the communities on the west side of the valley. Most of this damage will be quickly repairable, at least on a temporary basis.

Bridges and overpasses

The Utah study area contains no movable bridges or bridges crossing large bodies of water. As a matter of fact, the only long bridges are the viaducts crossing rail lines and yards in Salt Lake and in Ogden. Furthermore, the closure of any bridge would not isolate an important area of population or industry, as alternate routes are everywhere available, although in some places short by-passes would have to be constructed.

Figure 51 shows all the bridges and overpasses on the most important highway routes in the study area. Not shown are bridges carrying secondary traffic over the major routes and bridges carrying off-on ramps to the interstate highways.

The structural integrity of many overpasses and bridges in high-earthquake-intensity areas has come into sharp focus as a result of the 1971 San Fernando earthquake, in which freeway interchange and overpass structures were severely damaged, with many collapsing. A total of 58 State Highway bridges, all in a relatively narrow zone along a fault, were damaged, and, of these, 7 either collapsed or had to be demolished. Most of the highway structures in the Utah study area predate the San Fernando experience, and whereas designed to ASSHO standards they do not reflect concern for seismic loads.

Based on the damage in San Fernando, 5 percent of the highway bridges and overpasses may reasonably be assumed to suffer serious damage due to ground shaking. (Serious damage is defined as at least partial collapse, or other structural damage that puts the structure out of service for an indefinite period.) It is assumed that structures on very poor ground in MMI-VIII areas will have a damage ratio of 5 percent; also, that the damage ratio will be doubled for structures located on poor ground in MMI-IX areas. The locations of bridges and overpasses indicate that a very high proportion of these will be subject to damage from ground shaking rather than from poor ground conditions or fault movements. Table 70 shows the extent of expected serious bridge and overpass damage.

In addition, many bridges and overpasses will suffer repairable

Table 70.--Number and location of highway overpasses and bridges seriously damaged in the event of two postulated earthquakes in the four-county area

County Location	Number seriously damaged	
	Salt Lake Earthquake	Magna Earthquake
Weber	0	0
Davis	1	1
Salt Lake	3	3
Utah	1	1

damage; however, these will be temporarily out of service until they have been shored, differential displacements resurfaced, and other repairs made. For planning purposes, structures temporarily out of service will be estimated at twice the number seriously damaged. The numbers of damaged bridges in the table do not include bridges carrying secondary traffic over major routes. It is expected that one of these will have collapsed, blocking a major highway in Salt Lake County.

Mass transportation

UTA (Utah Transit Authority) is the major mass transportation system in the four-county study area. A few smaller bus systems carry an insignificant number of passengers. Continental Trailways and Greyhound Lines provide intercity service.

UTA operates 167 buses and serves the populated areas of Salt Lake, Davis, and Weber Counties. They operate two operation-and-maintenance facilities, one in Salt Lake City and one in Ogden. The buses are not equipped with two-way radio, which has proven to be very helpful in past serious earthquakes; however, new buses, which are now on order, will be so equipped.

Little damage to buses is expected, as they are stored out-of-doors except when being serviced. Blocked and damaged streets and freeways will cause some disruption of service in the event of a major earthquake.

Airports

There are 11 airports in the study area, counting some that will permit the landing only of small aircraft with day operation only. The Salt Lake City International Airport is by far the largest in terms of passenger and freight volume and equipment and is certainly the major commercial airport in the study area. The military airport at Hill Air Force Base is large and well equipped. The airports are located as shown in figure 52.

The great Alaska earthquake of 1964, with a magnitude of 8.4, provides a reasonable guideline for experience data on airports. After that earthquake, a total of 13 out of 64 airports inspected were found to have damage to runways or taxiways. Despite damage to runways and buildings, virtually all airports were operational within hours after the earthquake. Some resourcefulness was required to accomplish this. For example, the collapse of the control tower at the Anchorage International Airport required the use of radios in a grounded plane for air-traffic control.

Runways remained functional at airports in the San Fernando Valley after the 1971 San Fernando earthquake. However, there was glass breakage in the control towers at Burbank and Van Nuys Airports. The most critical problem was the loss of commercial electric power, resulting in blackouts of terminal buildings at several airports and the lack of power to pump aircraft fuel out of underground storage.

The foregoing experience is rather reassuring with respect to the most important function of an airport; namely, to allow airplanes to land and take off with people and supplies. It seems doubly so in the Utah study area, where east-west ground transportation may be virtually at a standstill for a day or two and where air transportation is more vital because of great distances from other centers of population.

Earthquake damage to airports may be divided into damage to buildings and structures, and damage to runways and taxiways. Damage to structures may be subdivided into that vital to operational aspects, such as control towers, fuel tanks, and similar features and that to less important service features. Detailed information was available on the construction of airport buildings. Some structural damage to some of the buildings may reasonably be expected in the event of either postulated earthquake. Emphasis in the following paragraphs is on the damage to runways and taxiways that must remain functional, despite other service inconveniences.

Both postulated earthquakes are expected to produce similar types of damage to airports in the study area. However, the Magna event, having its postulated fault going through Salt Lake Airport No. 2 and being a little closer to the Salt Lake International Airport, may produce more extensive damage to these than will the Salt Lake event.

The Salt Lake International Airport is located in an area of potentially liquefiable soil and also falls in the MMI-IX intensity zone. For planning purposes, it should be expected that serious runway and taxiway damage will result from these potentially liquefiable soils in spite of the excellent history of runways in other earthquakes. The airport may be serviceable for light planes within 24 hours, but it is expected, for planning purposes at least, that the airport will be out of service to large planes for 30 days. Surface access to the airport may also be impeded due to blocked or damaged roads, but a bypass could quickly be accomplished or an alternate route found.

Public utilities

Introduction

The public utilities included in this section of the report are water supply, natural gas, electrical power, sewage, and petroleum pipelines and are generally restricted to those within the four-county study area. Damage to these public utilities will have varying impacts on human needs, depending on the product supplied or handled by the utility. Potable drinking water is a critical human need, and drinking supplies will be needed immediately following the earthquake. Water will also be needed to fight any fires that might follow the earthquake. Natural gas is a critical product for heating in Utah during the winter months, and its uses for cooking and fuel for power generation are also important. Electrical power is a critical human need insofar as it affects home heating and emergency services, such as communications, medical services, refrigeration, transportation, and others. Untreated sewage can flow into storm drains and ditches and can be discharged into the Great Salt Lake and Utah Lake; however, ruptured sewer lines and cesspools may contaminate water wells. In any case, the availability of water for sanitary uses will be drastically curtailed in the heavily damaged area. Damage to petroleum pipelines could create fire hazards and shortages of fuel for critical needs.

The detailed studies of damage to public utilities resulting from the San Fernando earthquake of February 9, 1971, have been extremely useful in estimating the amount of damage that might result from the two postulated Utah earthquakes. However, it should be realized that the area affected by intense shaking in California was relatively small and that the available resources in material and manpower from the adjacent areas were immense.

Public utility systems, whether publicly or privately owned, generally are designed and operated in a manner intended to allow the systems to remain in a functioning condition after a disaster. All utilities are designed to act in emergencies and have considerable resources of manpower, equipment, and materials.

Experience from the 1971 San Fernando shock and from other earthquakes has shown that good planning and construction of public utilities can substantially reduce the earthquake hazard but certainly not eliminate it.

Earthquake forces and their effects are still imperfectly known. Additionally, certain geologic hazards can, at best, only be minimized. Utilities must cross earthquake faults. Facilities must sometimes be located in structurally poor ground areas, such as in potential landslide regions, on liquefiable sands, and on soft, deep alluviums. As an example, see the discussion of landslide effects on the water supply in Ogden under "Water Supply."

Each type of utility has its own characteristic design, function, and vulnerability to earthquake. So severe was the damage suffered by utilities in the San Fernando earthquake of 1971, owing to failure of highway bridges, dams, and aqueducts and power, water, and gas facilities, that it amounted to approximately one-half the economic loss sustained. Subsequently, the subcommittee on Earthquake Resistance of Public Utility Systems of the newly appointed Earthquake Council for the State of California issued a report in 1974 concluding that all utilities shared the need for buildings that would meet the building code requirements for earthquake design, that would more adequately protect all fragile equipment, and that would protect transmission lines on, above, and in the ground. Elements of utility systems as diverse as bridges, pipelines, mechanical equipment, cables, railways, and dams obviously present special problems unique to the operation of each utility.

Special design criteria should be developed and used in the areas of known seismic risk to minimize damage and facilitate restoration of service. It is apparent that there should be adequate standby and storage facilities for water and fuel and alternate routes for energy, communication, and transportation.

Data collection

Data, in most cases, were made available by the individual utility companies for their own facilities. Field inspections of certain key facilities were made. Information was also obtained from personal interviews and from earthquake studies which have been made by two of the utility companies.

The following information was collected on lines and critical facilities for all types of public utilities: detailed system maps; capacity or size; date of construction; construction materials; soils data; additional building data, including height or number of stories, ground-floor dimensions, and type of foundations; and earthquake design considerations, such as location of shut-off valves and flexible couplings, and seismic design and bracing for equipment and building.

It was necessary to collect certain location, capacity, and construction data that related only to a particular type of utility:

1. Water supply:
   - sources of supply
   - storage and regulation reservoirs and tanks
   - water treatment plants
   - pumping plants
   - pressure-control facilities.
2. Sewage:
   - sewage treatment plants
   - pumping plants
   - outfalls.
3. Natural gas:
   - pumping and regulation stations
   - storage tanks
   - gas terminals
   - underground-storage fields
   - gas plants.
4. Electric power:
   - power-generating plants
   - transmission lines and towers
   - substations.
5. Petroleum pipelines:
   - pumping facilities
   - storage facilities.

Water supply and sewage data were obtained from the following sources:

1. "Weber County Master Plan of Water, Storm Water and Sanitary Sewer," from the Weber Area Council of Governments.

2. "Davis County Comprehensive Study of Culinary Water, Pressure Irrigation Water, and Sanitary Sewerage," from Davis County Planning Commission.
3. "Salt Lake County Master Water, Sewer, and Storm Drainage Plan" from Caldwell, Richards, and Sorensen, Inc., Consulting Civil Engineers.
4. "Water, Sewer and Storm Drain Study, Utah County, Utah Vol. II Plan Report" from Utah County Council of Governments.
5. Water distribution maps and description of some facilities from Salt Lake City Water Department.
6. Construction and operation information on water and sewer facilities from the Water Quality Section of the Utah State Health Facilities, Division of Health, Department of Social Services.

Natural gas information, including the "Mainline Schematic" and construction data, was obtained from Mountain Fuel Supply Company, Salt Lake City.

Electric power information was obtained from Utah Power and Light Company, Salt Lake City, and from field inspections of representative facilities.

Petroleum pipeline information was obtained from Amoco Pipeline Company, Pioneer Pipeline Company, and Chevron Pipeline Company--all in North Salt Lake.

Information on utilities serving Hill Air Force Base in Davis County was obtained from a field inspection of the base and from interviews with the base engineering personnel.

Damage calculations

Causes of earthquake damage to utility distribution and collection systems, particularly to those below ground, can be considered in two parts: (1) that due to ground shaking; and (2) that due to differential ground movement, such as surface faulting, landslides, subsidence, and so forth.

Ground-shaking damage--basis for calculations

In order to estimate damage for the postulated earthquakes, it was necessary to make certain assumptions,based on experience regarding the distribution of damage.

According to Schussler (1906, p.75), earthquake-induced water-main breaks in the distribution system in San Francisco after the 1906 earthquake were as follows:

In and near the burnt area	276	breaks repaired as of July 18, 1906
Outside of the burnt area	24	breaks repaired as of July 18, 1906
Total	300	

The number of main breaks in the 4.7-square-mile (12.17 km^2) burnt area (mostly congested area) was about 59 per square mile (22.8 per km^2). 59 per square mile (22.8 per km^2) should be several times greater than the number of breaks in San Fernando in 1971, due to the large areas of structurally poor ground in San Francisco. Schussler also pointed out that in excess of 23,200 service connections were broken, largely due to the collapse of burning buildings rather than to soil failure.

The 1933 Long Beach, Calif., earthquake resulted in over 500 main line breaks in water, gas, and oil lines in the areas of greatest intensity. Clearly, the greatest damage was in the structurally poor ground areas, but the available data are not sufficiently complete to allow meaningful calculations.

Lastly, the 1971 San Fernando earthquake produced considerable amounts of useful data. Table 20 and figure 16 (both in Steinbrugge and others (1971), summarize the damage to underground utilities with respect to geographic location in the hardest hit area of San Fernando Valley. The application of these data is given in the following paragraphs.

Ground-shaking damage--sample calculations

In considering ground shaking, we assumed that the extent of damage was a function of the ground motion and that the majority of ground-vibration damage to underground utility collection and distribution systems was due to Intensity IX (and greater). Estimates of damage due to ground shaking were then made by comparing the relative urban areas affected by Intensity IX (and greater) ground motion in the San Fernando earthquake with similar areas involved in the postulated earthquakes. This analysis is based on the assumption that the utility distribution and collection systems are uniformly distributed in the urban portions of the study areas in the same manner as they were in the Itensity-IX zones affected by the San Fernando earthquake. The obvious limitations to this method include the lack of complete information regarding the type of lines, line deterioration, and localized surficial geology. Indeed, many waterline outages will be due to pressure surges finding weak spots in old deteriorated lines; the result is immediate damage instead of what otherwise would be maintenance problems spread over a long period of time. In any event, the outages would be real at a time of great need.

Table 71 lists the total area of the four-county study area and also those portions considered to be urban. For each postulated earthquake, areas were determined for Intensities VIII and IX, as shown in table 71.

On the basis of published isoseismal maps of the San Fernando earthquake and taking into consideration the distribution and degree of damage, it was determined that an urban area of about 12 square miles (31.1 km^2) was affected by Intensity IX (and greater). An urban area of about three times that, or 36 square miles (93 km^2) was affected by Intensity VIII (and greater).

On the basis of the foregoing, one may calculate the number of breaks as follows: There were about 380 breaks in natural gas mains and services in the 12-square-mile (31.1 km^2) area affected by Intensity IX (and greater) in the San Fernando earthquake; it was estimated that 38 breaks, or about 10 percent of these, were caused by ground shaking and the remaining 342 by ground-differential displacements. Table 71 shows that in the magnitude-7.5 event on the Wasatch fault all of the urban area of Salt Lake County, or 75 square miles (194.3 km^2) would be affected by Intensity IX. Using these data, the number of breaks in natural gas mains and services in Salt Lake County may then be estimated as follows:

Number of breaks per square mile due to vibration = 38/12 = 3.167
Number of main and service breaks in Salt Lake County = 3.167 x 75
= 238, or about 240.

Table 71.--Distribution of intensities in urban areas

County	Total land area (mi^2)	Urban portion of county: area (mi^2)	Urban portion of county: % of total county land area	Wasatch fault, magnitude = 7.5: Intensity IX: area (mi^2)	Wasatch fault, magnitude = 7.5: Intensity IX: % of urban area	Wasatch fault, magnitude = 7.5: Intensity VIII and greater: area (mi^2)	Wasatch fault, magnitude = 7.5: Intensity VIII and greater: % of urban area	Magna fault, magnitude = 7.5: Intensity IX: area (mi^2)	Magna fault, magnitude = 7.5: Intensity IX: % of urban area	Magna fault, magnitude = 7.5: Intensity VIII and greater: area (mi^2)	Magna fault, magnitude = 7.5: Intensity VIII and greater: % of urban area
Weber-----------	581	15	2.6	0	0	15	100	0	0	15	100
Davis-----------	297	12	4.0	11	92	12	100	9	75	12	100
Salt Lake -----	764	75	9.8	75	100	75	100	75	100	75	100
Utah----------	2,014	14	0.7	3	21	11	79	2	19	11	79
Totals-----	3,656	116	3.0	89	77	113	97	86	74	113	97

The 10 percent and 90 percent distribution of pipeline breaks was based on the aforementioned table 20 and figure 16 of Steinbrugge and others (1971) and on the observation that the zone of deformation caused by surface faulting along the San Fernando thrust fault was extremely wide, ranging from a few hundred feet to over a few thousand feet. This large disturbed zone was due to the geometry of the faulting and the amount of displacement. Similarly, the width of such a zone for normal or dip-slip faults, such as the Wasatch fault, would often be 1,500 feet (0.48 km)--this width has been considered in the calculations and in the discussion of geologic hazards which follows.

In Salt Lake County, referring to table 71, the magnitude-7.5 event on the Wasatch fault affects about six times more urban area in the Intensity-IX zone than did the February 9, 1971, shock in San Fernando, and also about twice the urban area in the Intensity-VIII (and greater) zones. For the entire four-county study area, the magnitude-7.5 event on the Wasatch fault affects about seven times the urban area in the Intensity-IX zone and about three times the urban area in Intensity-VIII (and greater) zones.

Geologic-hazards damage

Some assessment of the problems caused by surface faulting can be gained from a knowledge of the postulated fault locations as compiled in table 72. Using this table for the magnitude-7.5 event on the Wasatch fault, the postulated fault breaks affect an estimated 10-mile (16-km) length in the urban portions of Salt Lake County (principally Salt Lake City) and an estimated one mile (1.6 km) in Davis County (near the city of Bountiful). The magnitude-7.5 shock on the Magna fault affects Kearns and Granger in Salt Lake County.

An approximation of the influence of permanent ground displacement can be made by computing equivalent hazard areas. An equivalent hazard area is defined as the length of a faulting (table 72) times a 1,500-foot (480 m) wide zone.

For an event on the Wasatch fault, the equivalent hazard area in Salt Lake County would be as follows: (10-mile faulting) x $\frac{1500'}{5280'}$ = 2.84 miles^2 (7.36 km^2).

Table 72.--Length of surface faulting in urban areas

[Source: Fault maps by consultant staff]

County	Length of surface faulting in miles	
	Wasatch fault, magnitude = 7.5	Magna fault, magnitude = 7.5
Weber	0	0
Davis	1 (1.6 km)	0
Salt Lake	10 (16 km)	3 (4.8 km)
Utah	0	0
Totals	11 (17.7 km)	3 (4.8 km)

The following is an application of this method for natural gas mains and services in Salt Lake County in the event of a magnitude-7.5 event on the Wasatch fault:

Breaks due to differential ground movement = $2.84 \text{ mi}^2 \times \frac{342 \text{ breaks}}{12 \text{ mi}^2}$ = 80 breaks

where approximately 3 mi^2 is the Equivalent Hazard Area for Salt Lake County and 12 mi^2 for San Fernando (coincidentally the same number as for the heavily hit urban area of San Fernando)

The total estimated number of breaks in mains and services would be 240 + 80 = 320, as shown in table 79.

The above methodology was used in the following subsections to estimate damage to underground services, with results as shown in tables 77, 78, and 79.

Analysis

Water supply

For analysis purposes, water-supply systems may be considered in two parts. One of these consists of the bulk-supply systems, which come from outside of the area via aqueducts. The other part includes the local-supply, storage, treatment, pumping, pressure-control, and distribution systems within the service area. (See figure 53 for location of major aqueducts, waterlines, treatment plants, and major storage reservoirs).

Because potable water is a critical human need, any lengthy disruption of the bulk supply due to fault rupture or ground shaking will force dependence on local supplies, from wells and storage reservoirs. However, experience in California earthquakes indicates that damage to the wells and to treatment, and distribution systems in the heavily shaken and poor-ground areas may greatly reduce the potential supply and the distribution of potable water to residents in these locations. In these heavily damaged areas, supply of drinking water via tank trucks will be necessary until the treatment and distribution systems can be repaired. Estimated annual domestic water usage by county is shown in table 73.

The quantity of available stored water will depend upon the depth of the previous winter snowpack in the mountains, rainfall, and time of

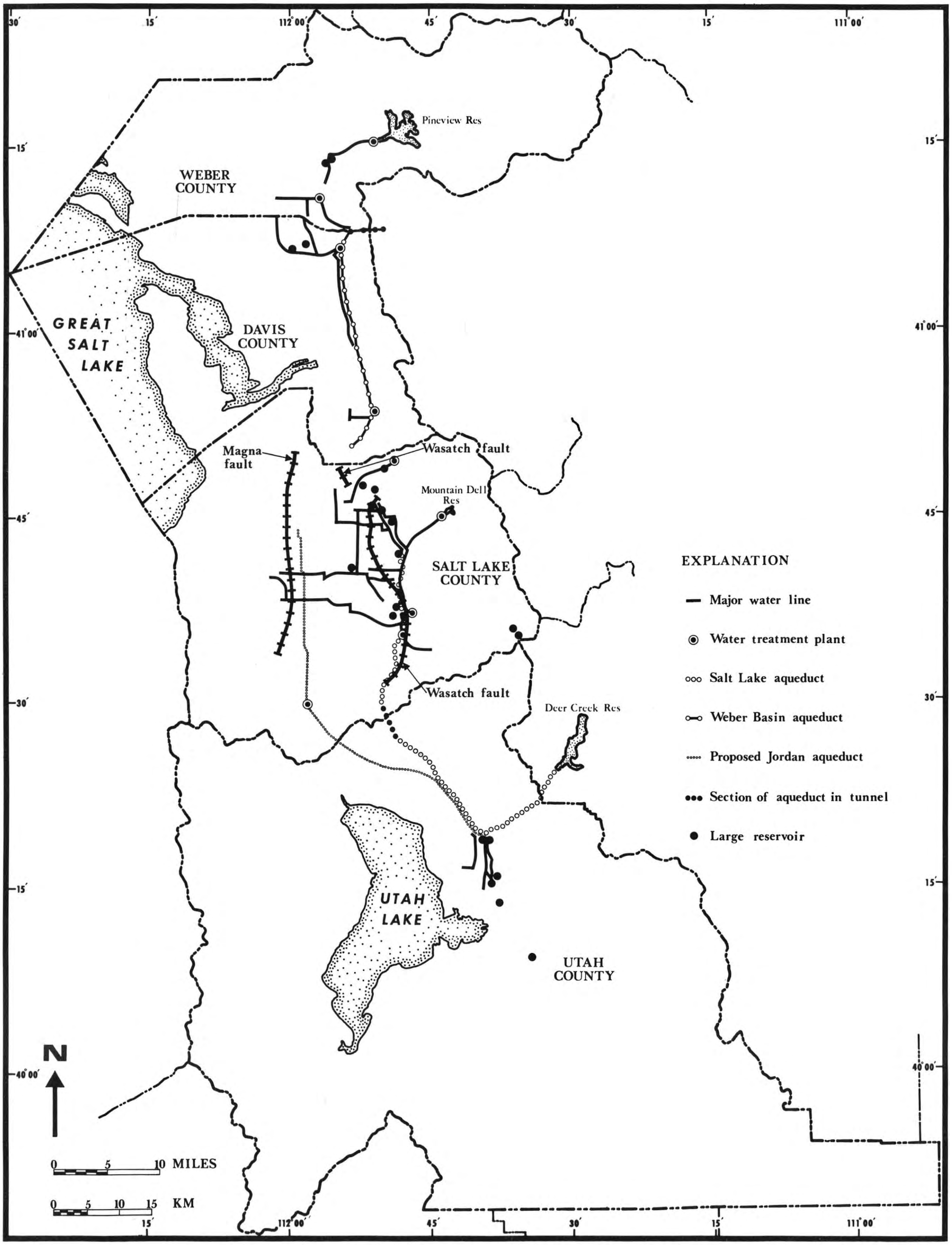

Figure 53.--Major water lines (24 inch and larger), water treatment plants, and large reservoirs. (Shown fault breakage is assumed for planning purposes.)

Table 73.--Summary of annual domestic water usage

(in acre feet)

County	Estimated Yearly Usage
Weber	26,000
Davis	7,500
Salt Lake	130,000
Utah	41,000
Total	204,500

year. Following a year of low snowpack and rainfall, and at the end of summer, the storage will be at a minimum.

There are 26 underground water-storage reservoirs having a two-million-gallon (7,570 m^3) capacity or more in the study area. These are located in figure 53. It can be assumed that they are all constructed of reinforced concrete or are concrete lined.

Supplies from wells will be curtailed owing to electrical power outages, damage to equipment, and contamination from adjacent ruptured sewer lines.

The amount of repair effort and period of outage for aqueducts and water mains ruptured by surface-fault movement or shaking will be significant, inasmuch as all fault crossings are buried beneath the surface in a pipe or tunnel (fig. 53). The ability to isolate ruptured sections is essential in order to prevent serious erosion and provide a working area. The Big Cottonwood and Salt Lake aqueducts in Salt Lake County are flow-line conduits with no in-line valves. If either of these lines were to rupture, water would have to be shut off at the treatment plants. It is likely that extensive flood and washout damage would occur in the vicinity of the gravel pits near the mouth of Big Cottonwood Canyon, where the lines cross the postulated Wasatch fault rupture, before flow could be terminated, compounding the difficulties of restoration. All of the water mains crossing the postulated Wasatch fault rupture have means for isolating the areas subject to rupture by surface fault movement; however, these systems are not automatic, and controls would have to be initiated following an earthquake. The Salt Lake City Water Department presently has a valve program in which all main valves within the system are tested every two years. Main valves that are operated electrically can also be operated manually if power fails. The locations of control devices may be such that large quantities of water will be released at the fault break, causing serious erosion.

A good example of the effects of a large landslide on a water system was provided by the June 19, 1975, landslide at the eastern end of 21st Street in Ogden. The slide was part of an ancient landslide formed from lake deposits consisting of silts, clays, and fine sands.

The overall length of the slide was 900 feet (275 m) from toe to main scarp, and the vertical relief is about 200 feet (61 m). The main scarp of the slide is 700 feet (214 m) long, east to west, is 40 feet (12 m) high, and borders residential property immediately to the south. Springs and seeps have been observed issuing from the lower portion. The slow movement on June 19th was probably aggravated by a very wet spring and heavy runoff in the area.

The landslide ruptured a 42-inch (1-m) water main that carries water down Ogden Canyon to the 23rd Street Reservoir, which has a 53-million-gallon (200,000-m^3) capacity. The water main was immediately shut off. The Weber County and the Utah State Offices of Emergency Services cooperated with the Defense Depot, Ogden, in obtaining 2,400 feet (731 m) of 8-inch (20-cm) steel pipe, which were used as temporary lines across the slide. A 10-inch (25-cm)-long rubberized section was installed in the middle of each line to give flexibility in case the slide moved again. Two 9 x 14 feet (3 x 4m) pressurized concrete boxes were installed at the ends of the temporary lines to eliminate the need for pumps, and a third block was poured to cap the old line. During the repair work, a second landslide occurred above the repair area, knocking out the South Ogden Highline Canal and causing water to be temporarily shut off again. Work was completed on the 8-inch (20-cm) lines, and water began flowing into the reservoir again exactly 2 weeks from the date of the first landslide.

About one-half of the population of Ogden (40,000 people) was temporarily restricted to water use for eating and cooking purposes. This was later liberalized to allow watering lawns every other day. A section of the city east of Washington Boulevard between 18th and 36th Streets was affected by the main break.

This Ogden landslide gives some idea of what could be expected in terms of population and area affected, repair time required, and repair effort required, following a break in one main water line serving a large community. Earthquakes have induced landslides in the past, and this would be a real possibility in the four-county study area, particularly during the spring. During a major earthquake in the study area, there would be numerous breaks due to land movement. (See the discussion of "Geologic-Hazards Damage" earlier in this section and the results of the methodology in table 77.)

Most of the water supply in Weber and Davis Counties is supplied by WBWCD, the Weber Basin Water Conservancy District. The district operates three water treatment plants, one in Weber County and two in Davis County. The city of Ogden operates its own water treatment plant just below Pineview Reservoir. Water for Davis County from the WBWCD flows directly out of the Weber River into the Davis aqueduct, which runs along the west face of the Wasatch Range parallel to the Wasatch fault. Most other water in the two counties (Weber and Davis) is supplied from locally owned springs and wells.

Hill Air Force Base purchases 30 percent of its water from WBWCD. Connections to the base are at the south and west gates. The remaining 70 percent of the water supply is from 6 wells on the base. These wells are 600 feet (183 m) deep, and water is drawn from the 400-foot (122-m) level. There is one 3.5 million gallon (13,250 m^3) reservoir located at the southeast end of the base. This is a compacted earth reservoir lined with concrete. There is one other medium-size reservoir and several steel water tanks on base, including a 1-million-gallon, surface-mounted steel tank. The reservoir and tanks are filled once each day, and water flows by gravity to the distribution system.

In Utah County all water supplies are locally owned and operated by the individual cities and towns. Water sources are springs and wells. There are no water treatment plants in the county.

Salt Lake County has a diversity of water supplies (table 74). Most of the water for county residents outside of Salt Lake City originates from wells and from the Deer Creek Reservoir via the Salt Lake aqueduct. Salt Lake City's main sources of supply are five canyon streams that drain into the valley (table 75), four of which have water treatment plants.

The 69-inch (175-cm)-diameter, 150-cubic-feet-per-second (4.2-m^3/sec) Salt Lake aqueduct, which supplies 25 percent of the county's water, flows 42 miles (68 km) from Deer Creek Reservoir to a terminal reservoir at 33rd South and Wasatch Drive. The aqueduct runs parallel to and crosses traces of the Wasatch fault at numerous locations along its

Table 74.--Salt Lake County water supply--approximate percentage by source

Source	Percentage
Deer Creek (aqueduct)	25
Little Cottonwood Creek	8
Big Cottonwood Creek	17
Emigration Canyon	1
Parleys Canyon	8
City Creek	6
Wells	35
	100

Table 75.--Salt Lake City water supply--approximate percentage by source

Source	Percentage
Deer Creek (aqueduct)	6
Little Cottonwood Creek	16
Big Cottonwood Creek	38
Emigration Canyon	2
Parleys Canyon	17
City Creek	10
Minor sources	1
Wells	10
	100

route. (See fig. 53). For most of the distance, the aqueduct is a concrete pipe that has been laid in a trench, varying in depth from 5 to 20 feet (1.5 to 6.0 m), and backfilled. Aqueduct water is treated at the Little Cottonwood Plant.

Water from Big and Little Cottonwood Creeks accounts for about 50 percent of Salt Lake City's supply. After treatment, the water is collected in a 3.5 x 4.5-foot (1 x 1.4-m)-conduit paralleling the Salt Lake aqueduct and stored in the same terminal reservoir. This conduit, along with the Salt Lake aqueduct, crosses the postulated Wasatch fault break near the mouth of Big Cottonwood Canyon. Figure 53 shows the major water lines in the four-county study area and their relationship to the postulated fault breaks.

Both Big and Little Cottonwood Treatment Plants are located in proximity to the postulated Wasatch fault rupture. All four of Salt Lake City's treatment plants have the ability to shut down half of the plant in order to clean the tanks. This would facilitate inspection and repair of earthquake damage, and if damage to tanks is limited to one side of the plant only, it would also allow partial plant operation following an earthquake. None of Salt Lake City's treatment plants have bypass valving, which would permit untreated water to bypass a heavily damaged plant and flow directly into the effluent pipes to be made available for firefighting purposes. All of the city's treatment plants have emergency power. Chlorine cylinders on line are typically chained down, and chlorinators are bolted to the floor. Estimated damage to water-treatment facilities is shown in table 76 .

The only canyon waters supplying Salt Lake County that do not cross the postulated Wasatch fault break are those of City Creek Canyon. However, if the postulated Wasatch fault break were extended through the downtown area, this source would also be disrupted, hampering firefighting efforts in the downtown area.

A number of artesian wells in the Murray area also provide a source of water for downtown Salt Lake City; the Murray area would be relatively unaffected by postulated surface faulting, but the water source would be subject to shutdown if power were lost. This water is fed to the downtown

Table 76.--Damage to water treatment plants

County	Total number of plants	Nonfunctional facilities: Wasatch fault, magnitude = 7.5	Nonfunctional facilities: Magna fault, magnitude = 7.5
Weber	2	1	1
Davis	2	1	1
Salt Lake	4	3	2
Utah	0	0	0
Totals	8	5	4

area, under pressure, by a pumping station located in a building that is of non-earthquake-resistant masonry construction, built in 1931. Water is transported from the pumping station to the downtown area via a thin-walled 3/16-inch (0.5-cm) steel pipe, 30 inches (76 cm) in diameter. This pipe is in poor condition, having suffered numerous breaks and electrolysis damage in the past, and is likely to be damaged severely by either postulated earthquake. This source of water is also vulnerable in that the artesian-well supply is likely to be contaminated by broken sewer lines.

Damage to water-distribution systems from the two postulated earthquakes is listed in table 76.

A major source of water supply for the Salt Lake Valley will be available some time in the near future through the Central Utah Project. The Jordan Aqueduct, which is presently under construction in Salt Lake County, will make available an additional 94,000 acre-feet (116,000,000m^3) of water per year to the county. The aqueduct will run from the mouth of Provo Canyon to a treatment plant near Point-of-the-Mountain. From there, treated water will flow north along the west side of the valley, terminating at 40th West and 21st South, to the west of Salt Lake City (fig. 53). The Jordan aqueduct will be less vulnerable to surface faulting than the Salt Lake aqueduct if, at points where it crosses zones of surface faulting near the mouth of Provo Canyon, it is constructed at the surface as an open channel. This would take much less time to repair following an earthquake than would a buried pipe.

For many years, the Salt Lake City Water Department has been well aware of the earthquake threat posed to the city's water system. Water-department personnel are all trained in earthquake-response procedures. An inventory of pipe is on hand for emergency repairs to the system. Accurate, up-to-date maps of the system are routinely maintained by the department. The department has also initiated earthquake studies of their own, from which much of the information in this section was gathered.

<u>Magnitude 7.5 on the Wasatch fault--expected damage patterns</u>.--

Table 77.--Damage to water-distribution systems

County	Wasatch fault, magnitude = 7.5 Breaks in mains	Wasatch fault, magnitude = 7.5 Services leaks	Magna fault, magnitude = 7.5 Breaks in mains	Magna fault, magnitude = 7.5 Service leaks
Weber	10	10	10	10
Davis	40	60	30	40
Salt Lake	300	430	250	350
Utah	10	10	10	10
Totals	360	510	300	410

For planning purposes it should be assumed that 60 percent of Salt Lake City's annual water supply, that portion originating from Big and Little Cottonwood Creeks and the Salt Lake aqueduct, will be initially lost and will not be fully restored for at least 90 days. All water mains crossing the postulated fault rupture in Salt Lake County will probably be severed. For planning purposes, the 3rd East pumping station will be nonfunctional, so water from the Murray wells will be lost to the downtown area. The only major source of water immediately available to fight fires in downtown Salt Lake will be City Creek Canyon. Some water will most likely be available from storage tanks and Mountain Dell Reservoir to areas in Salt Lake City east of the fault.

Throughout much of the Salt Lake Valley, water for drinking will need to be supplied, for the most part, by tank trucks, as breaks in sewer lines are likely to contaminate many of the water lines that are still intact following the earthquake.

Water supplies in Weber and Utah Counties will suffer minimal disruption, as the shaking is not likely to be severe and no surface rupturing occurs in these two counties for the postulated earthquake.

For planning purposes it should be assumed in Davis County that water supplied to some communities by the WBWCD will be temporarily disrupted, for 90 days or more, because of damage to the Davis County aqueduct. These communities will have to rely on local wells and tanker trucks for their water. Because most urban areas within Davis County will experience heavy ground shaking, it is likely that many of the local well supplies will be contaminated from broken sewer lines.

Damage to the water system at Hill Air Force Base will consist of some sanding up of the deep wells, the loss of some of the water tanks, breaks in mains, and service leaks. Assuming the loss of all WBWCD water and at least half of the water supplied from wells, the remaining 35 percent of the normal supply will be adequate for indefinite vital human consumption. This does not include water for the normal mission of the base, which uses large quantities of water for cooling purposes. If all water supply were eliminated, it has been estimated that there is enough water in base storage (reservoirs and tanks, assuming that they are full prior to the earthquake) for vital human consumption for 1 week.

Referring to figure 53, it can be seen that two of the large (2 million gallon or more) underground reservoirs in Salt Lake County are on or within one-quarter mile (0.40 km) of the postulated Wasatch fault surface rupture. Failure of these reservoirs should be assumed for planning purposes. An additional five reservoirs are within one mile (1.60 km) of the fault and could be seriously damaged. Failure of a large reservoir would result in loss of water supplies that could be vital following an earthquake. Local flooding would cause damage to property and even loss of life. There are numerous steel water storage tanks in the study area that are of smaller capacity, and many are also located in the foothills east of the city, on or near the fault zone. Large underground reservoirs in the other counties would be subject to shaking damage, but all except two of these are in areas of less intensity than Salt Lake County. Performance of concrete-lined reservoirs in past California earthquakes has been quite good when subject only to ground shaking. It should be noted, however, that both of the large reservoirs in Weber County and all of the large reservoirs in Utah County are between one hundred feet (or less) (30.48 m) and one-quarter mile (0.40 km) of documented extensions of the Wasatch fault.

Magnitude 7.5 on the Magna fault--expected damage patterns.-- An event on the Magna fault is not likely to be nearly as disrupting to the water supply as a Wasatch fault event. High-intensity areas within the four-county region would experience numerous pipe breaks due to severe ground shaking, but none of the major sources of water would be cut off by surface faulting. Also there are no large storage reservoirs near the postulated Magna fault rupture.

Sewage

For the most part, individual cities and towns within the study area operate and maintain their own sewage treatment systems. Treated effluent eventually flows into the Utah or Great Salt Lakes.

For analysis purposes, sewage systems may be considered to consist of collection systems, pumping plants, treatment plants, and outfalls. See figure 54.

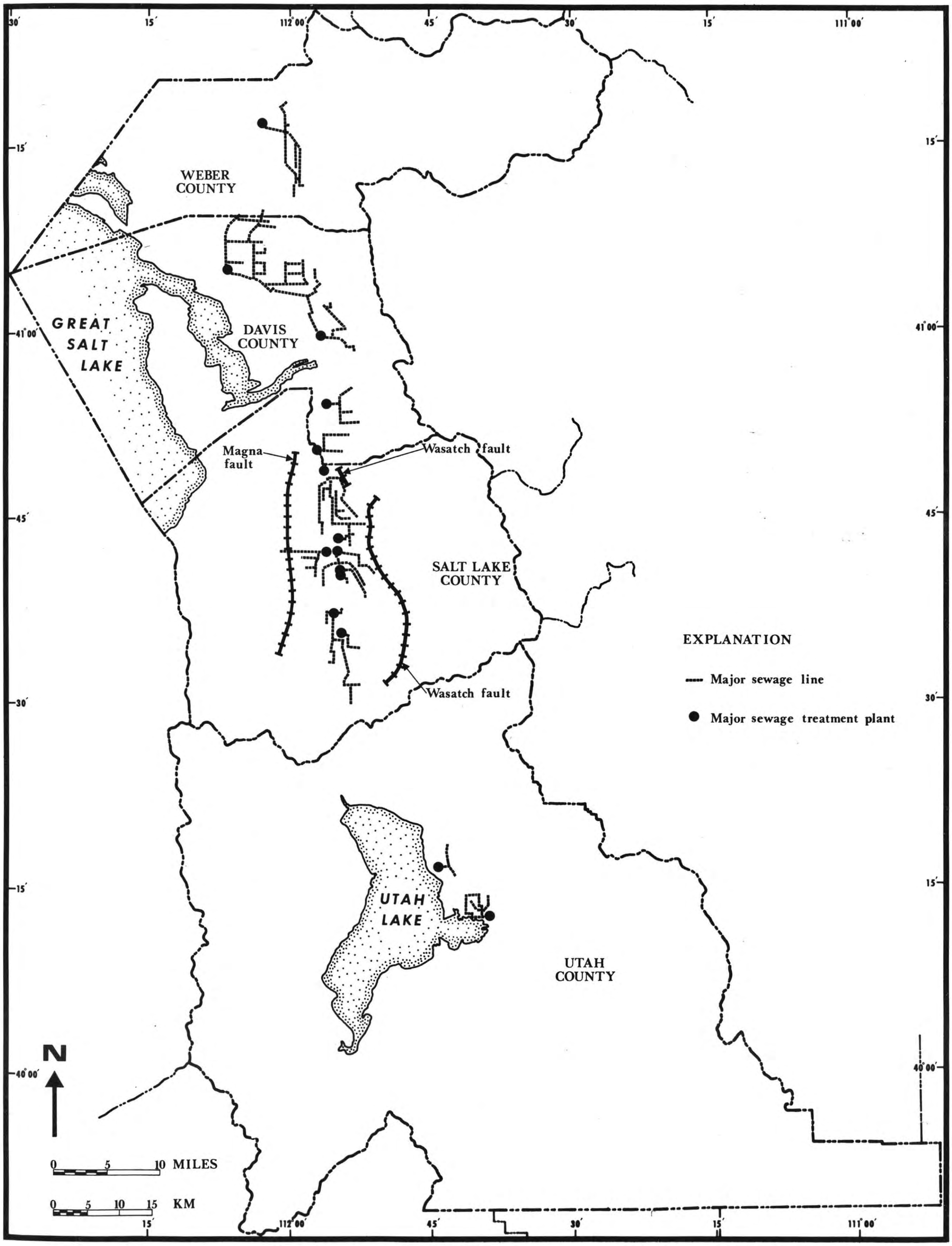

Figure 54.--Major sewage lines (24 inch or larger) and sewage treatment plants. (Shown fault breakage is assumed for planning purposes.)

Sewage-collection systems are susceptible to earthquake damage as a result of broken and crushed buried pipelines. These lines are usually of clay products, which are relatively brittle and can tolerate little movement without fracture. The magnitude of the damage is dependent on the size of the urban area affected by strong ground motion; damage is greatest where permanent ground movements occur owing to fault rupture, landslide, or poor ground conditions. The distribution of damage will be similar to that suffered by other buried conduits, such as those carrying water, natural gas, and petroleum products. Table 78 was developed using the methodology described in the Introduction to the "Public Utilities" section and assuming that 10 percent of the sewage-collection-system damage was due to ground shaking, and the rest was due to permanent ground movements.

The time necessary to determine the overall damage and to make repairs to a damaged collection system depends on the area involved and the availability of manpower, equipment, and materials. For example, in the relatively small area affected by the San Fernando, 1971, earthquake, 90 miles (145 km) of sewer lines were surveyed by pulling television cameras through them. From a practical standpoint, the sewer-collection lines will not be used significantly until the adjacent water-distribution systems are restored.

Pumping plants are susceptible to earthquake damage as a result of damage to buildings, piping, machinery, and equipment and of loss of electrical power. Raw sewage must either bypass damaged pumping plants by gravity flow or be dumped into the flood-control systems.

Treatment-plant buildings, tanks, piping, smokestacks, machinery, and equipment are all subject to earthquake damage. If the treatment plants are inoperable, untreated sewage must bypass the plant and be dumped onto spreading beds, the river, or the lakes.

Magnitude 7.5 on the Wasatch fault--expected damage patterns.--Collection systems will likely suffer widespread damage in the urbanized portions of Salt Lake and Davis Counties (table 78). For planning purposes, much of these two counties should be considered without sewage services for 3 to 6 months.

Table 78.--Damage to sewer lines

County	Wasatch fault, magnitude = 7.5		Magna fault, magnitude = 7.5	
	Miles of line affected	Line breaks	Miles of line affected	Line breaks
Weber	1	30	1	30
Davis	5	130	3	90
Salt Lake	34	940	25	690
Utah	1	30	1	30
Totals	41	1,130	30	840

Damage will be minimal in the lower intensity areas of Weber and Utah Counties.

All collection lines and mains will be ruptured where they cross the postulated fault rupture (fig. 54). For planning purposes, 50 percent of the pumping and treatment plants in Salt Lake and Davis Counties should be considered inoperable for one month.

Magnitude 7.5 on the Magna fault--expected damage patterns.--Table 78 indicates that sewage-collection systems should suffer substantial damage in Salt Lake and Davis Counties. The amount of damage would be less than that from a Wasatch fault event, because few lines cross the postulated fault rupture. For planning purposes, these heavily damaged areas should be considered without sewage service for 3 to 6 months. For planning purposes, 50 percent of the pumping and treatment plants in Salt Lake and Davis Counties should be considered inoperable for 1 month. Weber and Utah Counties will suffer minimal disruption.

Natural gas

For analysis, natural gas systems may be considered in two parts, similar to the division in water supply. One of these is the bulk-supply system, which comes from outside of the area via steel transmission pipelines. The other part consists of the underground storage, pumping, and distribution systems. (See fig. 53 for location of major gas-transmission facilities.) MFS, Mountain Fuel Supply Company, is the primary distributor of natural gas in the study area.

No storage tanks are located within the study area. One natural underground storage reservoir is located near the study area in Coalville. This reservoir is used primarily to control intermittent surges and ebbs in the gas supply and is not of sufficient capacity to provide a significant backup source of supply if transmission lines were interrupted between Coalville and Rock Springs, Wyo.

The major portion of bulk natural gas for the study area is piped via three feeder lines from Rock Springs, Wyo. One 16-inch(40-cm) line branches off at Coalville, Utah, and enters the study area via Weber Canyon to serve the Ogden area. The two remaining feeder lines (20- and 24-inch)

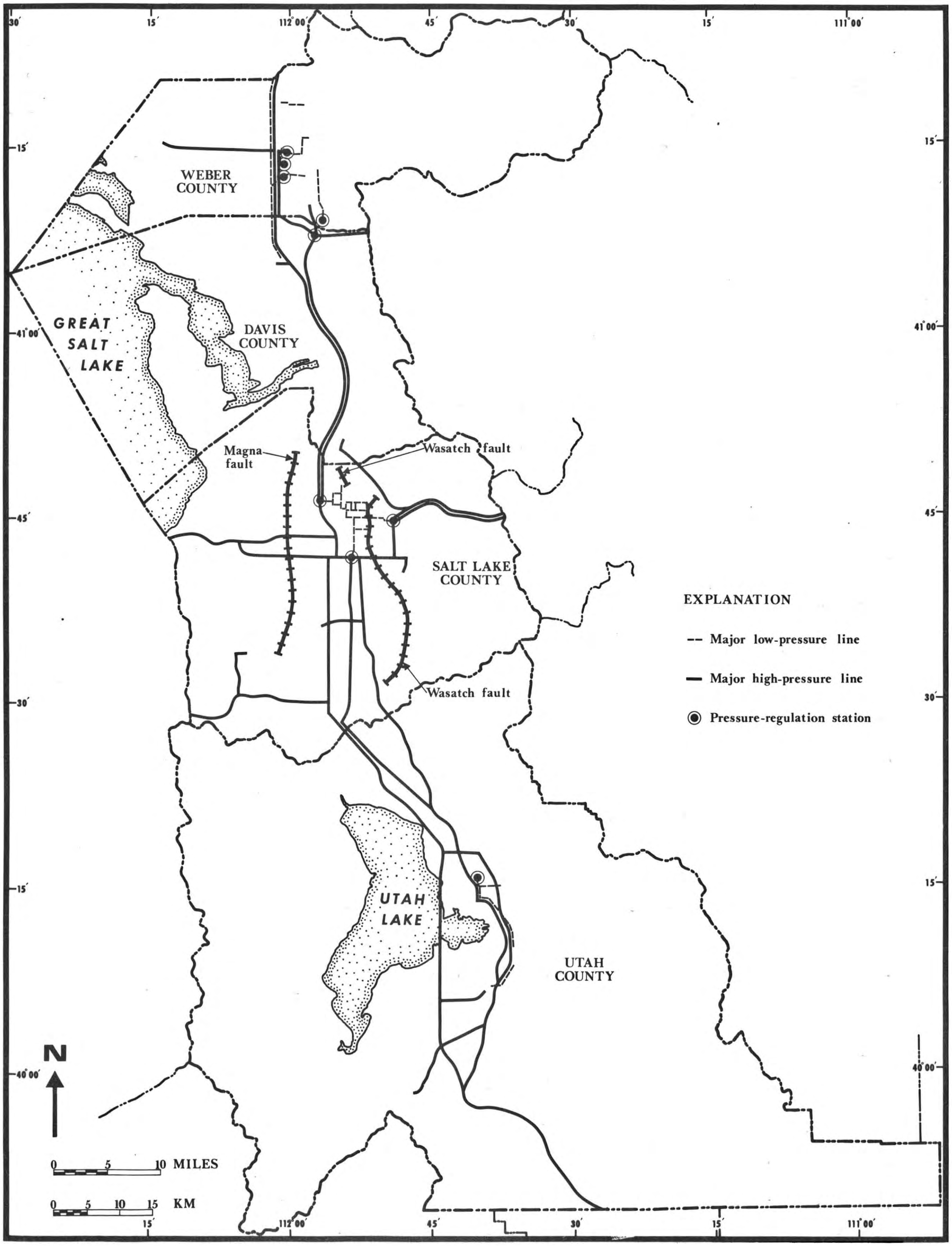

Figure 55.--Major natural gas transmission facilities. (Shown fault breakage is assumed for planning purposes.)

(51-and 61-cm) enter the study area via Emigration Canyon. Another significant source of supply originates from gas fields in the central and eastern portions of Utah and enters Utah County from the south via an 18-inch (46-cm) pipeline.

The major portion of the study area's natural gas supply, approximately 60 percent, is carried by the two welded-steel, high-pressure lines (250-380 psi) via Emigration Canyon. This gas is depressurized to 125 psi and distributed at the Sunnyside pressure-regulation station near the mouth of the canyon. The station is composed of several small one-story buildings of old, non-earthquake-resistive construction. The transmission lines and valves, however, are mostly below grade and, therefore, not likely to be damaged by building collapse. At one point within the facility, where crossover valves are located, the lines are above grade. However, this occurs in a small, recently constructed masonry building not likely to suffer earthquake damage.

Experience in California earthquakes indicates that disruption of the underground distribution system can result in lengthy outage times. Areas must be isolated and leaks located and repaired before service can be restored. Damage to underground lines is usually intensified in poor-ground and landslide areas.

Damage to natural gas distribution systems was estimated by using the methodology discussed in the "Introduction," with results shown in table 79.

Additional damage to distribution systems can be caused by structural damage to buildings, which affects the entering gas lines. Toppling of unanchored water heaters will cause ruptures of connecting gas lines. Fortunately, in past earthquakes, extensive structural fires attributable to natural gas leaks have not occurred, but this does not mean that a problem does not exist.

All of the family-housing areas at Hill Air Force Base are heated by natural gas on a firm (noninterruptable) basis by Mountain Fuel Supply Company. There is no standby heating system for the facilities. The airmen dormitories and older barracks living quarters are gas heated on an interruptable basis and have emergency-heating-oil standby systems.

Table 79.--Damage to natural-gas distribution systems

County	Wasatch fault, magnitude = 7.5		Magna fault, magnitude = 7.5	
	Breaks in mains and services 1/	Customers affected	Breaks in mains and services 1/	Customers affected
Weber------------	10	430	10	430
Davis ----------	40	1,920	30	1,280
Salt Lake-------	320	14,270	260	11,720
Utah ----------	10	430	10	430
Totals-------	380	17,050	310	13,860

1/Half are main breaks; the other half are service breaks.

The base has a sufficient heating oil supply so that all buildings operating on the standby oil system could be heated for at least 30 days.

Mountain Fuel Supply Company has been studying the problem of possible earthquake damage to its facilities for many years. The engineering department of the company has recently prepared a report covering the relationship of the Wasatch fault to its high-pressure gas lines.

Magnitude 7.5 on the Wasatch fault--expected damage patterns.-- For planning purposes, it should be assumed that the postulated earthquake will rupture two feeder lines in Salt Lake County, where they cross the fault break. One is a 16-inch (40-cm) line at 3300 South and 13th East in Salt Lake City; the other is a 20-inch (51-cm) line in North Salt Lake. Valves that can isolate the breaks are located on either side of the fault in both cases. Until repairs can be made, some natural gas might be available on a limited basis to Salt Lake County from transmission lines in Weber and Utah Counties.

Some damage to transmission-line pumping stations is likely; however, this should be repaired by the time that line ruptures are repaired. The estimated damage to the distribution system is shown in table 79.

Magnitude 7.5 on the Magna fault--expected damage patterns.-- No major gas lines cross the postulated fault rupture, so a Magna event will not be quite as disruptive. The most serious effect on natural gas systems by this earthquake would be the widespread disruption of the distribution system to individual customers and plants in high-intensity areas (table 79).

Electrical power

A large proportion of the electric power available to the study area is generated outside of the four counties, as indicated in table 80. Electric power for most of the users in the study area is supplied and distributed by UP and L (Utah Power and Light Company). Figure 56 locates the electric-power generating facilities and lines in the study area, and table 81 lists the dates of construction and sizes and types of electric generating plants in the study area.

Table 80.--Electrical bulk power[1/]

[Source: Utah Power and Light Company 1974]

Type of power	Power-generation source: Outside of study area in megawatts	Power-generation source: Inside of study area in megawatts	Total bulk power in megawatts
Steam	1,328	330	1,658
Hydro	316	0	316
Gas	0	14	14
Totals	1,644	344	1,988
Percents	83	17	100

1/The quantities shown are total rated hourly capacities of electrical generating plants.

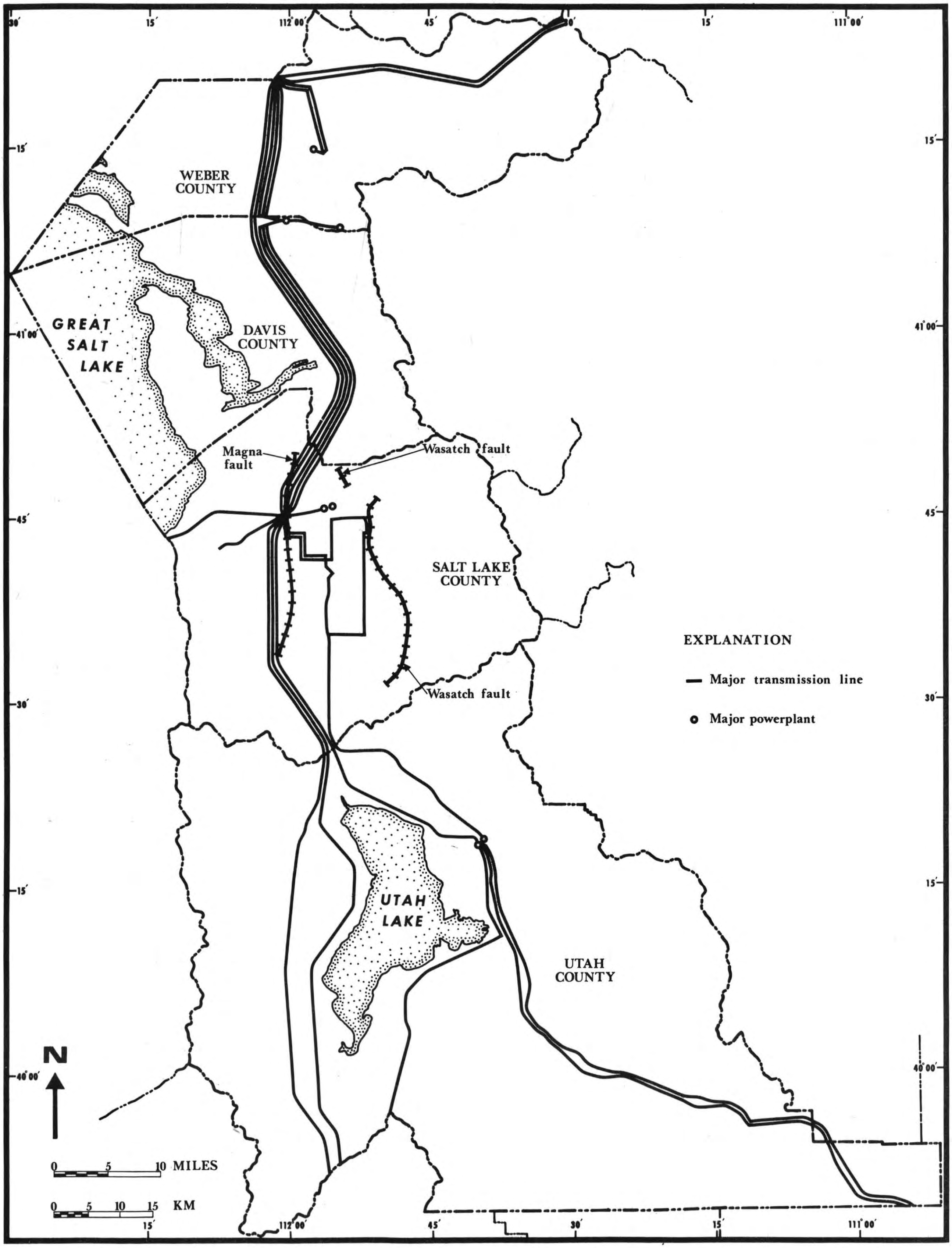

Figure 56.--Major power transmission lines and electric power generating facilities. (Shown fault breakage is assumed for planning purposes.)

Table 81.--Electric generating plants in the four-county study area

Date constructed	Plant	Size	Type
1936	Hale No. 1	17,500 KW	Steam-electric
1950	Hale No. 2	47,000 KW	-----do-------
1951	Gadsby No. 1	66,000 KW	-----do-------
1952	Gadsby No. 2	75,000 KW	-----do-------
1955	Gadsby No. 3	100,000 KW	-----do-------
1911-1924	Jordan	24,750 KW	-----do------
1971	Little Mountain	13,850 KW	Gas turbine

Even if the local facilities were extensively damaged, the overall effect on the total bulk power supply would be small. Damage to the incoming bulk-power transmission lines would have a much greater effect.

Transmission towers are designed for heavy lateral forces due to wind and broken conductor conditions, and so they are inherently very earthquake resistant. However, they are susceptible to damage due to landslides and movements of supporting soils. Many of the transmission lines entering the study area traverse mountainous terrain, which is subject to extensive earthquake-induced landsliding. Additionally, transmission lines can be put out of service for varying periods of time owing to conductors swinging together and shorting, or for longer periods of time by lines being broken because of tension caused by surface fault movements. Also, shutdown of switching stations will put transmission lines out of service.

Information was received on the Gadsby No. 3 electric generating plant (built in 1955), which indicates that the building and equipment (boiler, generator, crane, coal bunker, and stack) were designed for moderate earthquake forces. UP and L design standards for items of electrical equipment at switching stations and terminals follow the latest edition of the UBC (Uniform Building Code, and, according to the engineering department of UP and L, transformers, circuit breakers, and other large items of equipment placed in substations after 1970 are anchored to their foundation to resist strong (zone-3) earthquake forces. In some cases this has been accomplished by welding the steel frame at the base to steel plates that have been cast into the concrete foundation with anchor bolts.

Field inspections were made of two large terminal substations, one intermediate distribution substation, and two small distribution substations.

One of the terminal substations is an older facility and contains some large transformers mounted on rails set in concrete foundations. These units could move on the rails and break their line connections during a large-magnitude earthquake. Newer transformers at both of the terminals and at the other three substations inspected were of a type that was mounted on steel frames that were not anchored to their foundations. This condition also existed for some of the oil-type circuit breakers at the terminals and at the intermediate substations. Experience with electric power equipment during the San Fernando earthquake of 1971 indicated that large unanchored equipment is subject to "walking" and overturning when acted upon by strong earthquake forces. This would sever lines and cause serious damage to equipment. The majority of oil circuit breakers at the intermediate substation and all the circuit breakers at the two small substations were supported by steel frames that were bolted to the foundation. At the newer terminal substation (built in 1970), oil circuit breakers are welded to anchored foundation plates.

Airblast circuit breakers at the terminal were supported on porcelain insulator columns. Capacitor banks at the terminal and at the intermediate substation were also connected to a steel-frame subassembly by porcelain insulators. These insulators are very adequate for vertical loads, but under earthquake-induced lateral-impact forces, this type failed in San Fernando.

At the older terminal, a brick bearing-wall building (built in 1913) contained master controls, switching equipment, and large rotating condensers that control voltages. Collapse of this building could seriously affect the function of the entire facility. The intermediate-distribution substation also had automatic controls and switching units, located in a newer (1960) building that should withstand moderate earthquake forces. The control and switching panels were bolted to the floor. A large battery rack in the building was not anchored to the floor; however, the batteries were braced at midheight and would be restrained during an earthquake. These batteries are used to operate circuit breakers and supervisory controls.

Throughout the study area, single, pole-mounted transformers are positively attached with a bolted frame to the power pole. However, two or more transformers are often placed on a suspended platform and have inadequate restraint.

The UP and L Company is aware of the earthquake potential of this area and recently commissioned a study to determine the hazard to its facilities from earthquakes.

Distribution-system damage can be widespread and severe, requiring considerable time, manpower, equipment, and materials to repair. This damage will consist of distribution lines and poles broken by falling parts of buildings and damaged by fire; numerous transformers damaged by falling to the ground and by fire; wires swaying together causing short circuits, wire breaks, and fires. Old, non-earthquake-resistant structures will suffer considerable damage. Underground distribution systems will suffer damage when affected by surface fault breaks, landslides, and earth settlements. Table 82 summarizes the miles of distribution lines in the study area and the percent of underground lines.

Table 83 indicates the number and percent of homes in the study area that are heated electrically. If an earthquake were to occur in winter and electrical distribution systems were interrupted, the number of homeless could be increased owing to lack of heating.

Assuming that all of the damage suffered by the electrical systems in the 1971 San Fernando earthquake was due to ground shaking, losses to the electrical distribution system in the study area were estimated and are summarized in table 84.

Electric power to Hill Air Force Base is supplied from two main delivery points, and there are five substations on the base. These substations are typical of those found throughout the study area and are susceptible to damage from tipping and walking of large transformers and collapse of capacitor banks.

Standby generators supply emergency power to the following facilities: hospital, command post, communication building, and airfield lighting vault. However, when these generators are not anchored to their foundations, they are subject to the same damage as the transformers from movement due to earthquake forces. The large diesel generator in the heating plant near the hospital is anchored to a thick concrete foundation and should remain functional following an earthquake.

Magnitude 7.5 on the Wasatch fault--expected damage patterns.-- For the purposes of this report it should be anticipated that 30 percent of the transmission lines entering the study area will be out of service either due to damage to the lines or to switching terminals.

Extensive damage to distribution systems is likely in the urban portions of Salt Lake and Davis Counties (table 84), whereas negligible damage is anticipated in the remaining two counties.

For planning purposes, at least one of the two electric generating

Table 82.--Number of miles of distribution lines in four-county study area

[Source: Utah Power and Light Company, 1974]

(1 mile = 1.61 km)

County	Overhead system	Underground system	Underground percent
Weber	770.97	68.27	8.13
Davis	444.17	50.03	10.12
Salt Lake	2,008.44	335.43	1/14.31
Utah	673.53	53.93	7.41
Totals	3,897.11	507.66	11.53

1/There are approximately 12.7 miles (20.4 km) of underground system in the fault zone, which would be 0.54 percent.

Table 83.--Homes heated electrically

[Source: Utah Power and Light Company, 1974]

County	All-electric customers	Total residential customers 1/	Percent all electric
Weber	1,499	39,515	3.79
Davis	1,092	17,835	6.12
Salt Lake	4,414	147,199	3.00
Utah	916	18,690	4.90
Totals	7,921	223,239	3.55

1/Includes single-family dwellings and apartments.

Table 84.--Damage to electrical-power distribution systems and substations

County	Wasatch fault, magnitude = 7.5 or Magna fault, magnitude = 7.5		
	Distribution transformers damaged	Circuits interrupted	Substations nonfunctional
Weber ------------------	90	250	1
Davis -----------------	320	920	1
Salt Lake ------------	2,190	6,250	15
Utah -----------------	90	250	2
Totals ---------	2,690	7,670	19

plants in Salt Lake County should be considered nonfunctional from the Wasatch fault event. Also, from table 84 it can be seen that 19 electric substations would probably be rendered nonfunctional from the earthquake. Fifteen of these are in Salt Lake County. Eleven of this number would be damaged because of ground shaking, and four are within one-quarter mile (0.40 km) of the postulated Wasatch fault rupture and would be nonfunctional owing to extreme ground movement.

Magnitude 7.5 on the Magna fault--expected damage patterns.--This event should have approximately the same effect on electric power as the Wasatch fault occurrence. Again, one electric generating plant and 19 substations would be rendered nonfunctional Three substations, including a large-terminal substation, are within one-quarter mile (0.40 km) of the postulated Magna fault rupture.

Petroleum pipelines

Major petroleum-pipeline routes are shown in figure 57. Only two lines cross the postulated fault rupture. These two 10-inch (25.4 cm) lines carry crude oil down Emigration Canyon and cross the fault near the five oil refineries located between Bountiful and Salt Lake City.

Important lines also branch out from the major pipeline routes to provide fuel for the Salt Lake City Airport and Hill Air Force Base. If these lines are broken, emergency operations would be hampered, as fuel for planes would have to be trucked.

All of the major pipeline routes, as well as the five refineries within the study area, are located in zones of high-intensity shaking. The probability of major fires and pollution, caused by pipeline breaks and damage to refineries, is high. Pipelines have shutoff valves along their routes, but these are manually activated and, in the event of breakage, some time would elapse before these valves could be closed.

Magnitude 7.5 on the Wasatch fault--expected damage patterns.--Rupture will likely occur to both lines crossing the postulated faulting. For planning purposes numerous other breaks caused by intense ground shaking should be anticipated. The likelihood of fire from these breaks and of damaged oil refineries will be high.

Emergency operations will be handicapped because of interrupted fuel

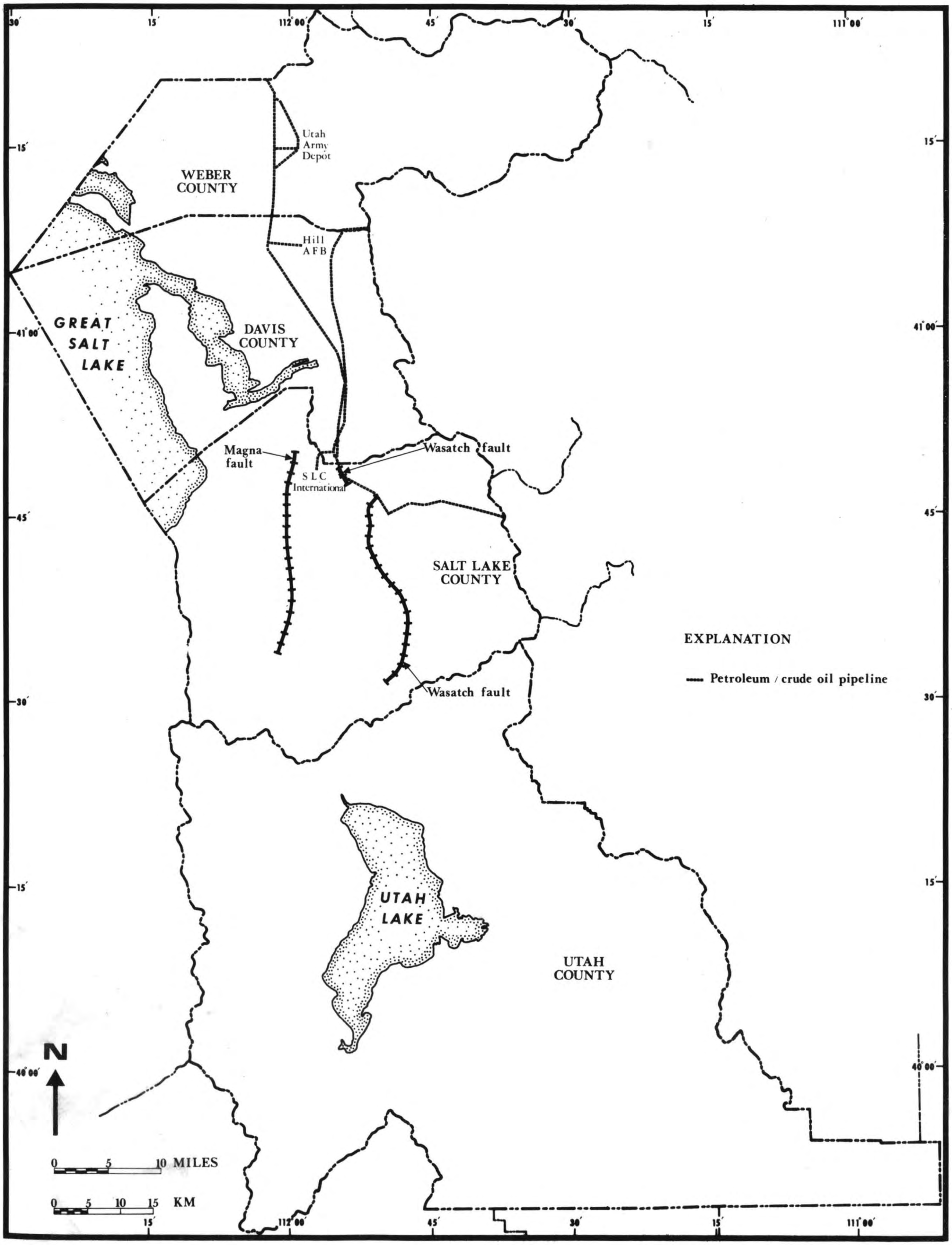

Figure 57.--Major Petroleum/crude oil pipelines. (Shown fault breakage is assumed for planning purposes.)

supplies via pipeline to the airport and air base. Some or all of the fuel for aircraft will have to be trucked.

Magnitude 7.5 on the Magna fault--expected damage patterns.--Damage will be similar to that for the Wasatch fault event, with the exception that no petroleum pipelines will be severed directly by surface faulting.

Public schools

Introduction

School buildings are distributed throughout the four-county study area in proportion to the resident population density. If a school remains in a safe condition following an earthquake, it can be used, if necessary, for mass shelter and feeding of the homeless population. Therefore, for planning purposes, it is important to know the location and distribution of schools considered most likely to be available for these functions following an earthquake. This section deals with this matter, as well as with the potential deaths and injuries of the student-faculty population.

In contrast to California, where public schools built after 1933 have been required by law to be designed for a high degree of earthquake resistance, local government agencies in Utah did not require that any consideration be given to earthquake design for buildings until after the 1961 edition of the UBC,(Uniform Building Code), was adopted by most city and county governments in Utah. This edition of the UBC required that buildings in Utah be designed for moderate (zone-2) earthquake forces.

The catalyst for California earthquake-design legislation was the 1933 Long Beach earthquake; several school buildings of unreinforced-masonry and wood-floor construction suffered severe damage or collapse. Fortunately, the earthquake occurred after school hours, and a potentially catastrophic situation was averted. However, the destruction was so extensive that, in that same year, the California legislature passed a law requiring all new public-school construction to be highly earthquake resistant. The performance of structures built under this law has been excellent in subsequent shocks.

Data collection

Data on schools in the four-county study area were obtained from the following sources:

1. "1974-75 Utah Public School Directory," Utah State Board of Education. This directory provides a complete listing of all schools in Utah, including location, total student enrollment, grade levels, and numbers of administrative staff.

2. Copies of DCPA "All Effects Data Collection Forms," giving construction data for schools in Weber County.
3. Construction information, collected from computer printouts for a school-safety study being prepared by the Utah State Building Board.

The above sources supplied the vital information, which was sufficient for the analysis purposes of this report. Accordingly, no additional data were collected, nor was it necessary to conduct field inspections of various buildings in the four-county study area.

Table 85 is an inventory of all public schools and school enrollments in the four-county study area.

Analysis

Because of the 30-year time lag between California and Utah in requiring earthquake-resistive design, there is a higher percentage of students in Utah attending classes in public school buildings that are not designed for earthquake forces and are, therefore, potentially unsafe. Over half of the public school students in the study area attend class in potentially unsafe buildings built prior to 1961.[1/] Nearly one-fourth of the students in the study area are attending classes in buildings built prior to 1933, when Salt Lake City first adopted the UBC (table 86). It is likely that those pre-1933 structures located in high-intensity zones will suffer severe damage or collapse in either postulated earthquake.

Serious damage or partial collapse of 25 percent of the public school buildings in the study area built prior to 1961 is a real possibility on the basis of damage from the postulated earthquakes. The most vulnerable schools are those built prior to 1933 with unreinforced-masonry-bearing walls using sand-lime mortar and wood-floor and roof construction. Damage to this type of building has been spectacular following major earthquakes in California and elsewhere.

1/Earthquake-design provisions were included as an appendix to the Uniform Building Code for many years prior to 1961, so it is probable that some Utah school buildings built before 1961 were designed to resist earthquake forces; however, the actual number in this category is unknown.

Table 85.--Public schools in the four-county study area

[Source: Utah Public School Directory, 1974-75. Note: This table does not include colleges, universities, or special schools]

County	Elementary		Junior High		Senior High	
	Total no. of facilities	Total enrollment	Total no. of facilities	Total enrollment	Total no. of facilities	Total enrollment
Weber -----------	40	16,833	12	8,004	5	7,739
Davis -----------	35	17,400	9	8,774	6	8,148
Salt Lake-------	113	65,225	30	30,672	16	26,422
Utah------------	47	19,387	13	9,262	8	9,278
Totals-----	235	118,845	64	56,712	35	51,587

Table 86.--Public school enrollment by age of facility 1/

[Source: Utah State Building Board]

County	Enrollment in schools built prior to 1933	Enrollment in schools built between 1933-1961	Enrollment in schools built between 1961-1975
Weber--------	5,693	12,295	14,588
Davis-------	5,753	13,143	15,426
Salt Lake--	31,895	37,631	52,793
Utah -------	10,715	19,322	8,427
Totals------	54,056	82,391	91,234

1/Based on age of original structure.

Three or four partial collapses, trapping hundreds of students, is a reasonable possibility. Table 87 lists, by county, the number of school buildings built prior to 1933, with occupancies greater than 300, that are still being used for classes. Figure 58 is a map of these facilities.

Those schools built directly on or near the actual zone of surface rupture are much more likely to have serious damage or partial collapse, regardless of when they were built; several school buildings within the study area are located near faults. California now has a law that prevents school construction within a certain distance of a known active fault zone; Utah does not.

Schools most likely to be available for mass shelter and feeding following an earthquake are those built after 1970, when Utah was placed in seismic-risk-zone 3 and when buildings should have been designed for strong earthquake forces. Table 88 lists these facilities by county. Figure 59 maps their locations. Most of these newer schools have a cafeteria, which would be important in feeding the homeless from an earthquake. However, lack of electric power and natural gas would adversely affect this potential resource.

Magnitude 7.5 on the Wasatch fault--expected damage patterns.--
Table 89 indicates that the study area will suffer extensive loss of classrooms following the postulated earthquake. Much of this will be due to older schools being closed until their safety for occupancy can be verified. A substantial number of newer buildings, however, are expected to sustain only minor damage, and these facilities should be available for mass shelter and feeding.

Of more concern is the potential for loss of life and injuries to occupants of schools in the four-county study area. Table 90 indicates that nearly 1,000 lives might be lost if a magnitude-7.5 event on the Wasatch fault were to occur during school hours.

Eight schools in Salt Lake County (6 elementary, 1 junior high, and 1 high school) are within one quarter mile (0.40 km) of the postulated surface fault rupture. For planning purposes it should be considered that each of these schools would suffer partial collapse. It should be

Table 87.--Public schools built prior to 1933 with present occupancy of more than 300

County	Number of Schools
Weber	9
Davis	9
Salt Lake	43
Utah	12
Total	73

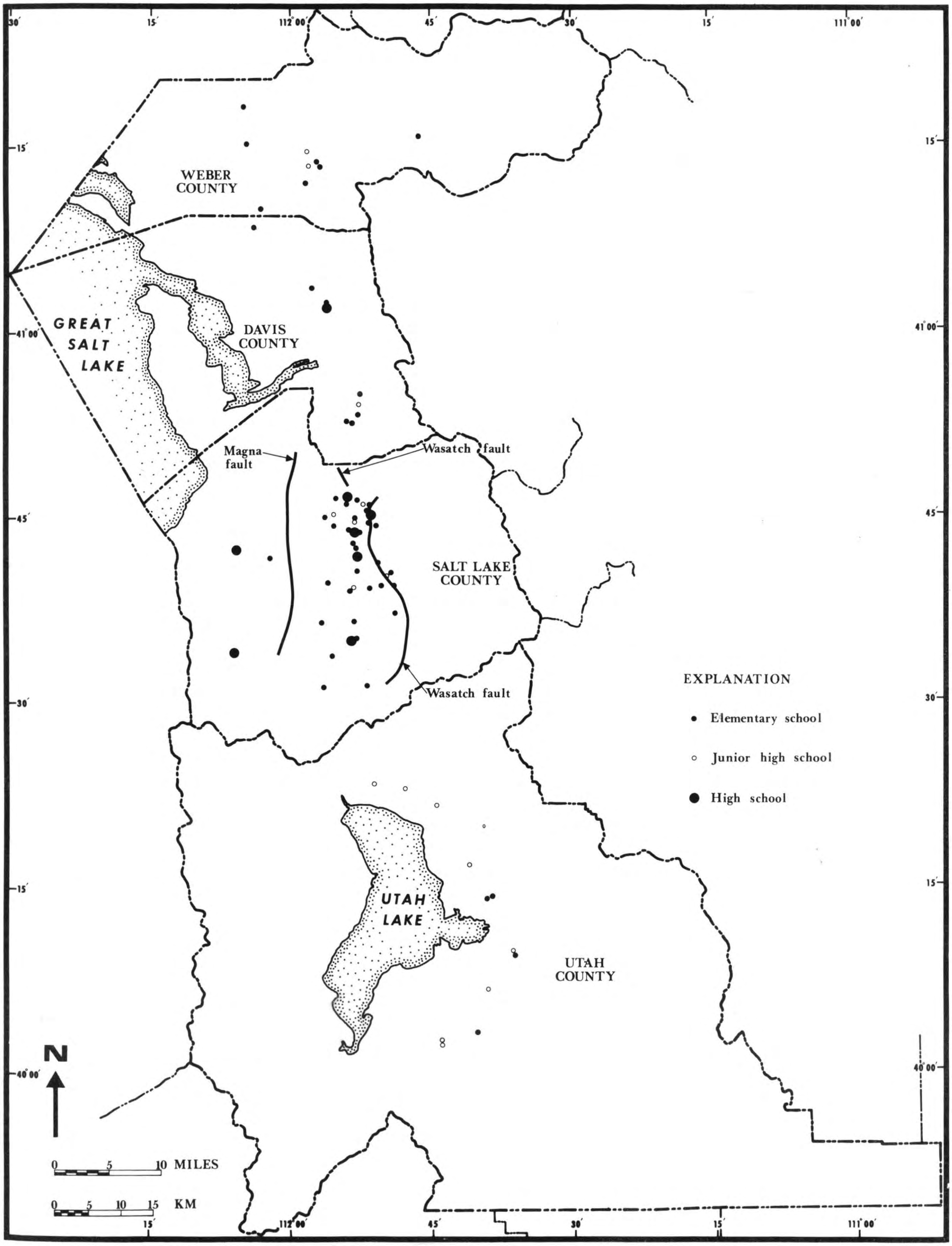

Figure 58.--Schools built prior to 1933 with occupancies greater than 300. (Shown fault breakage is assumed for planning purposes.)

Table 88.--Public schools built after 1970

County	Number of schools
Weber	3
Davis	3
Salt Lake	12
Utah	1
Total	19

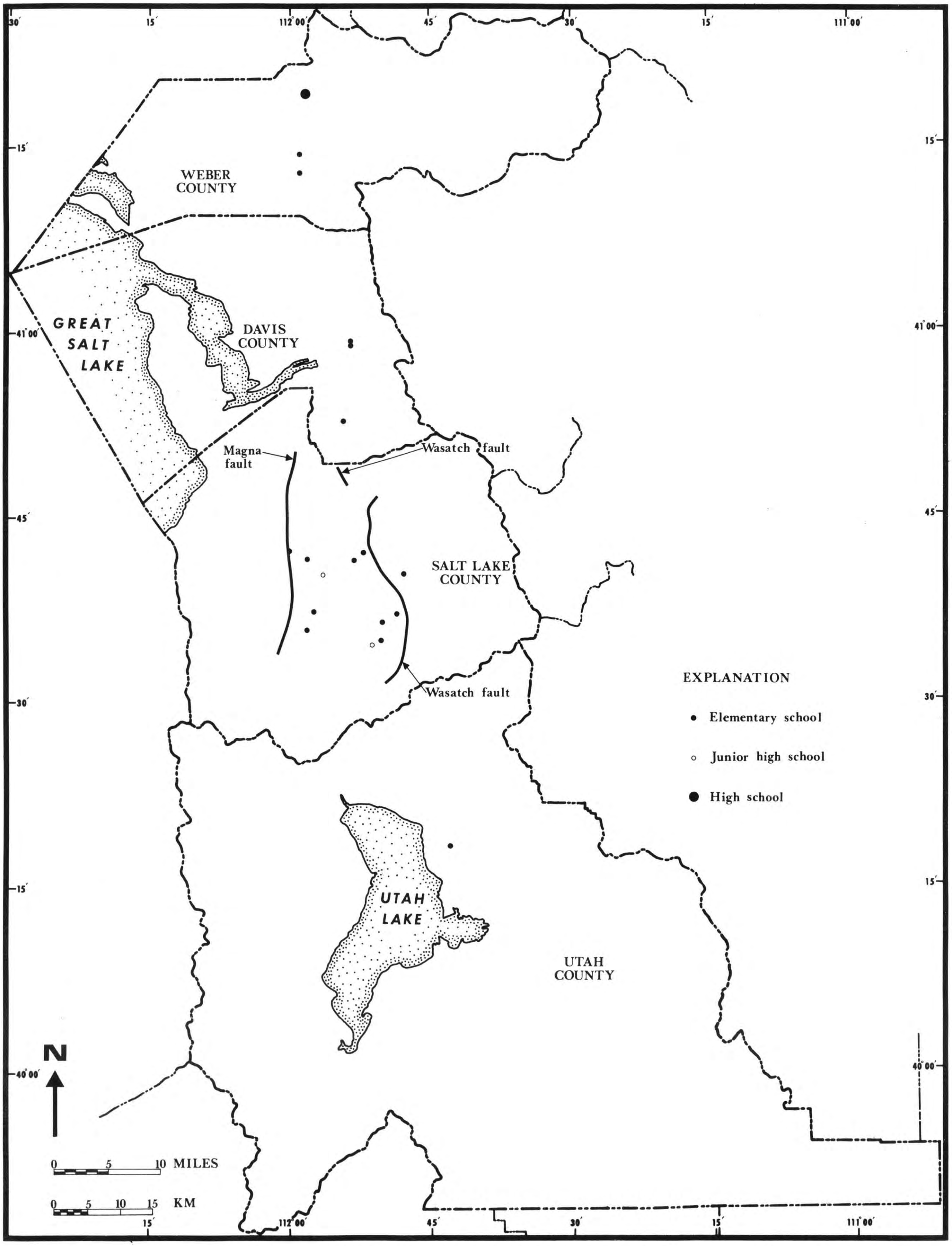

Figure 59.--Schools built after 1970 with occupancies greater than 300. (Shown fault breakage is assumed for planning purposes.)

Table 89.--Loss of public school classrooms, in percent

County	Wasatch fault, magnitude = 7.5	Magna fault, magnitude = 7.5
Weber ----------------	25	25
Davis ---------------	30	30
Salt Lake -----------	40	35
Utah ----------------	30	30

Table 90.--Public school deaths and serious injuries[1/]

County	Wasatch fault, magnitude = 7.5		Magna fault, magnitude = 7.5	
	Deaths	Serious injuries	Deaths	Serious injuries
Weber----------	30	120	30	120
Davis----------	70	280	70	280
Salt Lake------	480	1,920	360	1,440
Utah-----------	50	200	50	200
Totals----	630	2,520	510	2,040

1/If earthquake occurs while school is in session.

noted, however, that the public schools are in regular session for only one-third of each day and for about 18 percent of the total year, thereby reducing the overall risk.

Magnitude 7.5 on the Magna fault--expected damage patterns.--The impact of this earthquake on public school buildings would be much the same as that for the Wasatch fault event. The variations in Salt Lake County, indicated in tables 89 and 90, are due to the fact that six schools are located within one-half mile (0.80 km) of the postulated Magna fault rupture and three are within one-quarter mile of the rupture (0.40 km).

Foodstuffs

Emergency feeding of homeless and displaced persons, including those affected by loss of power or fuel as well as those displaced by structural damage, is an early problem for the responding agencies. Available supplies of food in local supermarkets are normally adequate to satisfy customer needs of the market area for a number of days, depending somewhat upon resupply schedules. Wholesale warehousing capacities, before earthquake losses are assessed, may be adequate to carry the market area normally served for about 7 days. The disruption of transportation routes, coupled with loss to vehicles, will require that local stocks of food be husbanded, and losses in stocks from direct earthquake damage will magnify the problem. There are no back-up facilities within close proximity of the study area. The nearest major population centers where large quantities of food might be available are located in Colorado or California.

Schools have long been considered as staging areas for people needing food and shelter at a time of disaster. Nearly every local resident is aware of the location of the nearest school, and most publicly owned school facilities will be available and can support the emergency needs of displaced persons. Large shopping centers located out of vulnerable congested areas should also be considered in the programs for development of care facilities. Because they are keyed to the population growth patterns and transportation networks, shopping centers are regional in concept, and they offer a facility that will remain at least partially functional in terms of access to food and drug services. The shopping centers, under private ownership, do not necessarily have assembly areas to shelter large groups and require great coordination and advance planning to establish emergency procedures.

Data collection

Major warehouses containing foodstuffs were identified by the Utah Retail Grocers Association, the Freeport Center Association, and the L.D.S. General Church Welfare Committee. The locations of these food resource facilities are shown in figure 60. There are approximately nine food-storage warehouse buildings located at the Freeport Center in Clearfield, Davis County, Utah.

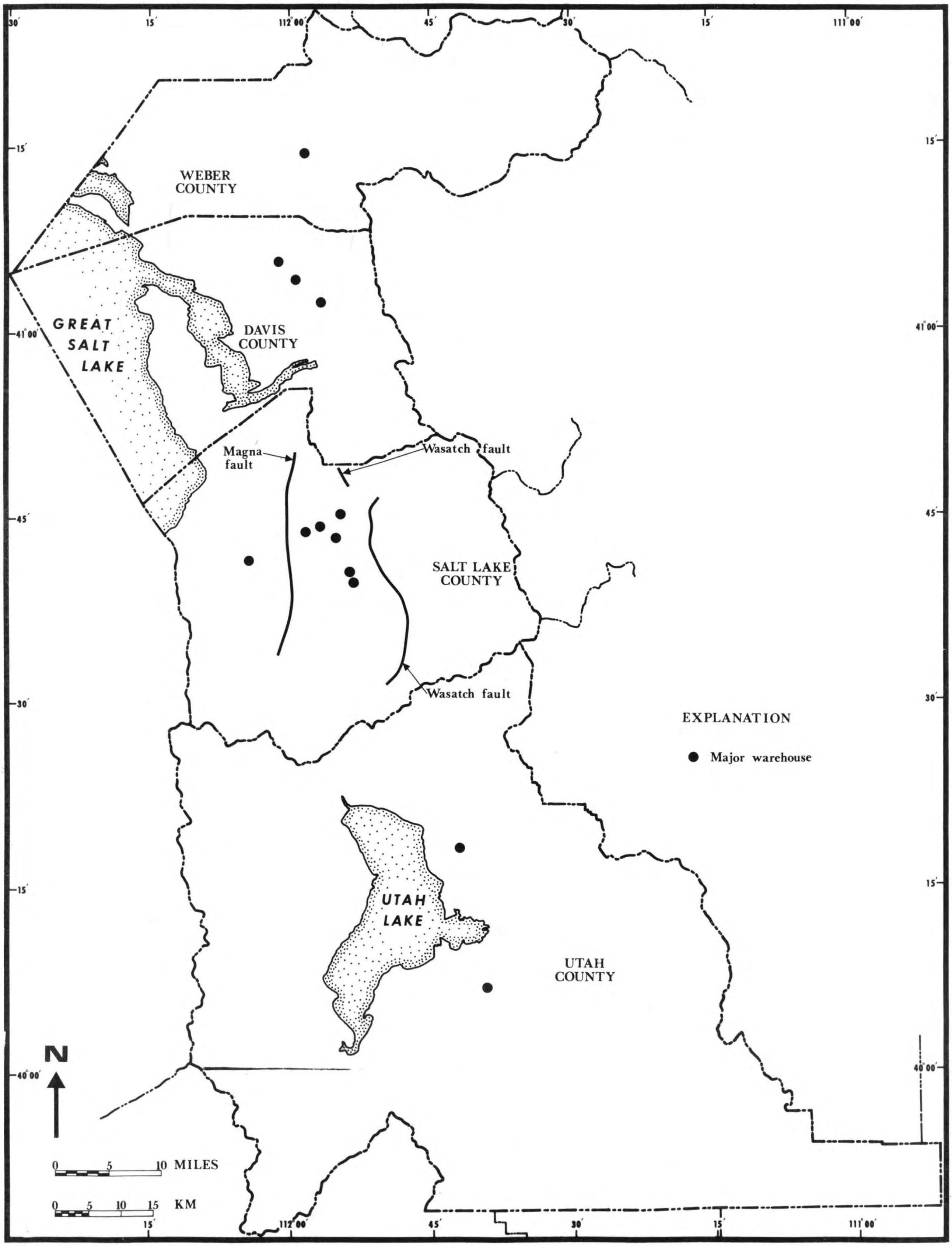

Figure 60.--Major foodstuff warehouses. (One dot may represent more than one facility. Shown fault breakage is assumed for planning purposes.)

The following information was gathered on 22 of the 24 major food storage warehouses, either by field inspection, analysis of building-description reports, or interviews with key personnel: year built, number of stories, type of construction, floor area, type of food stuff, refrigeration, emergency power, building access, and fire sprinklers.

A total of 8 of these 24 warehouses are owned by the L.D.S. Church as part of its welfare program.

Analysis

Food-storage warehouses of the L.D.S. Church are typically older buildings of masonry-wall construction. These buildings are solidly built and are well maintained. All but one of the buildings were built prior to 1961 and were probably not designed specifically to resist earthquake forces. However, church design standards have been equal to or better than the building code standards, and good quality control and inspection procedures have been followed.

The most common type of construction in the private food-storage warehouses was masonry walls and wood-roof systems.

Refer to table 91,which gives the numbers of foodstuff warehouses in the study area by county and date of construction. As can be seen from this table, about 69 percent of private warehouses were built prior to 1961 and nearly 88 percent of the L.D.S. Church warehouses are in this category. Earthquake-design provisions became part of the UBC (Uniform Building Code) with the 1961 edition, and the four-county study area was placed in seismic risk zone 2. Structures in zone 2 were to be designed for moderate earthquake forces. The study area was changed to zone 3 in 1970, and structures were to be designed for strong earthquake forces.

Three of the private food-storage facilities are newer structures, which use concrete tilt-up wall panels with both concrete and wood-roof systems. A tilt-up panel is a reinforced concrete wall that is constructed as a panel in a horizontal position, raised to a vertical position, and tied to its adjoining tilt-up wall panel by weld attachments or by cast-in-place reinforced-concrete columns (pilasters) located between the panels. In the 1971 San Fernando earthquake, this type of construction in the heaviest hit areas experienced building

Table 91.--Numbers of major foodstuff warehouses in the four-county study area by county and date of construction

[Source: Utah Retail Grocers Association; the Freeport Center Association; and L.D.S. General Church Welfare Committee]

	Private warehouses			L.D.S. warehouses		
County	Pre-1961	1961-1970	1970-present	Pre-1961	1961-1970	1970-present
Weber	0	0	0	1	0	0
Davis	8	1	1	1	0	0
Salt Lake	3	1	2	3	0	1
Utah	0	0	0	2	0	0
Totals	11	2	3	7	0	1

damage that averaged almost 20 percent of the cash value of the building. Similar buildings with reinforced, hollow, concrete block or reinforced brick experienced similar damage. Contents within the structures, which commonly lost part of their roofs, were damaged, but no experience figures are known with respect to the foodstuffs. Eight of the warehouses at the Freeport Center were built about 1942, with a wood frame and roof and concrete floors. A new building at the Center, used for food storage, is of concrete tilt-up wall construction.

Partial roof failure is expected to be a frequent problem in the hardest shaken areas. Stocks of nonrefrigerated foods will last for days, but the most serious problems from a food-loss standpoint stem from damage to refrigerated warehouses, as damage to the building can also rupture insulation. This kind of building damage, compounded by an extended loss of electric power and the resulting loss of refrigeration, is expected to cause serious foodstuff losses at most locations. All of the warehouses on which data were gathered have refrigeration, but none have emergency electrical power.

Other factors contributing to food losses would be damage due to falling stock, building collapse, and water. Rainwater, or water from fire-protection sprinkler systems, can destroy paper cartons containing foodstuffs, or loosen labels, making content identification difficult or impossible.

Post-disaster distribution of food to communities within the study area will be seriously hampered if ground transportation facilities are disrupted for an extended length of time.

The study area has one advantage that would alleviate the problem of supplying food to the population following a major disaster such as an earthquake; that is, that perhaps half of the Mormon families in the study area have food stored for emergency situations, in keeping with L.D.S. Church policy. This fact, combined with the food-storage warehouses of the L.D.S. Church, would make the study area partially self-sufficient following either postulated earthquake.

Magnitude 7.5 on the Wasatch fault--expected damage patterns.--For planning purposes in either postulated earthquake, most of the refrigerated foodstuffs in the study area will be lost because of spoilage if the earthquake occurs during mild weather. About 25 percent of the nonrefrigerated foodstuffs will be lost owing to reasons previously mentioned. Table 92 lists the number and percent of foodstuff warehouses in the study area that could become nonfunctional due to building damage. Table 92 shows that, for planning purposes, five of the private warehouses and three of the L.D.S. Church warehouses could be rendered nonfunctional by either earthquake event. Most of the major warehouses will suffer building damage of varying degrees, as the majority are of non-earthquake-resistant pre-1961 construction; but many of the nonperishable items, such as canned goods, are likely to be salvageable. It should be noted from figure 60 that no warehouses are located on the postulated Wasatch fault rupture.

Magnitude 7.5 on the Magna fault--expected damage patterns.--Damage to foodstuff warehouses from an event on the Magna fault will be similar to damage due to the Wasatch fault event, inasmuch as these warehouses are located in areas where earthquake intensities are expected to be the same from either event. No warehouses are located near the postulated Magna fault rupture either.

Table 92.--Number and percent of major foodstuff warehouses rendered nonfunctional due to building damage

County	Wasatch fault or Magna fault, magnitude = 7.5			
	Private warehouses		LDS Church warehouses	
	Number	Percent of total	Number	Percent of total
Weber-----------	0	0	0	40
Davis-----------	3	30	0	20
Salt Lake-------	2	33	2	50
Utah------------	0	0	1	30
Totals-----	5	---	3	---

Fire following earthquake

One of the greatest potential dangers to be faced during the period immediately following a major earthquake is the threat of fire, which, if unchecked, could lead to a major conflagration under certain situations. The threat of a fire always exists following any earthquake, and this threat exists for all areas and building categories considered in this report.

The memory of the three-day fire that followed the 1906 shock in San Francisco and accounted for 80 percent of the property loss in that city has contributed much to the thinking on the probable effects of large, damaging earthquakes. This thinking is also colored by the fact that over 100,000 persons were killed, injured, or missing in the 1923 Tokyo earthquake and fire.

When a major earthquake occurs, the public depends on the fire services for non-fire-related assistance immediately following the earthquake. The strategic location of fire stations and equipment throughout the populated areas gives them the capability to respond to all types of emergencies. The problems of firefighting in such situations are increased when available fire department personnel and equipment are diverted to emergency medical aid and other functions. These problems are further compounded by possible damage to fire stations, firefighting equipment, and communications; disruption of access routes to reach fires; and earthquake-related problems resulting in partial or total loss of the water supply.

Data collection

Fire-department personnel and appartus information was obtained on the four major fire departments operating in Salt Lake County: Salt Lake City, Salt Lake County, South Salt Lake, and Murray. This information was also obtained for the Ogden and Provo Fire Departments. (See table 93.) Locations of all fire stations in the four-county study area are shown in figures 43 and 44 in the section on "Public Structures." Strengths of departments in the urban areas were obtained directly from the departments concerned, together with information on rescue equipment, ambulances, and communications.

Water supply lines are shown on figure 53, in the section on

Table 93.--Fire department personnel and apparatus

	Salt Lake City	Salt Lake County	South Salt Lake	Murray	Ogden	Provo
Number of volunteer fire fighters	0	101	19	24	0	10
Paid fire fighters	355	205	15	16	125	48
Total personnel	355	306	34	40	125	58
Total fire fighters on duty	95	63	4	6 week days 4 week ends	37	14
Pump trucks	20 full time 5 grass fire trucks	40	6	5	6 full time 3 reserve	7
Ladder trucks	3 full time 1 reserve	1	2	0	1 full time 1 reserve	1
Elevated platforms	1	0	0	0 (1 - 55' water tower)	1	1
Rescue trucks	1 full time 1 reserve	1	1	1	0 (1 salvage truck)	2
Ambulances	0	8	0	0	0	3 full time 1 reserve
Radio frequencies	3	11 reserve unit 5 ambulance 1 fire truck	1	4	2	1 two-way 4 receive only
Radio frequencies shared w/other fire departments	2(paramedic program and highway patrol)	1 (South Salt Lake)	1(Sandy)	0	0	3 on mobile units only (Orem, Utah County, and State fire area)

"Public Utilities." Water-supply information was obtained from sources listed in that section.

Congested areas were established on the basis of studies of Sanborn maps made available through the Insurance Services Office of Utah. The congested areas were related to population through census-tract information, based on the 1970 Census Block Statistics of Salt Lake City, Ogden, and Provo-Orem.

Analysis

Background information.--Records of earthquakes in the United States indicate that fires often occur after severe earthquakes. Table 94 shows a partial history of fire occurrence after earthquakes in the United States. Fires that spread in an uncontrolled manner for long periods of time are defined as conflagrations for the purpose of this report.

Three principal conditions, occurring together, make conflagration probable following severe earthquakes. These conditions include the following:

1. high density of combustible construction;
2. unfavorable weather conditions, high winds, and low humidity; and
3. impaired firefighting capabilities caused by blocked access, water-supply shortage, trapped or damaged fire apparatus, and injured or diverted personnel.

The simultaneous occurrence of these conditions in the congested areas of the four counties included in this report is unlikely. There is generally no high density of combustible construction. During the summer, some long periods of hot, dry weather occur, and strong canyon winds from the eastern mountains affect the valleys of Provo, Salt Lake, and Ogden. The brush fire hazard is not serious, and no major brush fires have occurred. Major streets in the congested areas are wide (132 feet (40m), so access for emergency apparatus normally should not be seriously hampered. The most serious impairment to fire department operations would probably be due to the loss of a major portion of the water supply in Salt Lake County, owing to the major water sources crossing the Wasatch fault on the east side of the valley. These water

Table 94.--Fires following earthquake

[Source: A Study of Earthquake Losses in the Los Angeles, California Area, NOAA, 1973. Abbreviations: N.B.F.U., National Board of Fire Underwriters; B.F.U.P., Board of Fire Underwriters of the Pacific; P.F.R.B., Pacific Fire Rating Bureau; B.S.S.A., Bulletin of the Seismological Society of America]

Earthquake	Date	Magnitude	Number of reported fires	Reference
San Francisco, Calif.	Apr. 18, 1906	8.3	50 fires 3 hours after	N.B.F.U., 1906.
Santa Barbara, Calif.	June 29, 1925	6.3	1 dwelling	B.F.U.P., 1925.
Long Beach, Calif.	Mar. 10, 1933	6.3	2 fires in Los Angeles, 11 to 15 in Long Beach	N.B.F.U., 1933.
Imperial Valley, Calif.	May 18, 1940	7.1	4 (?) including Mexico	"The Insurance Journal", May 1940.
Kern County, Calif.	July 21, 1952	7.7	Major refinery fire	B.S.S.A., v.44 p. 270, 1954.
Bakersfield, Calif.	Aug. 22, 1952	5.8	1 dwelling	B.F.U.P., private report, 1952.
San Francisco, Calif.	Mar. 22, 1957	5.3	1 at 2-story apartment	Calif. Div. Mines, Special Report, 1957.
Anchorage,1/ Alaska	Mar. 27, 1964	8.4	4 "minor"	N.B.F.U. and P.F.R.B., 1964.
San Fernando, Calif	Feb. 9, 1971	6.4	109	Steinbrugge and others, P.F.R.B., 1971.

1/Oil fires elsewhere in Alaska not included.

lines could be ruptured by surface faulting. This condition also occurs to a lesser extent in the other three counties. (See the section on "Water Supply." The four-county area has never been subjected to conflagration or even to major earthquake-related fires.

The municipal and Salt Lake County Fire Departments, although somewhat undermanned in most of the study area, are essentially well equipped, are well trained, and are capable of rendering mutual aid. (See table 93.) Widespread disaster plans and reciprocal agreements are in effect to provide assistance as required. Apparatus, fittings, and hose are fairly well standardized, thereby facilitating prompt emergency operations among neighboring communities. The Salt Lake City Fire Department still uses special threads but is converting to National Standard, and most couplings and fittings should be changed over within six months from the date of this writing. The Salt Lake City Water Department still uses the older type threads, so adaptors will be needed when using this system. Utah State Law now requires that all fire department hose couplings and fittings have National Standard threads as soon as possible. Generally, fire stations are well distributed and properly situated throughout the area served by the six departments listed on table 93. County fire departments in Davis, Weber, and Utah Counties are very limited and not well distributed.

A movement of the Magna fault is not likely to significantly affect the water supply available for fighting fires in the four-county study area. No major supply lines serving Salt Lake City cross the Magna fault. There are two main waterlines serving the Kearns and Magna area that cross the fault. An earthquake on the Wasatch fault, however, would be much more serious, because many major water supply lines cross the fault in Salt Lake County. This is also true, but to a lesser extent, in Weber County.

By geographic necessity, Salt Lake City water supplies originating east of the Wasatch fault (approximately 80 percent of the city's supply) must cross the postulated fault rupture in order to reach the downtown area. These supplies will not be available for fighting fires immediately following the postulted Wasatch fault event, as all mains crossing the fault rupture will be broken. This leaves the city with two remaining major sources of water: City Creek Canyon, which accounts for 10 percent of the city's annual supply, and the artesian well basin in Murray, which accounts for another 10 percent.

Water flow from these two remaining sources and their storage reservoirs may be increased significantly for an extended period of time in the event of an emergency. However, the availability of artesian well water for fire fighting in the downtown area immediately following a magnitude-7.5 event is doubtful. Water from the Murray wells must be pumped to the downtown area, and the old Third East pump station, built in 1931 of non-earthquake-resistive masonry, is likely to be nonfunctional because of building damage immediately following a major earthquake. The station also lacks emergency power, so, even if the building were to survive a major event without serious structural damage, it would be shut down if its power supply were disrupted.

It is not anticipated that water supplies for firefighting in other counties within the study area will be seriously reduced by either one of the postulated earthquakes (Wasatch fault, Salt Lake epicenter, or Magna fault), as ground-shaking intensities are generally lower in Weber and Utah Counties and no surface faulting occurs within any of the other three counties.

Any one of the three counties, however, might expect similar disruption of water supplies originating east of the Wasatch fault if surface faulting occurs in that county.

For additional material relating to water supply, the reader is referred to the section on "Public Utilities."

Information relating to city and county emergency communications by radio and telephone are covered in the section on "Communications" in this report.

Congested area conditions.--The following comments apply to the congested business district areas in Salt Lake City, Ogden, and Provo (See fig. 40 in the section "Deaths and Injuries"); they outline the extent of the problem and delineate critical areas that may exist or special conditions that are of concern.

Salt Lake City: The principal business district includes a 15-block area covered by Census Tract #22. Peak population in this 194-acre (79-hectare) area is estimated to be 89,581. The blocks are 635 $feet^2$ (59 m^2), and 28 percent of this area is dedicated to streets, 66-132 feet (20-40m) in width, with 65 percent of the remaining available block area covered with construction. Of the construction in the area, 14 percent is completely protected by automatic sprinklers, 61 percent is fire resistive, and a major portion of the remainder is masonry, joisted. Joisted refers to the use of wood joist floor and roof systems as opposed to concrete floors and roofs.

There are 37 high-rise buildings (75 feet (23m) or higher) in the principal business district, ranging in height from 5 stories to 27 stories. Construction of these high-rise buildings are 52-percent reinforced-concrete frame (mainly the older structures); 16 percent independent steel frame, covered with reinforced concrete; 16 percent spray-on protected steel frame; and 16 percent masonry, joisted. The maximum height of the masonry, joisted buildings is eight stories. An additional five high-rise buildings are within two blocks of the principal business district, including a 32-story office building. This spray-on protected steel building was designed and built with earthquake-resistant considerations. Additional high-rise buildings (mainly apartments) are located in various areas of the city and Salt Lake County. No high-rise buildings are presently provided with automatic sprinkler protection.

Most of the remaining buildings in the business district are one to three stories in height. Some old masonry construction remains, with heavy metal and masonry cornices and parapets that add to the structural-failure hazard. All electric signs that extended out from buildings over sidewalk areas have been eliminated by city ordinance. Elevators are not installed to resist earthquake shocks expected in the area.

Fires could involve large groups of buildings, but owing to the wide streets, fires should not spread beyond the block or origin except under unusual circumstances.

Industrial districts are generally located west of the downtown business district. Buildings are mainly masonry joisted or metal with some fire-resistive and wood-frame construction. Building heights are generally one story, areas are moderate to large, and some buildings are closely spaced. Larger, newer buildings are generally provided with automatic sprinkler protection. Fires could spread to involve a large group of buildings.

The city has adopted the 1973 edition of the Uniform Building Code, Volumes I and II. An amendment to the code requires all new high-rise buildings to have automatic sprinkler protection.

Ogden: The principal business district covers a 15-block area covered by Census Tract #11. Estimated peak population (1975) in this 219-acre (89-hectare) area is considered to be 13,250. The blocks are 635 $feet^2$, (59 m^2) and 37 percent of this area is dedicated to streets, 66 (20 m)-132 feet (40.2m) wide. Forty-five percent of the remaining available block area is covered with construction. Of the construction in the area, 10 percent is completely protected by automatic sprinklers, 16 percent is fire resistive, and a major portion of the remainder is masonry, joisted.

There are five high-rise buildings (75 feet(23 m) or higher) in the principal business district, ranging from 5 to 13 stories. The buildings are either reinforced-concrete frame or reinforced-concrete protected-steel frame. None are provided with automatic sprinkler protection. Most of the remaining buildings are one to three stories in height. Some old masonry construction remains, with heavy metal and masonry cornices and parapets, which add to the structural-failure hazard. Elevators are not installed to resist earthquake forces.

Fires could involve large groups of buildings, but because of the wide streets fires should not spread beyond the block of origin.

Industrial districts are mainly located west of the downtown business district, near or along the railroad lines. These include a few manufacturing plants, several small bulk-fuel storage plants, and some large flour mills with storage bins that are six to eight stories in height. Most industrial occupancies are widely spaced and have low building heights. Larger, newer buildings are provided with automatic sprinkler protection.

The city has adopted the Uniform Building Code.

Provo: A 16-block area includes the principal business district in Provo. Estimated peak population (1975) in this area is considered to be 9,000.

The blocks are 390 feet^2 (36 m^2); the two major streets (Center Street and University Avenue) are 132 feet (40 m) wide, and the other streets are 82.5 feet (25 m) wide. The business district consists of about 60 percent open space and dedicated streets. Construction is mainly masonry, joisted. Only four fire-resistive buildings and three buildings provided with automatic sprinkler protection exist in this principal business district. Heights are generally one to three stories. Large group fires are possible; however, the spreading of fires, involving more than one block, is unlikely due to the frequency of masonry fire walls, open spaces, and good street widths.

Industrial districts are mainly located south of the business district along the railroad tracks. Buildings are mainly one and two stories high and of noncombustible and masonry, joisted construction. There is a small amount of automatic sprinkler protection. In several cases, fires could involve large individual buildings or groups.

The city has adopted the 1973 edition of the Uniform Building Code.

General: Large university campuses are located in Salt Lake City,Ogden, and Provo along the east foothills of each valley. The University of Utah, east of Salt Lake City, mainly has buildings of fire-resistive construction, with some of noncombustible, ordinary and wood-frame construction. The majority of the buildings are moderate in height, are well spaced, and are moderate to large in area. Several large buildings are provided with automatic sprinkler protection.

Weber State University, southeast of Ogden, has mostly new buildings, which are well spaced. New construction is primarily fire resistive, including a 12-story student apartment building.

Brigham Young University, located northeast of Provo, has a large campus with building construction that is mainly fire resistive. The majority of the buildings are two and three stories, with a few ranging up to seven stories. Buildings are well spaced, and several large buildings are provided with automatic sprinkler protection.

Large, major shopping centers in each county are provided with automatic sprinkler protection. Industrial operations exist outside the major communities. These are generally separated from other community areas and may not become an immediate emergency problem in the event of an earthquake.

Residential districts in Salt Lake City, Ogden, and Provo consist mainly of small to moderate size, 1- or 2-story, moderately spaced, brick, brick-veneer, and wood-frame dwellings. Wood-shingle roofs are common, but many dwellings have composition roofs. There are no large housing developments with exclusively wood-shingle roofs. Newer wood-frame condominium and apartment complexes have been erected in each county. Almost all dwellings have natural gas connections.

In general, the fire service finds itself in an almost impossible situation at a time of area-wide disaster. Because it is on a ready standby basis during normal day-by-day operations, many different types of emergency service operations are in the category of "the fire department can or will do that." Rescue may be cited as an example of life safety taking precedence over fire fighting; fires may be unattended while the fire forces effect rescue and search.

Magnitude 7.5 on the Wasatch fault--expected damage patterns.--In the event of a 7.5-magnitude shock on the Wasatch fault, serious loss of water for firefighting purposes is expected to occur in Salt Lake and Davis Counties, with minimal disruption of water supplies in Utah and Weber Counties. (See section on "Water Supplies.")

Although some major fires will likely occur owing to utility failures in the principal business districts of Salt Lake City, Ogden, and Provo, a conflagration is not probable. This is primarily due to the fire breaks created by a large number of wide streets, freeways, large open parking areas, and essentially masonry construction in the built-on areas. Large fires probably will be limited to the block of origin. However, for planning purposes, at least two block fires should be expected, one such fire in Salt Lake City and one in Provo.

Building construction is more concentrated in Salt Lake City than it is in Ogden or Provo, with correspondingly more fire-resistive buildings, high-rise buildings, and buildings protected by automatic sprinkler systems. Some of the older masonry, joisted buildings in these areas are unoccupied on the upper floors. Several of the newer high-rise buildings have mechanical equipment floors in the middle stories, which could result in fires due to mechanical equipment failure. Should a fire start in these upper stories, with generally impaired water supplies, a heavy loss of life could occur. The earthquake could shatter many fire-resistive enclosures around stair and elevator shafts, allowing fire to progress from story to story where combustible material exists. For planning purposes, one multi-story building fire with heavy involvement of firefighting forces should be anticipated.

With impaired water supplies, major fires could occur in large shopping malls and congested masonry, joisted and wood-frame apartment-condominium complexes, but the fires should be limited to the building group.

Firefighting and emergency-equipment response to many areas would be impaired by the littering and blockage of streets by building debris, but the generally wide streets and alternate routes (minor amount of deadend streets) should reduce the delay.

<u>Magnitude 7.5 on the Magna fault--expected damage patterns</u>.--Many of the same conditions would occur in the populated areas with a 7.5-magnitude shock on the Magna fault, except the major sources of water in the four-county study areas should not be seriously impaired. (See section on "Water Supplies.") The population density in the immediate vicinity of the Magna fault is considerably less than in areas along the Wasatch fault.

Many of the fire problems resulting from a movement of Wasatch fault would also occur with an event on the Magna fault, but the availability of water could make a considerable difference in the final result.

Debris removal

Debris removal, for the purposes of this four-county study, may be placed into two categories: (1) that which requires immediate removal or moving, and (2) that which can be moved later. The first category includes debris in public ways in sufficient quantities to prevent the passage of emergency vehicular traffic and debris covering injured persons. In the case of blocked streets, it may be sufficient to move the debris aside with bulldozers in order to clear a single traffic lane. Later removal (in the second category) can be by skiploaders and trucks. Streets and freeways blocked by collapsed overpasses will pose a much more serious removal problem, because the concrete or steel members will have to be cut into smaller pieces to facilitate removal, and heavy equipment will be required.

Salt Lake City has one advantage in debris removal for emergency vehicular traffic in that all of the major streets within the downtown area are 132 feet (40.2 m) wide including the sidewalks. It is likely that emergency vehicles could use all of these streets following a major earthquake with minimum disruption from building debris. The city also has a sign ordinance in effect in the downtown area as part of its beautification program in which signs are not allowed to project over sidewalks. Although signs are not a major problem in debris removal, the life hazard from falling signs is considerably reduced by the ordinance.

The careful removal of debris covering trapped and injured persons is a time-consuming and meticulous job requiring cranes, skiploaders, cutting equipment, and considerable manual labor. For example, the collapse of buildings at the Veterans" Hospital, which was caused by the 1971 San Fernando earthquake, resulted in the deaths of 47 persons, and 60 people were trapped in the two buildings. The rescue operations were not completed until some 58 hours after the collapse according to the Los Angeles City Police Department.

In heavily damaged areas, it will be difficult if not impossible to determine where bodies remain in the rubble. Following the Managua, Nicaragua, earthquake of December 23, 1972, large areas of rubble were sprinkled with gasoline and set afire to destroy buried bodies as a precautionary measure against the outbreak of epidemics.

The debris-removal problem for rescue of people trapped in their own homes is likely to be acute, because the majority of private residences within the study area are of unreinforced-masonry construction and some of these homes are likely to suffer at least partial collapse, especially in the higher intensity areas and within the zones of deformation due to faulting. Also, as collapsed homes are likely to be located over a wide area, it would be difficult to use any available debris-removal equipment effectively.

Additional problems exist in search and rescue operations outside the congested areas indicated in figure 40. Numerous older, unreinforced-masonry apartment buildings and schools are scattered throughout the uncongested portions of Salt Lake City. It is likely that some of these buildings will suffer at least partial collapse in either postulated earthquake.

The demand for debris-removal equipment for use in search and rescue operations will vary according to the time of day when the postulated earthquake occurs. A daytime occurrence would direct most efforts to congested downtown areas where large numbers of people might be trapped either in collapsed buildings or by fallen debris. An earthquake at night would require rescue efforts over a widely scattered area at apartment buildings and homes.

Debris from the second category may be removed at a later time using heavy equipment and trucked to disposal sites. This category includes debris from collapsed structures, which falls into public thoroughfares, parking lots, vacant lots, and that within the building site.

A major earthquake would draw heavily on all available equipment and manpower in order to remove debris. The Associated General Contractors of Utah have a program for disaster relief entitled "Plan Bulldozer," by which participating contractors would make available their equipment and manpower for emergency operations following a major disaster such as a large earthquake.

Data collection

The principal sources of debris may be classified as follows:

1. unreinforced-brick-masonry parapets and bearing walls with wood roofs and floors;
2. inadequately anchored cornices, masonry walls, marquees, signs, precast concrete wall panels, and veneer;
3. glass windows;
4. fallen wires, pole- and platform-mounted transformers, and poles;
5. collapsed and partially collapsed multistory buildings; and
6. collapsed and partially collapsed highway, freeway, and railway bridges.

The principal sources of building debris are the pre-1961 unreinforced-brick-masonry bearing-wall buildings and the old as well as new high-rise buildings. These data, for selected congested areas, are given in tables 38 and 39; these selected areas are geographically located in figure 40.

Principle sources of data on buildings in congested areas were the Sanborn maps, personal inspection by the consultant staff, and the consultants' own personal knowledge of the age and type of construction of various buildings.

Data on freeway collapses are given in the section on "Transportation" and need not be repeated here.

Analysis

Debris from pre-1961, unreinforced-brick buildings is expected to be the biggest problem from the standpoint of blocked streets resulting from building collapse. Beginning at intensities as low as VII, unreinforced-brick-masonry parapets start to topple. As the ground motion increases, entire bearing walls fall and roofs and floors also sometimes collapse. Alternately, roofs and floors can remain supported by numerous interior bearing partitions, such as those found in apartment buildings, even though the brick exterior walls may be gone. Parapet correction programs in California have resulted in the removal of many unreinforced-brick-masonry parapets and nominal anchorage of the walls below to the roof systems. The four-county study area has no parapet correction program. However, experience in the San Fernando earthquake indicates that in areas having Intensity VII some walls that had received such corrections failed below the roof line, and large areas of the walls were thrown down. Therefore, a parapet correction program would not result in greatly improved conditions in Intensity VIII and IX areas in the postulated earthquakes. Although unreinforced-brick-masonry walls would still be thrown down when subjected to these high intensities, the quantity of resulting debris would be reduced if the study area were to initiate a parapet correction program similar to that used in California.

Insufficient data were available to make a debris analysis for all pre-1961, unreinforced-brick-masonry buildings, and the analysis was restricted to the three selected congested areas shown in figure 40. Table 58 is an inventory of multistory buildings in each congested area, and table 59 gives numbers of old masonry buildings and their lengths of street frontage. For purposes of analysis, table 95 was used in conjunction with the following reasonable building street front and wall characteristics:

Average height of parapet wall:	3 feet (1 m)
Average thickness of parapet wall:	12 inches (30 cm)
Average number of stories:	2
Average total height of building:	30 feet (9 m) (first floor to roof)
Average thickness of wall below parapet:	14 inches (36 cm)
Average percent of openings:	40 (first floor to roof)

Table 96 is the result of the analysis. A review of this table indicates that the magnitude-7.5 event of the Magna fault produces about the same amount of debris as will the postulated shock on the Wasatch fault, as intensities in the three congested areas are the same for either event.

Other sources of debris, in addition to masonry walls, are inadequately anchored cornices, marquees, signs, precast-concrete wall panels, and veneer, but these will not produce large volumes of materials.

Glass windows are frequently broken due to the distortions of the building frames. In the case of the collapsed Psychiatric Unit at the

Table 95.--Estimated damage to non-earthquake-resistive brick-masonry buildings in congested areas in percent.

Intensity	Pre-1961 conditions		
	Collapsed parapets 1/	Collapsed walls	Collapsed buildings
VIII	40	20	10
IX	60	40	20

1/"Collapse" is defined to include major partial collapses.

Table 96.--Non-earthquake-resistive brick-masonry buildings in selected congested sections of the study area, constructed prior to 1961

City	Sanborn Map Volume	Wasatch or Magna fault, magnitude = 7.5: Brick in street (in tons) 1/	Wasatch or Magna fault, magnitude = 7.5: Number buildings collapsed 2/
Ogden----------	1	2,800	26
Salt Lake-----	1	1,300	4
	2	4,100	20
	3	5,200	23
Provo----------	1	1,500	15
Totals-------------------		14,900	88

1/From street-front walls only.

2/"Collapse" is defined to include major partial collapse.

Olive View Hospital in the San Fernando earthquake of 1971, broken glass was found as far as 100 feet (30.48 m) from this two-story structure. Broken glass creates a life hazard both inside and outside of damaged buildings, but it does not represent a significant debris problem.

Magnitude 7.5 on the Wasatch fault--expected damage patterns.--The most severe debris-removal problems are expected in downtown Salt Lake City if the earthquake occurs during the day. Most of this effort will concern search and rescue operations. A nighttime occurrence will require more widespread search and rescue operations, as most people will be in their dwellings. Clearing streets for passage of emergency vehicles is not expected to be a major problem because of the width of the streets.

The Wasatch fault event would produce about three times more debris in the zone of deformation due to surface faulting than would the Magna fault event when considering all of Salt Lake County. This is because the postulated Wasatch fault rupture extends through east-bench and foothill residential areas for about 90 percent of its length, whereas the postulated Magna fault rupture affects only large residential populations in Kearns and Granger, the balance of the fault rupture passing through sparsely populated areas.

Debris-removal problems would not be nearly as severe in the cities of Ogden and Provo, as intensities are less and the congested areas are smaller.

Multistory buildings are likely to suffer some glass breakage, and a number of reinforced-concrete pre-cast wall panels will fall.

Collapsed overpasses are discussed in the section on "Transportation."

Magnitude 7.5 on the Magna fault--expected damage patterns.--As intensities in the congested areas within Salt Lake City, Ogden, and Provo are the same for either postulated earthquake, the debris-removal problem will be the same for either event in these areas. As was mentioned, debris removal for areas in the fault zone in Salt Lake County will involve less for the Magna event than for the Wasatch event, because most of the postulated Magna fault rupture is in sparsely populated areas.

SUMMARY AND RESTATEMENT

General review

The Wasatch Front has a history of frequent seismic activity, which includes recent damaging events in northern Utah. To the present time, most large, Utah earthquakes have occurred in remote, sparsely populated areas. An exception to this was the 1962 event, which caused about one million dollars in property damage to Logan, Utah. Even more recently, a moderate earthquake caused damage to Malad, Idaho, near the Utah border. However, there is geologic evidence that large movements on the Wasatch fault have occurred within the past 200 years near the cities of Ogden, Salt Lake, and Provo. These areas of relatively dense population and large urban development are within close proximity to the Wasatch fault and to other faults where the greatest energy release could be experienced.

Two earthquakes were postulated for this study, having magnitudes that could rationally be supported as possible in this area. Analysis of the events indicate that under the worst condition as many as 2,300 people would die, and 9,000 additional persons would suffer injuries requiring hospitalization or immediate medical treatment. The number of deaths could be as high as 14,000 if deaths from dam failure are included in the casualty total. Such casualties would occur under the worst conditions of exposure, as during the rush hours, but could be approximately as great at any time during the working day. Conditions of exposure are altered at night, when people are at home, resulting in a reduction of casualties to a level of about 5-10 percent of the daytime losses. It is possible that as many as 30,000 people would be homeless or would require temporary shelter pending reestablishment or relocation.

For planning purposes, the number of homeless people in the four-county study area would be doubled (60,000 homeless people) if either postulated earthquake event were to occur during the winter months (November through March). The combination of freezing or sub-freezing temperatures, and either unsafe structures or a loss of electric power and natural gas for heating would make it impossible for many people to remain in their homes after a major earthquake.

Thus, the time of greatest concern for casualties is during the normal working day; the season of greatest concern for homeless people is in winter; and the areas of concern are the highly urbanized sections of the Wasatch Front from Ogden to Provo.

The purpose of this study has been to provide essential data relating to earthquake effects on local medical resources, estimated casualties and homeless, and immediate and vital public need, with the intent that administrators of emergency services can proceed with confidence in planning response to earthquake disaster.

The report has been concerned not only with human casualties and displacement, but also with impairment or destruction of facilities critical to the continuing normal functioning of the area. Hospitals and medical personnel, police and fire department personnel and equipment, communications, transportation, and utilities have been included.

The total-damage profile was developed through careful consideration of the seismicity, geological history, population density and distribution, and physical status of structural and lifeline installations throughout the region. A potential for broad fluctuation in the casualty figures result from the chance positioning of people at the time of the occurrence of the earthquake. An example is that of the Lafayette Elementary School in West Seattle, where, in the 1949 earthquake, a large brick gable over the entry collapsed directly onto an area normally used for assembly of pupils. Such assembly regularly occurred at 11:55 a.m. The earthquake occurred at 11.57 a.m., but fortunately during the spring vacation.

Effective remedial steps to maintain the essential public services or to return them to operation following a large earthquake will depend upon the prompt and informed actions of public agencies. Response planning should include not only consideration of disaster problems within a particular jurisdiction but also sharing of assistance with neighboring jurisdictions. Moderate response requirements experienced in one area can free resources to aid communities in more heavily damaged portions of the affected area.

The damage profile is quite different among the four counties within the study. A summary of the impairment to vital medical resources and vital public needs is presented in tables 97 to 100 for each of the four counties covered in this study. Estimated losses are also summarized in these tables.

Table 97.--Impairment and losses in Weber County from 7.5-magnitude earthquakes having epicenters in or near Salt Lake City

[County population = 134,500; land area = 581 square miles (1,505 km^2)]

	Degree of impairment					
	Wasatch fault			Magna fault		
	Minor	Moderate	Major	Minor	Moderate	Major
Medical resources:						
Hospitals----------	---	X	---	X	---	---
Manpower-----------	X	---	---	X	---	---
Supplies ----------	X	---	---	X	---	---
Bloodbanks---------	---	X	---	---	X	---
Ambulances --------	X	---	---	X	---	---
Vital public needs:						
Communications-----	---	X	---	---	X	---
Fire---------------	---	X	---	---	X	---
Police-------------	---	X	---	---	X	---
Electric power-----	X	---	---	X	---	---
Water--------------	X	---	---	X	---	---
Natural gas -------	X	---	---	X	---	---
Access roads ------	---	X	---	---	X	---
Airports ----------	X	---	---	X	---	---
Schools(as shelter)	X	---	---	X	---	---
Food supplies -----	X	---	---	X	---	---

	Estimated losses	
	Wasatch fault	Magna fault
Losses except dams:		
Deaths-------------	320	300
Serious injuries---	1,280	1,200
Homeless-----------	1,340	1,340
Losses from dam failure:		
Deaths ------------	8,000	8,000
Homeless-----------	7,200	7,200

Table 98.--Impairment and losses in Davis County from 7.5-magnitude earthquakes having epicenters in or near Salt Lake City

[County population = 112,500; land area = 297 square miles (769 km^2)]

	Degree of impairment					
	Wasatch fault			Magna fault		
	Minor	Moderate	Major	Minor	Moderate	Major
Medical resources:						
Hospitals	---	---	X	---	X	---
Manpower	X	---	---	X	---	---
Supplies	X	---	---	X	---	---
Bloodbanks	---	X	---	---	X	---
Ambulances	---	X	---	---	X	---
Vital public needs:						
Communications	X	---	---	X	---	---
Fire	---	---	X	---	---	X
Police	---	---	X	---	---	X
Electric power	---	X	---	---	X	---
Water	---	X	---	---	X	---
Natural gas	---	X	---	---	X	---
Access roads	---	X	---	X	---	---
Airports	X	---	---	X	---	---
Schools (as shelter)	---	X	---	---	X	---
Food supplies	X	---	---	X	---	---

	Estimated losses	
	Wasatch fault	Magna fault
Losses except dams:		
Deaths	190	180
Serious injuries	760	720
Homeless	2,710	2,710
Losses from dam failure:		
Deaths	500	500
Homeless	500	500

Table 99.--Impairment and losses in Salt Lake County from 7.5-magnitude earthquakes with epicenters in or near Salt Lake City

[County population = 495,000; land area = 764 square miles (1,980 km^2)]

	Degree of impairment					
	Wasatch fault			Magna fault		
	Minor	Moderate	Major	Minor	Moderate	Major
Medical resources:						
Hospitals----------	---	---	X	---	X	---
Manpower-----------	---	X	---	---	X	---
Supplies ----------	---	X	---	---	X	---
Bloodbanks---------	---	X	---	---	X	---
Ambulances---------	---	X	---	---	X	---
Vital public needs:						
Communications-----	---	X	---	---	X	---
Fire---------------	---	---	X	---	---	X
Police-------------	---	---	X	---	---	X
Electric power-----	---	---	X	---	---	X
Water--------------	---	---	X	---	---	X
Natural gas--------	---	---	X	---	---	X
Access roads-------	---	X	---	---	X	---
Airports-----------	---	X	---	---	---	X
Schools (as shelter)	---	X	---	---	X	---
Food supplies -----	---	X	---	---	X	---

	Estimated losses	
	Wasatch fault	Magna fault
Losses except dams:		
Deaths-------------	1,570	1,360
Serious injuries---	6,280	5,440
Homeless-----------	22,000	17,980
Losses from dam failure:		
Deaths-------------	0	0
Homeless-----------	0	0

Table 100.--Impairment and losses in Utah County from 7.5-magnitude earthquakes with epicenters in or near Salt Lake City

[County population = 160,000; land area = 2,014 square miles (5,216 km^2)]

	Degree of impairment					
	Wasatch fault			Magna fault		
	Minor	Moderate	Major	Minor	Moderate	Major
Medical resources:						
Hospitals----------	---	---	X	---	X	---
Manpower-----------	X	---	---	X	---	---
Supplies-----------	X	---	---	X	---	---
Bloodbanks---------	---	X	---	---	X	---
Ambulances---------	X	---	---	X	---	---
Vital public needs:						
Communications	X	---	---	X	---	---
Fire---------------	---	---	X	---	---	X
Police-------------	---	---	X	---	---	X
Electric power-----	X	---	---	X	---	---
Water--------------	X	---	---	X	---	---
Natural gas -------	X	---	---	X	---	---
Access roads-------	X	---	---	---	---	---
Airports-----------	---	X	---	---	X	---
Schools (as shelter)	---	X	---	---	X	---
Food supplies	X	---	---	X	---	---

	Estimated losses	
	Wasatch fault	Magna fault
Losses except dams:		
Deaths-------------	250	210
Serious injuries----	1,000	840
Homeless-----------	3,520	3,520
Losses from dam failure		
Deaths-------------	11,900	11,900
Homeless-----------	14,800	14,800

Conclusions

Weber County

From a postulated event on either the Wasatch or Magna fault, Mercalli shaking intensity in Weber County would be VIII, which is less than would be expected in either Davis or Utah Counties. The maximum number of estimated deaths in Weber County that might be caused by the earthquakes is 320, not including dam failure. Serious injuries could reach as many as 1,280. Temporary housing for 1,340 people may be required for an indeterminate length of time. If Pineview Dam were to fail, there could be as many as 8,000 deaths and 7,200 homeless in the Ogden area.

Hospitals in Weber County would have a 26 percent bed loss from the Wasatch event and about 18 percent from the Magna event. Medical personnel should be sufficient to care for the injured. Medical supplies and ambulances should be available to hospitals.

Damage to police and fire services and to various forms of communication would be moderate. Access roads and railroad lines across Great Salt Lake and east of Ogden through the mountains could be blocked, but access to Salt Lake City should be only slightly impaired.

Vital public utilities should have only minor impairment. Schools should remain in good condition and be able to provide shelter for homeless if the need exists.

Davis County

The maximum number of estimted deaths in Davis County could be 190 and injured could be 760 from all causes except dam failure. Homeless could number as high as 2,710 from earthquake-related effects--mostly from vibration effects as Davis County would be in Mercalli Intensity zone IX. Failure of Echo Dam could result in deaths and homeless in the town of South Weber.

The addition of two new hospitals in Davis County will be a definite asset to the area, because major damage to hospitals could be expected from an earthquake on the Wasatch fault. Over 50 percent of hospital beds could be nonfunctional from this event. Health manpower and supplies should be available, but moderate impairment of bloodbanks and ambulance services is possible.

Major impairment of fire and police facilities can be expected, but transportation systems and public utilities should experience only moderate damage. Schools will be able to provide shelter to a homeless population from Salt Lake County. Hill Air Force Base could also be used as a resource to house and feed a homeless population. The airfield at the installation will probably remain functional and could be used in place of the Salt Lake Airport for the first day or two.

Vibration damage to all types of manmade structures will increase from both postulated events as one moves south toward the epicenters on the Wasatch and Magna faults in Salt Lake County.

Salt Lake County

The highest number of casualties and the greatest damage to manmade facilities will occur in Salt Lake County for both postulated events, because both earthquake epicenters (and centers of energy release) are located in the county and because the greatest population density and congested building areas are also within the county.

As many as 1,570 deaths, 6,280 injured, and 22,000 homeless could be expected from the Wasatch fault event. Slightly smaller numbers in these three categories will result from the Magna event. The postulated location of the Wasatch fault surface rupture and the related zone of deformation within major residential areas of Salt Lake City and County contribute measurably to the casualty and damage situation.

Hospitals in Salt Lake County will have an 80-percent bed loss. Two major Salt Lake Hospitals are within the zone of deformation due to faulting, and partial building collapse for these facilities is possible. Health manpower, medical supplies (including blood), and ambulance service could be moderately impaired from either earthquake event.

Vital public needs in the form of fire and police services, electric power, natural gas (critical in the winter), and water for medical purposes and firefighting could all suffer major impairment. Many waterlines and gaslines would be severed by the Wasatch fault rupture.

Communication systems (radio, television, and telephone) should suffer moderate impairment, but emergency radio should be able to remain functional.

Transportation systems in a north-south direction may be blocked due to overpass collapse, but temporary bypasses can be constructed within a few hours and alternate routes could be used. If the Wasatch fault (as shown on the various figures in this report) were to rupture for the entire length, there would be major impairment of all east-west transportation routes in Salt Lake County that cross the fault, thereby isolating the east part of Salt Lake County (including two main hospitals) from the downtown area of the city and the majority of the residential population. The Salt Lake Airport would probably be nonfunctional for up to 48 hours from runway damage.

About 40 percent of Salt Lake County schools would be nonfunctional, but possibly 10 of the newer schools, built to resist strong earthquake forces, could be used as temporary shelter for the homeless population.

Distribution of foodstuffs may be difficult until east-west transportation routes are repaired or temporary bypasses are constructed.

Utah County

Shaking intensities in Utah County would vary from Mercalli Intensity IX in the north third of the county, to Intensity VIII in the Provo-Orem area, to Intensity VII south of Payson. Casualties and damage to manmade facilities would vary in proportion to the intensities. Expected deaths could be 250, serious injuries could be 1,000 and the homeless might equal 3,520. Failure of the Deer Creek reservoir in Provo Canyon could add an additional 11,900 deaths and nearly 15,000 homeless.

Over 50 percent bed loss could be expected in Utah County hospitals from the Wasatch fault event. However, impairment of health manpower, medical supplies, and ambulances should be minor.

Many police and fire services could be nonfunctional, but impairment of all other vital public needs should be minor. Although schools will suffer moderate impairment, some should be available for temporary housing and feeding purposes.

Part of the north-south interstate highway and the Provo Airport, east of Utah Lake, are in poor-soil areas, and impairment of these facilities may result. However, alternate highway routes can be used, and runway damage to the airport can be repaired in a few days.

MODIFIED MERCALLI INTENSITY SCALE OF 1931

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

II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.

III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated.

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

V. Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.

VI. Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.

VII. Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars.

VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimney, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motor cars disturbed.

IX. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.

X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.

XI. Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipe lines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

XII. Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

See (Wood and Neumann, 1931) for complete details of this Intensity Scale.

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