Lake Tahoe

NATURAL HAZARDS OF THE LAKE TAHOE BASIN

CALIFORNIA–NEVADA

FOR THE TAHOE REGIONAL PLANNING AGENCY

Prepared by the Tahoe Regional Planning Agency in cooperation with Cooper, Clark & Associates.

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Attention: William E. Cramer
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Gentlemen:

This review of the Basin's natural hazards was financed in part through a Comprehensive Planning Grant from the Department of Housing and Urban Development (Project Number CPA-CA-09-39-1037).

In general, the purpose of this study was to compile existing geologic data and delineate probable hazard zones, including areas subject to snow avalanches, on 7½-minute U.S. Geological Survey maps. These maps, together with an inventory of hazards, which is presented in this report, are intended to provide a starting point for future studies which will develop general planning guidelines and facilitate ordinance preparation and review procedures.

Our work was undertaken in close conjunction with Messrs. William Cramer and Peter Hollick of the Tahoe Regional Planning Agency (TRPA), and their assistance was most helpful. Also, TRPA'S various planning guide publications were an invaluable data source for our compilation of existing information.

Yours very truly,

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TAHOE BASIN, CALIFORNIA
FOR THE TAHOE REGIONAL PLANNING AGENCY

1.0 INTRODUCTION

1.1 GENERAL

This report presents the results of our Natural (geotechnical) Hazards Study of the Lake Tahoe drainage basin, California-Nevada (see Figure 1, Location Map).

There has been an increasing awareness of the potential impacts of geologic, topographic, climatic and seismic restraints on the proper development of the Tahoe Basin. This awareness has led to the initiation of natural hazards studies, and this report summarizes preliminary findings of one such study. Further, more detailed studies will be required to more accurately define the natural hazards, to develop mitigating measures where possible and to permit consideration of the natural hazards in the planning and development of the Lake Tahoe Basin.

Definitions of various technical terms used in this report are presented in Appendix C, Glossary. A select bibliography is presented in Appendix D.

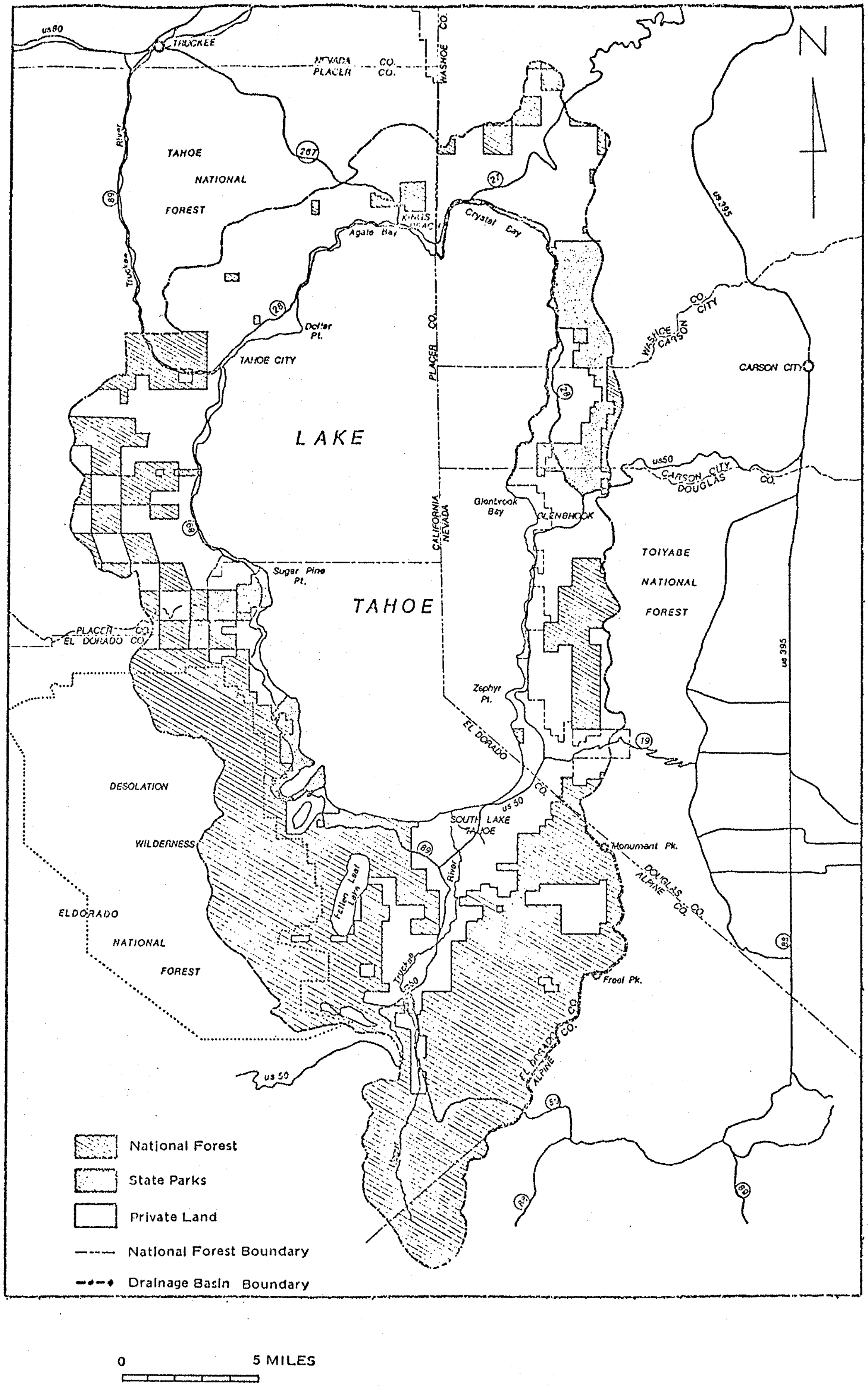
1.2 SCOPE

The scope of our services was as outlined under the following five headings:

1. *Inventory:* Prepare a list of potential geologic hazards. This inventory is intended to be a check list which can be correlated with the natural hazards maps, which are submitted with this report, and which can be used to help in the review of geologic, soils and environmental impact reports.

2. *Natural Hazards Mapping:* Prepare natural hazards maps which superimpose available geologic data and associated risk interpretations onto 7½-minute U.S. Geological Survey topographic maps.

3. *Report:* Supplement the inventory and natural hazards maps with a geotechnical report, including: (a) discussion of the geologic, climatic and seismic setting of the Lake Tahoe Basin; (b) a brief discussion of the seismic history of the Tahoe Basin; (c) discussion of the natural hazards maps, including method of preparation, limitations, reasons for hazard delineations, and a summary of hazards associated with each geologic unit; (d) discuss usage of these data by both TRPA and the general public, and (e) outline additional studies which should be undertaken.



LOCATION MAP

FIGURE 1

4. *Ordinance Review:* Review the current subdivision and grading ordinances and submit recommendations on measures which should be undertaken to upgrade such ordinances so that they more closely consider natural hazards and associated public safety.

5. *Natural Hazards Planning Guide:* Following TRPA staff review of the natural hazard data, prepare a natural (geotechnical) hazards planning guide in cooperation with the TRPA staff.

Item 4 above, Ordinance Review, is presented in Appendix B of this report, and Item 5, Natural Hazards Planning Guide, is presented in Appendix E of this report.

1.3 METHODOLOGY

Geologic data developed by Matthews (1968) and Burnett (1967) were used to establish the geologic base map. These data were supplemented with geologic, avalanche and climatic information from published and unpublished technical reports and maps (see Appendix D, Select Bibliography). It must be recognized that transposing the geologic and hazard information from the existing geologic map scale of 1" = 4,000' to a map drawn to a scale of 1" = 2,000' introduces the possibility of error in accuracy, and this should be taken into consideration in the application of the maps accompanying this report (Plates 1-A through 1-D).

A preliminary aerial photographic study of the entire basin area was made using colored aerial photographs obtained from the Forest Service (scale 1:15,840, September 4, 1971), and black and white high-altitude aerial photographs (scale 1:64,000, June-September 1973). Aerial photographs of the region made by the National Aeronautics and Space Agency (NASA) were also reviewed.

Our interpretations and recommendations are based on the above data sources. Original work was limited to a preliminary aerial photo interpretation. No field investigations were undertaken.

An excellent review of the climate of the Lake Tahoe Basin can be found in "Climate and Air Quality of the Lake Tahoe Region" published in 1971 and prepared by a technical committee appointed by the Tahoe Regional Planning Agency and the Lake Tahoe Basin Planning Team of the U.S. Forest Service. Since this publication is so complete, we will not describe the Basin's general climatic conditions in this report.

2.0 NATURAL HAZARDS

2.1 PHYSICAL SETTING

Lake Tahoe occupies a basin surrounded by 9,000-foot-high peaks of the Sierra Nevada Mountain Range. The eastern and western sides of the Basin are composed of granitic rocks with minor amounts of older metamorphic rocks. Volcanic rocks, some deposited as recently as 2½ million years ago, cover most of the northern portion of the Basin. The southern end of the Basin consists of moraines and glacial outwash deposited in the delta of the Upper Truckee River.

Rock units within the Tahoe Basin can be divided into the following four general groups, listed in order of their abundance: granitic intrusives, volcanic rocks, glacio-fluvial deposits, and metamorphic rocks (see Plates 1-A through 1-D).

Granitic rocks on the western side of the basin are generally more indurated and less easily eroded than similar rocks on the eastern side, due to the scouring action of past glaciers which removed the loose, weathered surface material.

In areas of deeply weathered and decomposed granite, especially where the protective vegetative cover has been removed, erosion and sedimentation can be a serious problem. Oversteepened, fractured, faulted, and glaciated granitic slopes are susceptible to landslide and rockfall hazards. In 1953, a rockslide occurred in fractured granitic rock along a road-cut at Emerald Bay. During the winter of 1955-56, a second slide occurred at this location and at least 200,000 cubic yards of material slid onto the road and into Emerald Bay (Matthews, 1968).

Poorly indurated volcanic rocks (mudflow-breccias and tuffs) easily weather and break down into relatively unstable clayey soils. However, well indurated volcanic rocks (latite, andesite, etc.), where not fractured or faulted, generally form stable slopes. In 1967, a mudflow involving more than 50,000 cubic yards of material occurred due to excessive storm water flowing across poorly indurated volcanic rocks adjacent to Second Creek near Incline Village (Glancy, 1969).

Five advances of glacial ice, 1,000 feet thick in some areas along the western side of the basin, have been recorded in the morainal deposits of the Tahoe Basin during the past 3 million years. As the glaciers retreated, they left behind large moraines (piles of broken and finely-ground rock). The finer sediments, carried by subglacial streams, formed an extensive outwash plain (or delta) at the southern end of the lake. This outwash material is easily eroded when excavated or otherwise disturbed. Also, the response of glacio-fluvial deposits to seismic ground shaking can be most hazardous, as indicated by the disastrous 1964 Alaskan Earthquake (Eckel, et al., 1971).

Scattered outcrops of metamorphic rocks are found on the higher peaks which were preserved from the scouring action of the glacial ice. The steep glaciated slopes, joints, and weathered bedding planes are responsible for the rockfall hazard associated with these rocks.

Table 1 outlines potential environmental problems associated with the various geologic units. This table was adopted from Matthews and Burnett (1971), with minor modifications.

2.2 INVENTORY OF HAZARDS

A natural hazard can be defined as a foreseeable alteration of the natural physiographic features, resulting in probable damage to wildlife habitat, property, and/or water quality, and possible injury to persons in the area.

Potential natural hazards within the Basin have been divided into two general categories: hazards relating to natural stability, and hazards caused by earthquakes.

Natural stability deals primarily with slope and mass wasting phenomena. Under this classification, we have included:

- Erosion - siltation
- Rockfalls
- Landslides
- Subaqueous landslides
- Debris avalanches
- Mudflows
- Snow avalanches
- Frozen ground
- Expansive and weak soils
- Flooding
- Volcanic eruption

Seismic hazards exist in the entire Basin, both on the slopes and in urbanized level areas. Hazards related to a major earthquake within the Basin are:

- Ground rupture
- Ground shaking
- Ground failure
    - Liquefaction
    - Lateral spreading
- Seiches
- Catastrophic inundation

Natural stability hazards such as landslides and flooding can also be triggered by seismic events.

SYMBOL	GEOLOGIC UNIT	DEGREE OF CONSOLIDATION	STREAM CHANNEL STABILITY	EROSION-SILTATION POTENTIAL	SOIL CREEP	NATURAL LANDSLIDE POTENTIAL	DISTURBED LANDSLIDE POTENTIAL	SEISMIC HAZARD POTENTIAL
Qal	Alluvium	L - M	M - H	M - H	L	L	M	M - H
Ql	Recent Lake Sediments	L - M	L - M	H	L - M	L - M	H	L - M
Qlo	Older Lake Sediments	L - M	M	M - H	L	L - M	M	L - M
Qta	Talus	L	L	L - M	M - H	L - M	H	M - H
Qls	Landslide Deposits	L	L	H	H	H	H	H
Qg	Glacial Outwash	L	M	M - H	L	L - M	M	M - H
Qm	Moraines	L - M	L - M	M - H	L - M	M	M - H	M
Qv	Intrusive Volcanic Rocks	H	H	L	L	L	L	L
Tv	Volcanic Rocks	H	H	L - H	L	L	L - M	L
Tv^p	Pyroclastic Rocks	L - M	L - M	M - H	M	M	M - H	M
gr	Granitic Rocks	H	H	L	L	L	L - M	L
gr^d	Decomposed Granitic Rocks	L	L	H	H	M	H	L - M
di	Intrusive Rocks (Diorite)	H	H	L	L	L	L - M	L
ms	Metasedimentary Rocks	H	H	L	L	L	M - H	L - M
mv	Metavolcanic Rocks	H	H	L	L	L	M - H	L - M
m	Undifferentiated Metamorphic Rocks	H	H	L	L	L	M - H	L - M

NOTE: Risk potential is indicated in terms of H = high, M = moderate, and L = low.

POTENTIAL ENVIRONMENTAL PROBLEMS RELATED TO GEOLOGIC UNITS IN THE LAKE TAHOE DRAINAGE BASIN, CALIFORNIA–NEVADA

REF: Matthews and Burnett, 1971.

TABLE 1

2.3 RELATIONSHIP OF HAZARDS AND ENVIRONMENT

In general, the following three factors must be considered in assessing natural hazards: topography, lithology (rock type), and geologic structure. Adverse conditions related to each of these factors can be outlined as follows:

I. Topography
   A. Slopes
      1. In excess of 30%
      2. Convex profile
      3. Talus
      4. North exposure
      5. In the lee of prevailing winds
   B. Drainage
      1. Springs or seeps
      2. Areas adjacent to drainage courses
      3. Water saturated soils
   C. Lack of vegetative cover

II. Lithology
   A. Poorly indurated rocks (e.g., volcanic mudflow-breccias, tuff, etc.)
   B. Poorly consolidated deposits (e.g., moraines, etc.)
   C. Highly-weathered rocks (e.g., decomposed granite)
   D. Glacial outwash (especially adjacent to Lake Tahoe)
   E. Old lakebed deposits

III. Geologic structure
   A. Fault zones
   B. Fractured - jointed rocks
   C. Exfoliation
   D. Steeply dipping beds, folds, etc.
   E. Zones of chemical alteration

The relationship between the above factors and potential hazards found in the Tahoe Basin are briefly outlined on Table 2, Hazards and Contributing Factors, and the potential hazards are discussed in detail in subsequent sections of this report.

	POTENTIAL HAZARD	CONTRIBUTING FACTORS		
		TOPOGRAPHY	LITHOLOGY	STRUCTURE
NATURAL STABILITY	EROSION-SEDIMENTATION	○	○	
	ROCKFALLS	○		○
	LANDSLIDES	○	○	○
	SUBAQUEOUS LANDSLIDES	○	○	
	DEBRIS AVALANCHES	○	○	
	MUDFLOWS	○	○	
	SNOW AVALANCHES	○		
	FROZEN GROUND		○	
	EXPANSIVE OR WEAK SOILS		○	
	FLOODING	○		
	VOLCANIC ERUPTION			○
SEISMIC	GROUND RUPTURE			○
	GROUND SHAKING	○	○	
	LIQUEFACTION	○	○	
	LATERAL SPREADING	○	○	
	SEICHES	○		
	CATASTROPHIC INUNDATION	○		○

TABLE
HAZARDS AND CONTRIBUTING FACTORS

3.0 NATURAL GROUND STABILITY HAZARDS

3.1 EROSION-SEDIMENTATION

The potential for erosion and sedimentation presents a serious hazard to the delicate environmental balance of the Lake Tahoe Basin. Erosion denudes the slopes of their valuable shallow soil cover (the soil cover is less than three feet thick in most of the Basin), and makes it difficult for vegetative cover to be restored once the soil has washed away. Sedimentation reduces the clarity of the lake, contributes to lake eutrophication, and clogs drainage courses and culverts, with consequent flooding. This hazard is most pronounced in areas consisting of poorly indurated, unconsolidated and deeply weathered rocks, such as decomposed granite, volcanic mudflow-breccias and tuffs.

Steep topography, moderate to high precipitation, loss of vegetative cover by lumbering and fires, and man-made improvements all contribute to the potential erosion hazard. A sedimentation survey of the Upper Truckee River in 1969 by the State of California showed that, of the total 30,000 tons of sediment annually transported by this river, 48 percent comes from roadways, 39 percent from natural streambanks, and 13 percent from sheet flow across slopes. This study further showed that the natural rate of sedimentation has doubled as a result of man's activity.

A considerable amount of study has been done on the erodibility of soils within the Tahoe Basin by the U.S. Department of Agriculture – Soils Conservation Service. One of the important parameters used by the Soil Conservation Service in determining erosion potential is the amount of soil-water storage. Bailey in 1974 also discusses the importance of the soils potential water storage ability in the control of runoff and erosion patterns. Four hydrologic or infiltration groups have been developed, Group A having the greatest infiltration capacity (greater than 0.30 inch per hour) and Group D having the least infiltration capacity (less than 0.05 inch per hour).

The Soils Conservation Service (U.S. Department of Agriculture, 1974) lists the following soil types as having a high erosion potential unless close-growing plant cover is maintained: Inville, Jabu, Jorge-Tahoma (cobbly sandy loams, 2 to 5% slopes), Meiss, Shakespear, Tahoma (stony sandy loam, 2 to 15% slopes), Tallac (gravelly coarse sandy loam (0 to 50% slopes) and Waca. Detailed, in-depth analysis of soil erosion potential, as well as the characteristics and location of the above soils can be found in the U.S. Department of Agriculture 1974 Soil Survey.

Our Hazard Map (Plates 1-A through 1-D) considers erosion as one of the hazards and shows, in general, areas where there is a potential for erosion based on rock and soil type as determined by the Soil Conservation Service.

3.2 MASS WASTING

The general term "mass wasting" applies to the dislodgement and downslope transport of rock and soil under the influence of gravity. Included under this heading, depending on the type of movement (fall, slide, flow) and size of material involved, are rockfalls, landslides, debris avalanches, and mudflows. The volume of material can vary from minor slumps of only a few cubic yards to extensive landslides involving millions of cubic yards. Such a massive landslide occurred in the poorly-indurated volcanic rocks of Slide Mountain in 1852, just northeast of the Tahoe Basin. This earthquake-triggered landslide involved an estimated 125 million cubic yards of material (Slemmons, 1965; Matthews, 1968).

Landslides and other types of mass wasting do not appear to be a common hazard within the Tahoe Basin. However, the potential for sliding does exist where there are steep slopes, loose or poorly consolidated soils or rock mantle, fractured and faulted rocks, and high precipitation. Seismic activity and poorly engineered grading can also increase the sliding potential of a particular area.

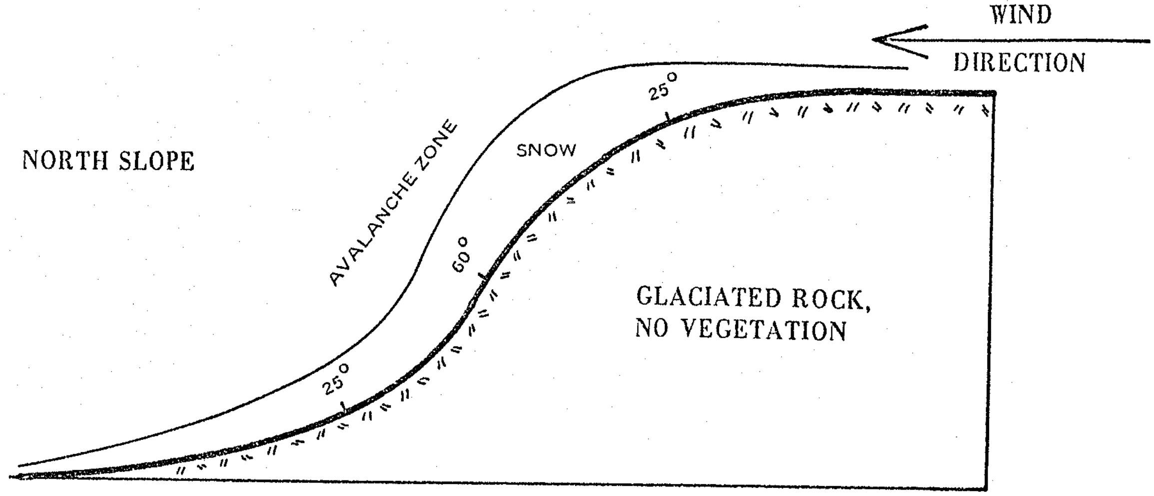
In recent years, the Basin has experienced a rockslide along Highway 89 at Emerald Bay and a mudflow near Incline Village (as noted in Section 2.1), which resulted in loss of life and property damage. As more development takes place within the Basin, the hazards associated with mass wasting may become more common.

3.3 SNOW AVALANCHES

Snow avalanches occur more frequently along the western side of the Basin where the average depth of the snow pack is from 100 to 200 inches. Hazardous avalanches regularly occur along Highway 89 at Emerald Bay and along Highway 50 at Meyers Grade. The Nevada, or eastern, side of the Basin is in the "rain shadow" of the western mountains and, therefore, receives less precipitation; the average depth of the snowpack on the eastern side of the Basin is from 16 to 66 inches (U.S. Department of Agriculture, 1970).

In determining potential snow avalanche hazard zones, we adopted the topographic criteria outlined by the Forest Service (U.S. Department of Agriculture, 1968). Slope angle, profile, and orientation are important factors in avalanche development. Ground surface roughness and an absence of vegetation are also major factors.

Figure 2 schematically depicts the type of area where an avalanche would most likely occur due to topographic conditions. The figure shows glaciated slopes of 25 to 60 degrees which have no vegetative cover and are curved outward (convex). On slopes which are convex, the compacted snow tends to develop tension cracks and creep downhill more easily under the influence of gravity.



CONDITIONS MOST FAVORABLE TO THE
FORMATION OF A SNOW AVALANCHE

FIGURE 2

3.4 FROZEN GROUND

For most soil types, freezing causes the soil to heave and/or an impervious ice sheet (frost concrete) forms near the surface. This phenomenon is especially common in the northern portion of the Basin where the volcanic rocks break down into a clayey soil which tends to retain water. The formation of ice in wet, poorly drained soils contributes to and accelerates downhill creep of soil, and it damages roads and building foundations by its expansive force during freezing. A thick layer of frost concrete will form an impervious surface on unprotected slopes, thereby preventing storm water infiltration into the ground and increasing surface water runoff. Excess water runoff increases sheet and gully erosion and contributes to flooding. Also, reduced water infiltration into the soil may ultimately affect the amount of water available for plant growth.

Studies by the University of Nevada (Skau, et al., 1970) show that ground insulated by either snow or a minimum of two inches of litter generally does not develop frost concrete.

3.5 EXPANSIVE AND WEAK SOILS

Expansive soil does not appear to be an extensive problem in the Basin area. However, expansive soils occur in areas of weathered volcanic tuffs, such as are found in the northern part of the region. Weathering of these tuffs generally produces large amounts of montmorillonite clay which expands when wet and shrinks when dry.

Weak soils, or those soils subject to differential settlement, occur in the poorly consolidated moraines and outwash deposits. This is especially the case for those deposits around the perimeter of the lake, because of the high groundwater table.

3.6 FLOODING

Flooding in the low-lying areas results from both rapid surface water runoff and clogging of natural drainage channels and culverts with debris and sediment.

Because of the steep terrain and the lake water level control at the outlet dam on the Lower Truckee River, lake perimeter flooding is a minor hazard within the Basin. Flash flooding occurs mainly in areas where development encroaches onto a natural drainage course or flood plain.

Improperly performed grading in steep areas and in those portions of channels where high velocity, turbulent flows occur, is a primary cause of increased erosion. On the other hand, channel alterations that reduce flow velocities in flood plain and other flat areas result in increased sedimentation; thereby, contributing to the flood hazard by reducing the channel capacity.

The remote possibility does exist that a massive landslide could block the outlet of the Lower Truckee River and create a dam which would back up the water in Lake Tahoe to an elevation of 6,400 or more.

3.7 VOLCANIC HAZARDS

A potential volcanic hazard is indicated in the Tahoe-Truckee Area by the relatively recent volcanic rocks in the northern portion of the area and the presence of a geothermal spring near Brockway (Alfos, et al., 1973). The possibility of a volcano erupting in the area is remote and, in any case, there is no preventive action which can be taken to avert it, or means available to predict where it might occur. Volcanic eruptions are generally preceded by numerous earthquakes, which usually provide ample warning to those who may be in the affected area.

4.0 REGIONAL SEISMICITY

4.1 GENERAL

The Lake Tahoe Basin is located in a region of active and potentially active faults. This conclusion is based on the following topographic features and historical data:

1. Movements have taken place along faults adjacent to the Basin within historical times (Lawson, 1912; Kachadoorian, 1967).

2. Sediments at the bottom of Lake Tahoe show recent offsets which are indicative of faulting (Hyne, 1972).

3. Steep cliffs (30 to 45 degree slopes) and other topographic features associated with active faulting are found on both sides of Lake Tahoe (Lindgren, 1896 and 1897; Louderback, 1924; Birkeland, 1963; Hyne, et al., 1972).

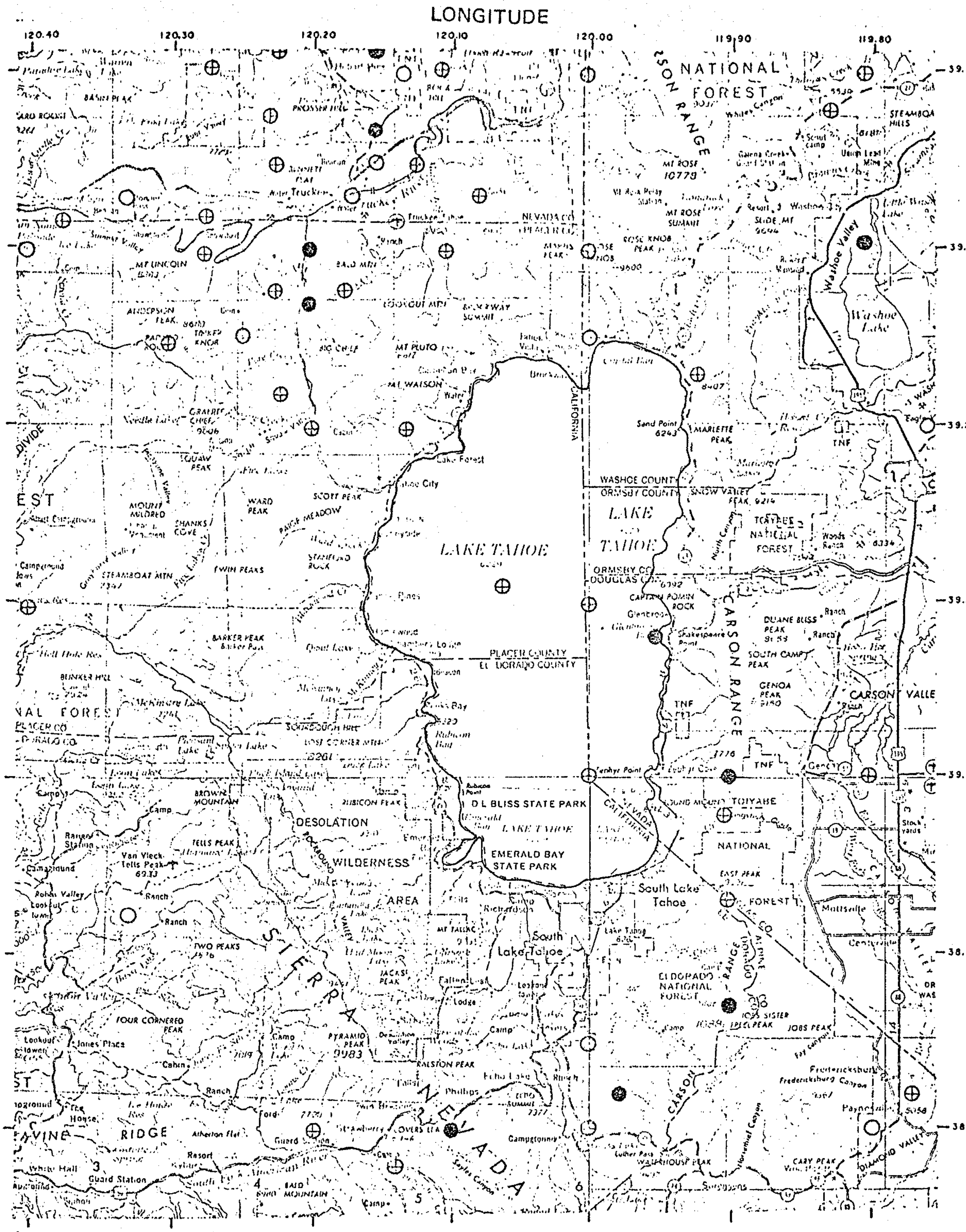
4. Earthquake epicenters, which indicate probable faults, have been located in and around the Basin. However, there are no recorded earthquakes of magnitudes greater than 5 having epicenters within the Basin (see Figure 3, Epicenters of Selected Historical Earthquakes in the Vicinity of Lake Tahoe from 1855 to 1971, and Appendix A, Epicenter Data).

4.2 SEISMIC SETTING

4.2.1 Historical Fault Movement

The major north-south fault zone which separates the eastern edge of the Sierra Nevada Mountains from the sequence of parallel fault block mountains of Nevada and Utah is located about 6 miles east of the Tahoe Basin. Lawson (1912) observed that this Sierran frontal fault experienced 44 feet of vertical ground displacement during an earthquake some time within the past 200 years. It is possible that major fault movement along the Sierra frontal fault could occur again, with resultant ground failure and severe ground shaking within the Tahoe Basin. Figure 4 is a schematic, east-west, geological cross-section of the State of California and the western portion of Nevada, showing the Sierra frontal fault and other major regional faults.

A magnitude 6 earthquake occurred in 1966 at Boca Reservoir, about 16 miles northeast of Tahoe City (Kachadoorian, et al., 1967). Resultant ground shaking within the Tahoe Basin lasted only 15 seconds and damage was relatively light; however, prolonged ground shaking (2 to 3 minutes) could have caused considerable damage due to landslides and liquefaction of some sediments.



EPICENTERS OF SELECTED HISTORICAL EARTHQUAKES IN THE VICINITY OF LAKE TAHOE FROM 1855 to 1971

MAGNITUDE

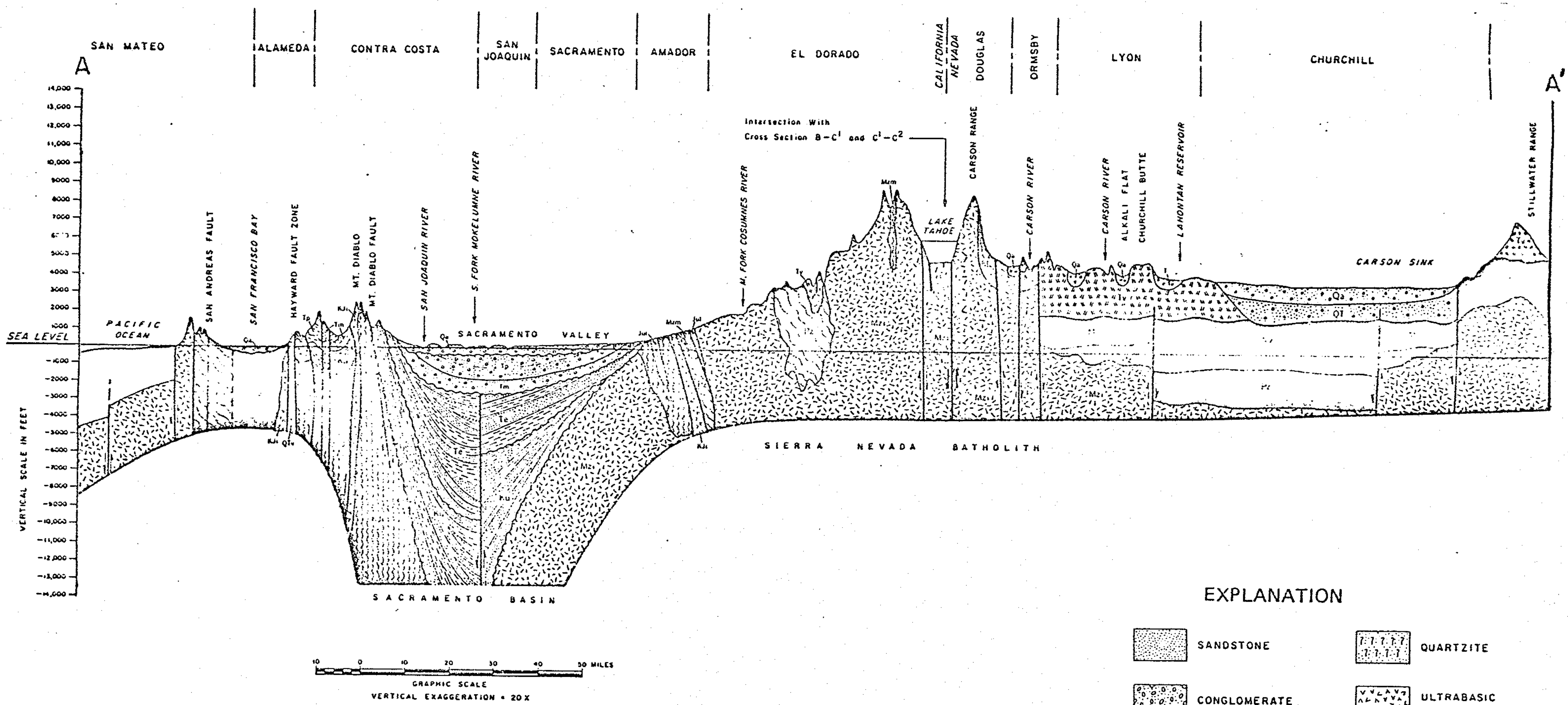
- ● GREATER THAN 4
- ⊕ 2—4
- O UNRECORDED

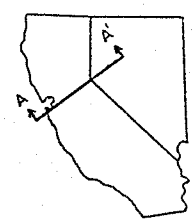
5 0 5 Miles

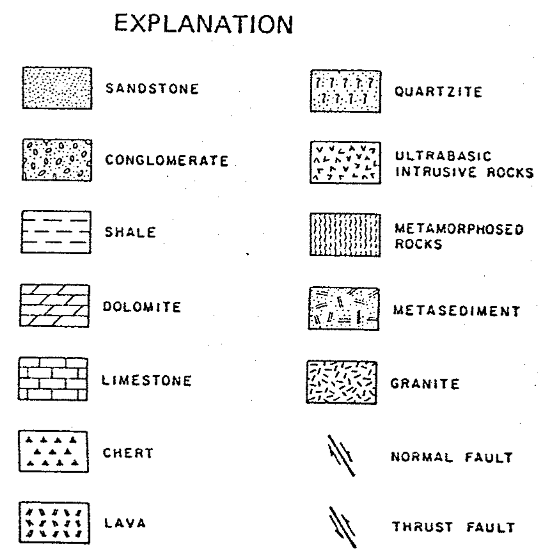
SOURCE: University of California Seismographic Station, Berkeley

See APPENDIX A, EPICENTER DATA

FIGURE 3







GEOLOGICAL CROSS SECTION OF CALIFORNIA AND WESTERN PORTION OF NEVADA

REF: American Association of Petroleum Geologists, 1968, Geological highway map, Pacific Southwest Region, California–Nevada: American Association of Petroleum Geologists, Tulsa, Oklahoma.

FIGURE 4

4.2.2 Faulting of Recent Lake Sediments

Seismic reflection profiles of Lake Tahoe by Hyne and others in 1972 revealed a 46-foot offset in the recent lakebed sediments off Dollar Point. These researchers have interpreted the offset as an active fault. Also, the deeper, buried sediments in the southern portion of the lake dip westward, possibly indicating recent fault movement along the western portion of the Basin. Indications of massive subaqueous landslides were also observed by Hyne within the lake bottom sediments.

4.2.3 Topographic Features Indicative of Active Faults

Although direct evidence is obscured by volcanic flows, glacial moraines and water, Lindgren noted in his extensive geological study of the area that the following topographic features could only be explained by faulting:

1. Surface evidence of active fault movement is apparent north of the Basin, along projections of the major Basin faults.
2. Recent lakebed deposits in the Truckee Valley have been tilted 25 degrees southward.
3. Pleistocene (within the last 3 million years) lake gravels in the Truckee Valley north of Lake Tahoe are 200 feet higher on the northeast side of the valley, indicating that some deformation has taken place along the eastern side of the valley.
4. Six hot springs (some as hot as 138° F) are located in the lake about 20 feet west of Brockway. These springs are believed to be related to a fault contact between volcanic and granitic rocks.
5. Steep scarps in granitic rock, approximately 2,000 feet high, border and extend down into the lake. If these slopes had been continuously exposed since the origin of the granitic rocks some 100 million years ago, they would be less steep due to the natural weathering processes.

Birkeland (1963), in agreement with Lindgren's findings, mapped several faults which offset the 2½-million-year-old volcanic rocks on the north shore of Lake Tahoe near Dollar Point at Stateline. Pakiser (1960) suggested that some of the volcanic flows in the northern portion of the Basin are a result of tension cracks which developed along the major boundary faults, providing access zones through which lava reached the ground surface.

Other physiographic evidence which may be indicative of geologically recent faulting within the Basin is seen in the capture of the Upper Truckee River at Meyers Grade; normally this river should drain through the South Fork of the American River (Matthews and Burnett, 1971).

4.2.4 Epicenter Data

Earthquake epicenter data for the general Lake Tahoe Basin region located between Latitudes 38.75° and 39.40° north and Longitudes 119.75° and 120.33° west were obtained from the University of California's Seismographic Station at Berkeley, California (Appendix A). Within these coordinates, the data indicate that 136 significant earthquakes have originated in the vicinity of the Basin since 1855. These epicenters are shown on Figure 3, Epicenters of Selected Historical Earthquakes in the Vicinity of the Lake Tahoe from 1855 to 1971. It should be noted that some of the epicenter locations, especially of earlier earthquakes, were roughly estimated and are questionable. Even recent epicenter locations are only approximate and may be up to 3 miles in error.

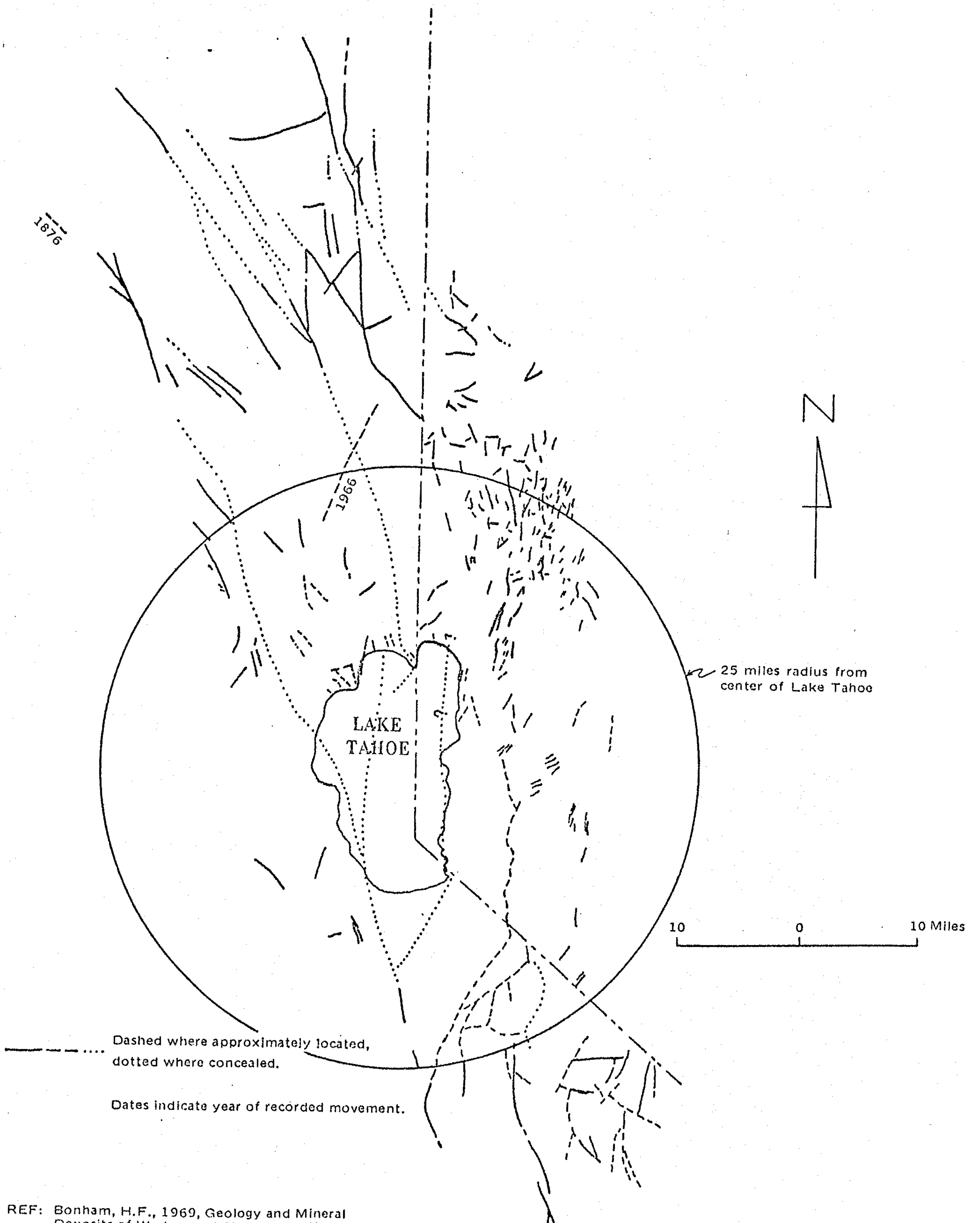
4.3 SEISMIC HAZARDS

4.3.1 Ground Rupture

Earthquakes are usually generated by movement along fault planes or by volcanic activity. Surface rupture occurs during an earthquake when fault displacement extends upward and intersects the ground surface. However, surface rupture does not occur every time a fault moves.

The length of surface rupture occurring along a fault trace, the width of the zone of surface rupturing, and the amount of displacement between opposite sides of the fault at the surface during a single earthquake are highly variable. These factors are believed to be related to the length of the fault. Studies have shown that the longer the active fault, the greater is the potential for a high magnitude or great earthquake. The greater the earthquake, the greater the possibility that a large amount of surface displacement will occur. The greatest displacement during a single earthquake documented in California occurred along the Owens Valley fault during the 1872 earthquake, when 23 feet of movement occurred.

All faults within the Basin are considered potentially active, as outlined under Section 4.0. Based on historical information and assuming that similar patterns of earthquake activity will occur in the future, it is estimated that a 7.0 magnitude earthquake or greater will occur on the average of every 110 years within 25 miles of the center of Lake Tahoe (R. Greensfelder, 1971). The major north-south faults along the boundary of Lake Tahoe appear to be the longest continuous faults traversing the Basin area. Of these faults, the fault along the west side of the Lake appears to be the longest, with a surface length of perhaps 50 miles (Figure 5). Theoretically, a fault of this length could generate a 7.5 magnitude earthquake with a probable maximum surface displacement of 10 feet (Bonilla, 1970).



REF: Bonham, H.F., 1969, Geology and Mineral Deposits of Washoe and Storey Counties, Nevada: Nevada Bureau of Mines Bulletin 70.

Cohee, G.V., et al, 1962, Tectonic Map of the United States: U.S. Geological Survey and American Association of Petroleum Geologists.

Geological Society of America, 1969, Tectonic Map of the United States.

Greensfelder, R.W., 1972, Crustal Movement Investigations in California: Their History, Date, and Significance, California Division of Mines and Geology.

Jennings, C.W., 1972, Unpublished map, California Division of Mines and Geology.

REGIONAL FAULTS
LAKE TAHOE AREA

FIGURE 5

4.3.2 Ground Shaking

Ground shaking is the oscillation or vibration of earth materials resulting from an earthquake. It is the most commonly experienced earthquake phenomenon, because it may be felt many tens or even hundreds of miles from the earthquake epicenter.

Vibrations created by an earthquake are sometimes related to the "degree of shaking" a person feels at a specific location. The Modified Mercalli Intensity Scale, which was established in 1931, relates this "feeling" to a numerical scale of I to XII. Since intensity is measured for a particular place, the intensity value given an earthquake will vary from place to place.

The strength of an earthquake can be more scientifically evaluated in terms of the Richter Magnitude Scale, which measures the magnitude of the earthquake on a seismograph and is independent of the place of observation. Magnitude is measured on a logarithmic scale by which every one-unit increase indicates an increase in energy released of roughly 30. For example, a magnitude 8 earthquake would have an energy 30 times greater than that of a magnitude 7 earthquake, and 900 times greater than that of a magnitude 6 earthquake. As contrasted with intensity, an earthquake has only one magnitude. A comparison between magnitude and intensity is shown on Table 3.

The severity and type of ground shaking and the impact of ground shaking on structures depend on several factors, including:

1. Magnitude of the earthquake.
2. Depth of focus.
3. Distance from causative fault.
4. Duration of shaking.
5. Local soil and groundwater conditions.
6. Relationship between the fundamental period of a structure and the predominant period of ground vibration.
7. Design of the building or structure.
8. Quality of materials and workmanship used during construction.

Richter Magnitude Number	Equivalent Modified Mercalli Intensity Index	Expected Modified Mercalli Maximum Intensity (at epicenter)*
2	I - II	Usually detected only by instruments
3	III	Felt indoors
4	IV - V	Felt by most people; slight damage
5	VI - VII	Felt by all; many frightened and run outdoors; damage minor to moderate
6	VIII	Everybody runs outdoors; damage moderate to major
7	IX - X	Major damage
8	XI - XII	Total damage

* Intensity will decrease in a nearly linear relationship with distance from epicenter.

COMPARISON OF RICHTER MAGNITUDE AND MODIFIED MERCALLI INTENSITY SCALES

REF: California Geology, "Earthquake Magnitude and Intensity", August, 1972.

TABLE 3

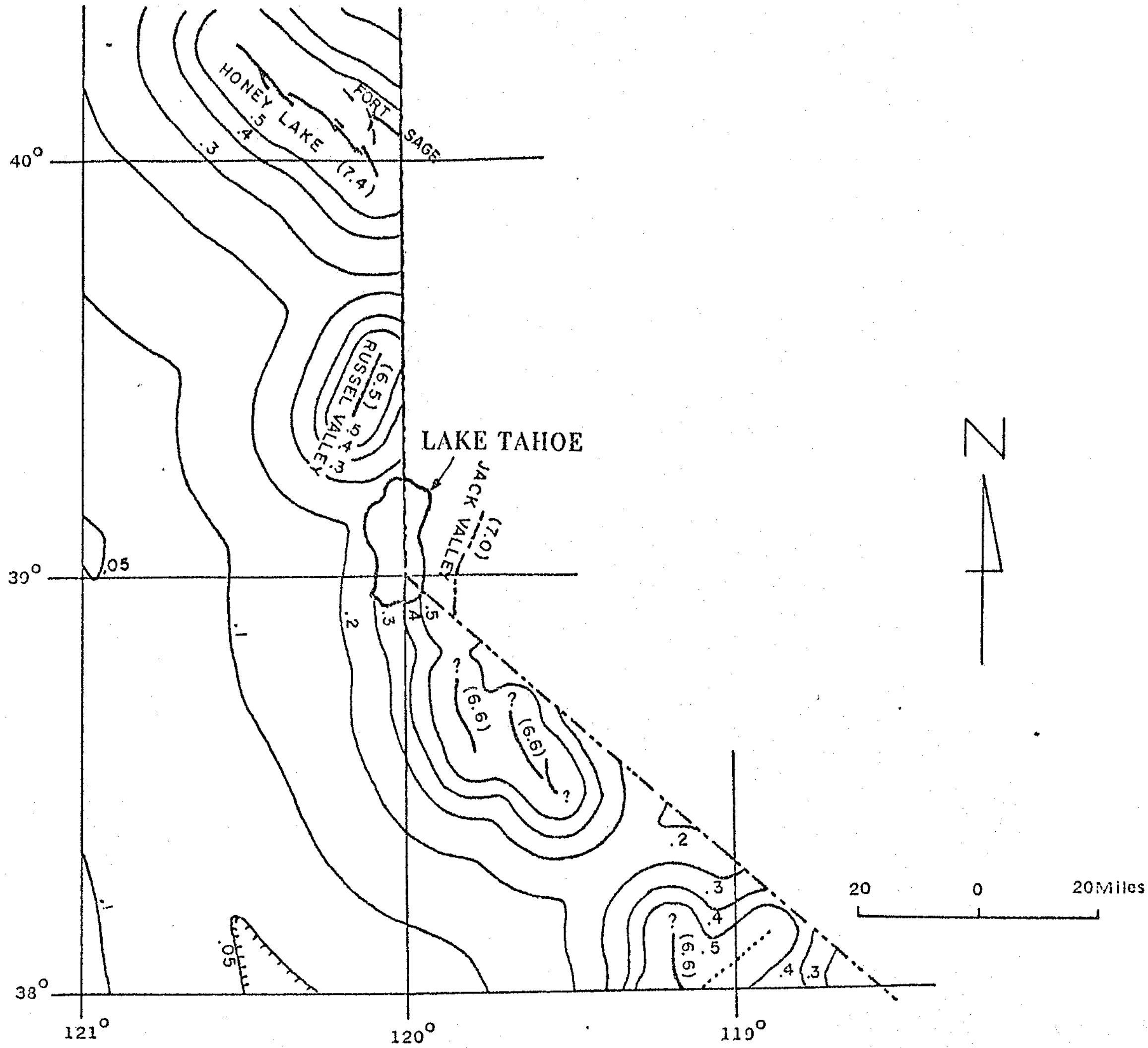
Hazards due to ground shaking are well known. Evidence has shown that ground shaking generally causes greater damage in areas underlain by loose, water-saturated soils than in areas underlain by competent rock. Such behavior has been repeatedly and strikingly demonstrated by large earthquakes, including those in San Francisco, 1906; Tokyo, 1923, Fukui, 1948; Arvin-Tehachapi, 1952; Chile, 1960; and Alaska, 1964. The severe damage in soft ground areas is generally a result of relatively high ground failure potential and large ground amplifications which are unfavorable to many types of structures.

The effect of ground motion on buildings depends not only on the characteristics of the ground motion, but also on the characteristics of the buildings. The fundamental periods for single-story buildings, 10-story buildings and 40-story buildings are roughly on the order of 0.1, 1.0, and 4.0 seconds, respectively. Earthquake bedrock motions near the causative fault generally have predominant periods of 0.2 to 0.5 second. The predominant period increases as the distance from the causative fault increases and/or as the motions propagate through thick alluvium. The motions may have predominant periods of several seconds when they reach the surface of soft soils. If a building is subjected to a series of vibrations having the same period as its fundamental period, large amplitude motions and internal stresses develop. On the other hand, if the same building is subjected to base vibrations having a period very different from its fundamental period, comparatively small effects will be induced. Accordingly, it is desirable to develop as great a difference as possible between the fundamental period of a building and the predominant period of the anticipated ground motion.

Not only will alluvial deposits generally modify the predominant period of the motion from that of the underlying bedrock, such soil deposits may also change the amplitudes, accelerations and velocities of the motion. Figure 6 is a generalized map of the maximum expected bedrock accelerations and predominant periods in the vicinity of Lake Tahoe.

The 1964 Alaskan Earthquake, with a magnitude of 8.4 and 4-minute duration, occurred in geologic terrain somewhat similar to that found in the Lake Tahoe Basin. Eckel (1971) states that, in general, the intensity of this earthquake was

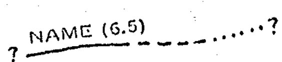
> "*greatest in areas underlain by thick saturated unconsolidated deposits, least on indurated bedrock, and intermediate on coarse gravel with low water table, and morainal deposits. Ground motion caused structural damage primarily by (1) direct shaking of some structures, (2) triggering landslides and subaqueous slides, (3) cracking underlying unconsolidated deposits, and (4) consolidating and subsiding loose sediments. The violent local waves that accompanied or followed most subaqueous slides were major indirect effects. All the subaqueous slides that were studied in any detail left new slopes nearly or quite*



MAXIMUM EXPECTED BEDROCK ACCELERATIONS IN THE VICINITY OF LAKE TAHOE

EXPLANATION

ACTIVE FAULTS

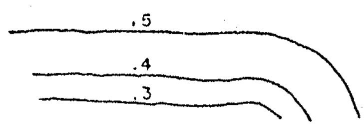


Dashed where approximately located, dotted where concealed.

Number in parentheses is the maximum expected earthquake magnitude for the fault.

Question marks at the ends of a fault indicate lack of strong evidence for its activity.

BEDROCK ACCELERATION CONTOURS



Units are decimal fractions of the acceleration of gravity, from 0.05g to 0.50g.

PREDOMINANT PERIOD OF BEDROCK ACCELERATIONS

Acceleration Range	Predominant Period
0.2g	0.35 seconds
0.1 — 0.2g	0.40 seconds
0.05 — 0.1g	0.50 seconds

Mean duration of motion 20-30 seconds

REF: Greensfelder, R.W., 1972, Maximum expected bedrock accelerations from earthquakes in California, California Division of Mines and Geology.

FIGURE 6

as steep as the preearthquake ones, some even steeper. This is the most significant and ominous finding from the investigations of these features, for it means that the delta fronts are still only marginally stable and hence are subject to renewed sliding, triggered by future earthquakes. The lesson is clear – any steep-faced delta of fine to moderately coarse materials in deep water presents inherent dangers of future offshore slides and destructive waves, whether or not it has slid in the past."

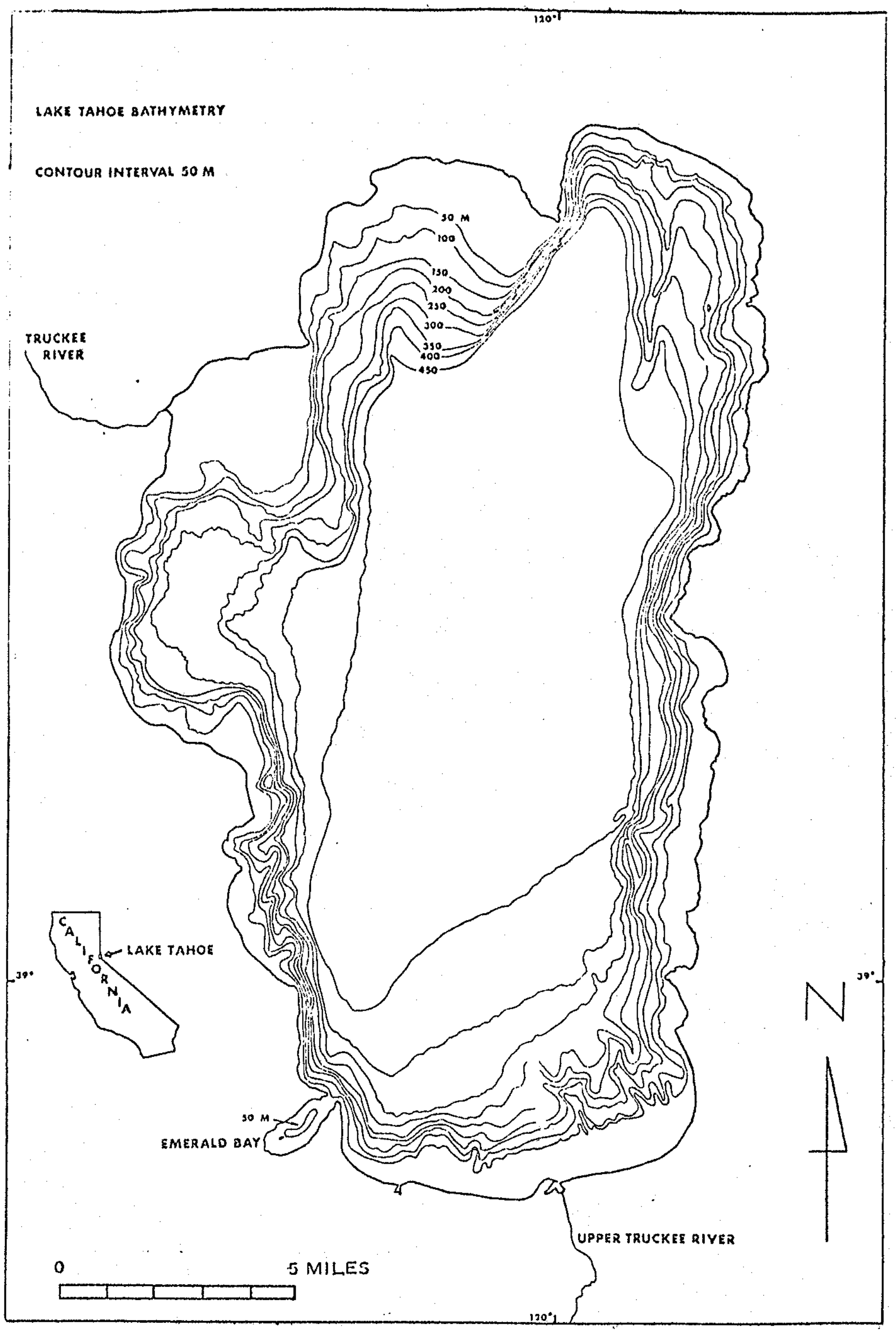
Seismic profiling by Hyne and others (1972) of the bottom of Lake Tahoe shows that the glacial outwash delta at the southern end of the lake slopes at angles up to 11^{o} (as shown on Figure 7), which is generally considered potentially unstable.

4.3.3 Ground Failure

Liquefaction is the type of ground failure most likely to occur in water-saturated silts, sands and gravels having low to medium in-situ density. When a soil of this type is subjected to vibration, it tends to compact and decrease in volume. If the groundwater is unable to drain during the vibration, the tendency of the soil to decrease in volume results in an increase in pore-water pressure. When the pore-water pressure builds up to the point where it is equal to the overburden pressure (effective weight of overlying soil) the effective stress becomes zero. In this condition, the soil loses all of its shear strength and assumes the properties of a heavy liquid.

Liquefaction during major earthquakes has caused severe damage to structures on level ground as a result of settling, tilting or floating. Many structures settled 3 feet or more and one structure tilted 80 degrees from the vertical during the 7.5 magnitude 1964 earthquake in Niigata, Japan (Wiegel, 1970).

If liquefaction occurs in or under a sloping soil mass, the entire mass will likely flow or translate laterally toward a lower elevation. An example of this type of slide occurred along the coastline near the town of Seward during the 1964 Alaskan Earthquake. The slide involved some 4,000 feet of coastline which moved seaward during the earthquake. Numerous landslides in clayey soils have also occurred as a result of liquefaction of thin sand layers and lenses included within the clay mass. Liquefaction of such layers and lenses not only reduces the shear strength of the sand itself, but it also causes reduction in the strength of the surrounding clayey soils due to the induced pore-water pressures.



SUBAQUEOUS CONTOURS OF LAKE TAHOE

CONTOUR INTERVAL 50 METER

REF: Hyne, N.J., Goldman, C.R., and Court, J.E., 1973, Mounds in Lake Tahoe, California-Nevada: A model for landslide topography in the subaqueous environment: Journ. of Geology, V. 81, p. 176-188.

FIGURE 7

Lateral spreading induced by earthquake shaking may occur as a result of soils moving toward an unsupported surface or slope, even though the slope may not be steep. Lateral displacement has occurred in soft saturated clays, such as bay and lagoon deposits. During ground shaking, these soft materials may flow, form wave-shaped masses, or squeeze laterally. This type of ground failure can also occur beneath fills, with the fill moving and developing severe longitudinal cracks. Considerable damage occurred as a result of this type of lateral spreading during the 1906 San Francisco Earthquake (Lawson, 1908).

4.3.4 Seiches

Seiches are water waves within an enclosed or restricted body of water such as a lake, bay or reservoir. The effect of seiches upon a water basin is analogous to the sloshing of coffee in a cup. These waves can be generated by changes in atmospheric pressure, wind and earthquakes. Wave height is amplified when the natural frequency of the water body coincides with the frequency of the causative force (e.g., ground shaking).

The 1966 Truckee earthquake (Magnitude 6) a few miles north of Lake Tahoe, may have produced a small seiche on the lake. A 0.4-foot wave surge was reported at the gauging well near the outlet dam on the Lower Truckee River; however, this well has a ¼-inch-diameter inlet to damp local wave action, and the recorded surge may have been less than the actual wave height. Also, wind blowing across the lake (fetch) at the time of the earthquake was creating 3½-foot swells which may have masked the seiche (Kachadoorian et al, 1967).

4.3.5 Catastrophic Inundation

A massive earthquake-triggered landslide falling into a lake could produce a wave several hundred feet high in the immediate vicinity of the landslide. A landslide in one of the fjords of Norway in 1934 involved 1.3 million cubic yards of material and produced a wave 90 to 180 feet high near the point of origin, and about 30 feet high several miles away (Wiegel, et al 1970). The 1964 Alaskan Earthquake caused a submarine landslide which created a wave with a maximum run-up of 104 feet, with run-up in much of the area being between 25 and 50 feet (Kachadoorian and Reuben, 1965).

A massive landslide into Lake Tahoe would be attenuated to a large degree; however, if a landslide should fall into a smaller lake, such as Fallen Leaf Lake, the wave run-up could exceed 100 feet or more.

Vertical displacement of the lake bottom along a fault (Section 4.2.2) could also generate a catastrophic wave inundating areas around the perimeter of the lake and topping the outlet dam on the Lower Truckee River. Estimating the probable height of such a wave is difficult, if not impossible. However, a minimum zone 10 feet above maximum high water (6,229 feet MSL), could be assumed based on the estimated probable future displacement

(Section 4.3.1) and past vertical fault movement on the bottom of Lake Tahoe (Section 4.2.2). Therefore, any construction around the perimeter of Lake Tahoe up to elevation 6,239 feet MSL should be carefully investigated and designed to withstand possible wave damage.

5.0 NATURAL HAZARDS MAP

5.1 GENERAL

Potential natural geo-hazard areas were superimposed on the geologic base maps (Plates 1-A through 1-D) by different types of shading. Horizontal shading was used to signify areas of existing or potential slope instability, vertical shading was used for seismic hazards, and diagonal shading was used for areas subject to snow avalanches. The darker an area is shaded on the map, the greater the hazard or combination of hazards.

5.2 CRITERIA

The criteria used in designating hazard zones are based on the high, moderate and low hazard groupings of the geomorphic units as described by Matthews and Burnett (1971). The major hazards considered under this classification are floods, landslides (and other related types of mass wasting), high water tables, fragile soil-plant relations, and easily erodible soils.

Seismic hazard zones are based on slope, rock and soil type, probable groundwater conditions, degree of consolidation and existence of faults and fracture zones.

Snow avalanche hazard zones were determined by: (1) slope and terrain characteristics as described in Section 3.3; and (2) precipitation and historical avalanche data.

5.3 LIMITATIONS

The location and delineation of natural hazard zones was based primarily upon existing regional data, and its reliability and precision are no more accurate than the generalized data upon which it is based. For this reason, localized hazards may occur in areas classified as relatively stable and, conversely, stable zones may be found in those areas classified as generally unstable. Subsequent detailed studies and future man-made alterations such as grading, will result in significant modification of these hazard boundaries.

In summary, the following limitations should be kept in mind when applying the information shown on this map:

1. The map is general and regional; it is intended for regional planning and not for specific site purposes.
2. Information is based almost exclusively on surface data; subsurface data are generally non-existant.
3. The hazard zones may include localized stable areas, and localized unstable areas may be found in areas indicated to be hazard-free.

5.4 USE OF NATURAL HAZARDS MAP

The purpose of this map is to provide a single reference source where general natural hazard zones can be located and identified. This information is necessary for regional planning purposes. A developer can use the map data to identify hazardous areas and either avoid the areas or investigate the particular site-related hazard in detail prior to safely developing an area. However, as discussed previously, the indicated extent and type of hazard in any particular area is subject to extensive revisions based on future studies.

A number of topographic lineations were observed on the aerial photographs; they are shown on the Natural Hazards Maps, Plates 1-A through 1-D. These features could have been caused by differential erosion along weak zones in the rock or by fracturing (cracks, joints or faults); determination of the origin of these features will require field investigation.

6.0 CONCLUSIONS

6.1 SUMMARY OF HAZARDS

Erosion and sedimentation present a continuing problem and hazard to the environmental quality of the Lake Tahoe Basin. The encroachment of man and his improvements has disturbed the delicate balance in the region and has doubled the rate of erosion and siltation. Future development should give careful consideration to this problem, and corrective measures such as a revegetation program, should be undertaken to mitigate the existing hazard.

As the higher slopes of the Basin are developed for skiing and family cabins, the hazard of mass wasting and snow avalanches will increase. Also, for this reason, areas adjacent to steep slopes consisting of fractured, loose or unconsolidated rock should generally be avoided when choosing new areas for development.

The potential for ground failure (liquefaction and lateral spreading) and severe ground shaking in the event of a major earthquake are perhaps the most serious natural hazards in the urbanized areas of the Tahoe Basin. Ground rupture with several feet of vertical displacement is theoretically probable along the Basin's major north-south faults adjacent to Lake Tahoe. A major seismic event could trigger landslides in steeply sloping areas, and large slides falling into the lakes in the basin could create catastrophic water waves. Loose rock, poorly-consolidated glacial material, and fine-grained volcanic sediments would be affected by violent ground shaking and could move laterally. Ground shaking could also initiate subaqueous landslides, particularly in the sloping glacial outwash deposits along the southern edge of Lake Tahoe.

6.2 FUTURE STUDIES

A program leading to the mitigation of natural hazards, of which our study is only the first step, can be outlined as follows:

1. Recognition of the hazards, delineation of their general location, and determination of the type of additional investigation required.
2. Detailed study of all hazard zones, accurate determination of their locations and extent and development of mitigating measures, if possible.
3. Establishment of tolerable risk zones, setbacks, building and other development design criteria, and other controls.

Hazards related to existing populated areas should be investigated during the 1974-75 planning period, and interim General Plan Seismic Safety and Safety Elements should be developed during this period. Outlined below are some of the specific studies that should be undertaken for the next study phase.

1. Review in detail color and infra-red aerial photographs of various scales, as well as other remote sensing photographic data, and perform detailed aerial photograph interpretations.

2. Perform a geologic reconnaissance of the urbanized areas to evaluate existing geologic and soil hazards data.

3. More closely delineate zones where faults may traverse urbanized areas. If necessary, some field explorations, including geophysical studies, trenching and borings, may be performed at this time. It is anticipated that boring logs and soils data for high-rise buildings and other structures in the area will be made available for this phase of the investigation.

4. In urbanized areas, outline zones which may be subject to liquefaction and mass wasting, within the limits of accuracy permitted by the available boring data and field investigations.

5. For select high-occupancy multi-story buildings, collate available subsurface data and, through soil dynamic techniques, analytically evaluate the potential for ground failure and the magnitude of maximum potential ground shaking.

6. Using current structural engineering analytical techniques, evaluate the probable behavior of the select high-occupancy multi-story buildings.

7. Review the potential for seismic, geologic, soil engineering, flood (including hydraulic characteristics and capacities of local streams) and avalanche hazards within significant areas to be developed.

8. Inspect steep slopes, cliffs and unconsolidated sediments adjacent to lakes and main roads for adverse conditions which could affect their natural and seismic stability.

9. Plan and initiate a basic data evaluation program to determine the adequacy of existing information on identified natural hazards.

Geotechnical and/or Seismic and Safety Element studies in subsequent years would be significantly influenced by the 1974-75 studies. In general terms, post-1974-75 items could include:

1. Special studies such as:

   A. Seismic ground response studies for critical areas.

   B. Assessment of the potential effects of seismic loading on the structural stability of high-occupancy buildings (public buildings, schools, multi-story buildings, gaming houses, etc.) and critical structures (hospitals, utility structures, firehouses, etc.).

   C. Detailed fault-trace studies in highly developed and potential development areas.

   D. Detailed avalanche, flooding and mass wasting studies in high-risk areas.

   E. Inventory of rock, sand and gravel resources.

2. Formulation of hazard abatement programs to minimize risk to life and property. Such programs could include:

   A. Building inspection programs to identify unsafe structures and instigate necessary corrective measures.

   B. Contingency plans for major natural disasters including earthquakes, major landslides and avalanches.

   C. Educational programs to develop community awareness of seismic hazards.

3. Instigation of natural hazard monitoring programs which could include:

   A. Measurements across active fault lines by geodimeter net and tiltmeters.

   B. Accelerometer recording instrumentation in major structures.

   C. Inclinometer monitoring of major potentially active landslides.

   D. Monitoring snowpack movement in areas with a high potential for avalanches.

4. Geotechnical planning services to extend and upgrade the interim Seismic Safety and Safety Elements of the General Plan for Tahoe Basin.

7.0 CLOSURE

We would be pleased to discuss any portions of this report which might require clarification or amplification. Because of their size, the Natural Hazards Maps, Plates 1-A through 1-D, are submitted separately with this report. The following appendices are attached:

Appendix A	Epicenter Data
Appendix B	Ordinance Review
Appendix C	Glossary of Geotechnical Terms
Appendix D	Selected Bibliography
Appendix E	Natural Hazards Planning Guide

Respectfully submitted,

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APPENDIX A
EPICENTER DATA

DATE	LATITUDE	LONGITUDE	QUALITY*	MAGNITUDE
2-5-1855	39.33	120.17	D	
10-6-1868	38.75	119.83	D	
3-29-1874	38.75	120.00	D	
12-12-1876	38.75	120.00	D	
12-12-1876	38.75	120.00	D	
8-31-1912	38.92	120.33	D	
3-31-1925	39.33	120.33	D	
3-31-1925	39.33	120.33	D	
3-16-1928	39.17	119.75	D	
4-9-1930	39.25	120.00	D	
4-9-1930	39.25	120.00	D	
6-25-1933	39.00	120.00	D	
1-31-1934	39.00	120.00	D	
3-17-1937	39.40	120.13	D	
8-6-1937	38.80	120.10	D	4.5
2-4-1940	39.25	120.25	D	
4-5-1941	38.75	120.00	D	
7-10-1942	39.20	119.75	D	
10-15-1942	39.00	120.00	D	
10-22-1942	39.25	120.00	D	
12-12-1942	38.80	119.80	D	
12-17-1942	38.87	119.90	C	5.1
12-17-1942	38.87	119.90	D	
12-17-1942	38.87	119.90	D	
12-17-1942	38.87	119.90	D	
12-19-1942	38.93	119.90	C	2.9
12-20-1942	38.80	119.80	D	
12-21-1942	38.80	119.80	D	
12-21-1942	38.80	119.80	D	
12-22-1942	38.80	119.80	D	
4-1-1943	39.35	120.15	D	
4-18-1943	39.35	120.15	D	
2-19-1945	38.85	120.00	D	
2-14-1946	39.30	120.20	D	
3-11-1947	39.30	120.00	D	
3-11-1947	39.30	120.20	D	

HISTORICAL EARTHQUAKE EPICENTERS IN THE VICINITY OF THE LAKE TAHOE BASIN

*See PLATE A-4

DATE	LATITUDE	LONGITUDE	QUALITY*	MAGNITUDE
6-29-1958	38.82	119.77	B	3.3
5-24-1959	39.20	120.20	D	3.1
5-21-1950	38.80	120.20	D	2.0
6-18-1960	39.00	120.00	D	
6-20-1961	39.32	120.27	C	2.8
6-24-1961	39.32	120.37	B	2.4
7-14-1961	39.28	120.22	C	3.4
8-12-1961	39.27	120.20	B	4.0
9-10-1962	39.42	120.22	B	3.0
1-15-1963	39.11	120.06	C	2.8
3-23-1963	38.78	120.14	C	3.0
7-15-1963	39.39	120.03		2.7
1-5-1965	39.23	119.92		3.5
7-25-1965	39.10	120.40		2.9
9-12-1966	39.42	120.15		6.0
9-12-1966	39.42	120.15		4.1
9-12-1966	39.42	120.15		4.4
9-12-1966	39.42	120.15		4.3
9-12-1966	39.42	120.15		3.4
9-12-1966	39.42	120.15		3.2
9-12-1966	39.42	120.15		3.0
9-12-1966	39.42	120.15		4.3
9-12-1966	39.42	120.15		4.2
9-12-1966	39.42	120.15		5.3
9-12-1966	39.42	120.15		3.2
9-12-1966	39.42	120.15		3.3
9-12-1966	39.42	120.15		3.3
9-12-1966	39.42	120.15		4.1
9-12-1966	39.42	120.15		3.5
9-12-1966	39.42	120.15		3.1
9-12-1966	39.42	120.15		3.5
9-12-1966	39.42	120.15		3.5
9-12-1966	39.42	120.15		3.5
9-12-1966	39.42	120.15		3.2
9-13-1966	39.42	120.15		3.6
9-13-1966	39.42	120.15		4.1
9-13-1966	39.42	120.15		3.2
9-13-1966	39.42	120.15		3.4
9-14-1966	39.42	120.15		3.1

HISTORICAL EARTHQUAKE EPICENTERS IN THE VICINITY OF THE LAKE TAHOE BASIN

*See PLATE A-4

TI-2A (1-71)

DATE	LATITUDE	LONGITUDE	QUALITY*	MAGNITUDE
9-8-1947	39.30	120.20	D	
9-8-1947	39.30	120.20	B	4.5
9-8-1947	39.30	120.20	D	
9-8-1947	39.30	120.20	D	
9-8-1947	39.30	120.20	B	4.7
11-12-1947	39.30	120.40	D	
11-25-1947	39.30	119.80	C	4.0
12-1-1947	39.20	120.20	D	3.7
3-28-1948	39.00	119.90	D	4.6
12-27-1948	39.25	120.00	D	
12-7-1949	39.00	119.80	D	3.8
2-3-1950	39.00	120.00	D	2.1
1-22-1951	39.08	119.95	B	4.8
6-30-1951	39.40	119.80	D	3.3
7-28-1951	39.40	120.00	D	3.0
1-11-1953	39.35	120.12	C	3.1
3-22-1953	38.82	119.98	A	5.0
3-22-1953	38.82	119.98	B	2.9
3-22-1953	38.82	119.98	B	3.1
3-22-1953	38.82	119.98	B	4.3
7-30-1953	38.80	120.00	D	2.5
8-22-1953	39.22	120.22	B	2.7
8-24-1953	39.25	120.30	B	3.5
9-22-1953	39.20	120.13	C	3.4
10-29-1953	39.35	120.22	B	3.3
11-27-1953	39.30	120.00	D	2.4
12-7-1953	39.10	120.00	D	3.2
2-26-1954	39.30	120.10	D	2.8
2-26-1954	39.30	120.20	D	2.7
4-7-1954	39.37	120.15	B	4.3
6-7-1954	39.38	119.82	D	3.2
12-13-1954	39.28	120.17	B	3.6
12-29-1954	38.98	119.90	C	3.3
8-18-1955	39.30	120.27	B	3.5
2-24-1956	39.33	120.08	C	3.0
2-12-1958	39.38	120.22	C	2.7

HISTORICAL EARTHQUAKE EPICENTERS IN THE VICINITY OF THE LAKE TAHOE BASIN

*See PLATE A-4

DATE	LATITUDE	LONGITUDE	QUALITY*	MAGNITUDE
9-14-1966	39.42	120.15		3.1
9-14-1966	39.42	120.15		4.6
9-14-1966	39.42	120.15		3.5
9-14-1966	39.42	120.15		4.6
9-14-1966	39.42	120.15		3.3
9-15-1966	39.42	120.15		3.2
9-15-1966	39.42	120.15		3.4
9-16-1966	39.42	120.15		3.0
9-16-1966	39.42	120.15		3.4
9-18-1966	39.42	120.15		3.3
9-19-1966	39.42	120.15		3.3
9-19-1966	39.42	120.15		3.2
9-21-1966	39.42	120.15		3.1
9-22-1966	39.42	120.15		4.4
9-22-1966	39.42	120.15		3.5
9-22-1966	39.42	120.15		3.8
9-27-1966	39.42	120.15		3.3
9-28-1966	39.42	120.15		3.6
9-28-1966	39.42	120.15		3.7
9-28-1966	39.42	120.15		3.3
9-28-1966	39.42	120.15		3.5
9-29-1966	39.42	120.15		3.1
9-29-1966	39.42	120.15		3.3
2-12-1967	39.40	120.10		3.0
11-21-1970	39.40	120.27		3.1

*Quality refers to accuracy of epicenter location from A (best) to D (poorest). Epicenters with an "A" accuracy rating are generally considered to be located within a 3-mile radius of the earthquake source; "B" accuracy rating is within 6 miles; "C" accuracy rating is within 10 miles; "D" accuracy rating is greater than 10 miles.

HISTORICAL EARTHQUAKE EPICENTERS IN THE VICINITY OF THE LAKE TAHOE BASIN

REF: Seismographic Station, University of California, Berkeley.

APPENDIX B
ORDINANCE REVIEW

APPENDIX B

ORDINANCE REVIEW

GRADING ORDINANCE NO. 5

It is our recommendation that the minimum excavation and grading provisions as set forth in Chapter 70 of the Uniform Building Code (1973 edition) be adopted. This chapter was added to the Building Code in 1964 as a result of knowledge and experience developed in Southern California. The code is easy to use and enforce and allows for flexibility while providing a high standard of protection for the health, safety and welfare of the general public.

The following is a critique of existing Grading Ordinance No. 5 of the Tahoe Regional Planning Agency, adopted February 10, 1972:

Section 3.00 Definitions

Area of Instability - delete the word: "foreseeable"

Clearing of vegetation - delete the words: "total or partial" and establish a percentage, say, 25% or more.

Drainage Way - delete the words: "but at other times are destitute of water".

Flood Water - delete the words: "in flood plains".

Geological Terms - delete the words: "Glossary of Geology and Related Sciences" and restate as follows: The Latest Edition of Glossary of Geology.

Grading - delete the word "permanently".

Section 4.0 Permit Procedure

There should be a provision under this or a subsequent section for a performance bond.

Section 4.11 Exceptions

Paragraph (1): Add at end of paragraph: *and does not create a slope greater than two horizontal to one vertical in unconsolidated material.*

Paragraph (2): Add at end of paragraph: *with a slope flatter than five horizontal to one vertical, and does not obstruct a drainage course.*

Paragraph (3): Add, after "excavations": *under the direction of soils engineer or engineering geologist.*

Paragraph (4): the word "authorized" is misspelled.

Paragraph (5): Add at end of paragraph: *provided there are sufficient controls to prevent erosion.*

Paragraph (6): Delete entire paragraph.

Section 4.22 Information Report:

On line three, the word "person" should be replaced with soils engineer or engineering geologist.

Paragraph (8): Add after "showing": *existing tree locations, size, and species, and......*

Paragraph (12): Add after "including": *percentage of compaction, slope, and......*

Add after "control,": *drainage.*

Section 5.20 Specific Requirements of Subsurface Investigations

Line 2: Change "will" to may.

Paragraph (1): Delete "where past land movement is evident".

Paragraph (6): Add after "folds": *fractures.*

Section 7.103 Setbacks

Line 4: Add after "feet": *unless required by an engineer.*

Line 6: Add after "from": *the toe of.*

Section 7.114 Compaction

Add after "90%": *ASTM D1557-70*

SHORELINE ORDINANCE NO. 6 (Adopted March 22, 1972)

Section 4.22(2) Information Report

This section should include a statement requiring that seismically induced water waves also be considered in the "design wave".

SUBDIVISION ORDINANCE NO. 7 (Adopted March 22, 1972)

Section 5.22 Conservation

Add: *(e) Slope instability*

Section 8.23 Right-of-Way, Location, Alignment

Line 2: The "two foot" right-of-way extension beyond the disturbed natural ground surface appears rather minimal; perhaps a five foot minimum would be more appropriate.

LAND USE ORDINANCE NO. 13 (Adopted February 10, 1972; Amended May 24, 1973)

This ordinance appears adequate. A Natural Hazards Planning Guide, which is referred to in Section 8.27(1) of this ordinance, is presented in this report in Appendix E.

MISCELLANEOUS COMMENTS

Sand and gravel operations exist at several locations around the lake and may become a problem as the area develops. We suggest that you give some consideration to establishing a mining ordinance. On July 27, 1971, Marin County adopted an excellent mining ordinance which may be of some guidance to you. We provided some assistance in drafting this ordinance and the only modification we would suggest, is that existing mining operations (Section 23.06.100) be made to comply with all provisions of this ordinance within five years.

APPENDIX C

GLOSSARY OF GEOTECHNICAL TERMS

APPENDIX C

GLOSSARY OF GEOTECHNICAL TERMS

Acre-foot	A volume of water one foot deep covering one acre.
Alluvium	A general term for unconsolidated stream deposits of clay, silt, sand and gravel.
Andesite	Fine-grained extrusive volcanic rock.
Attenuate	Decrease in amplitude with increase in distance from the source.
Chemical alteration	Changes in the bulk chemical composition of a rock, usually resulting in a less competent rock.
Colluvium	A general term applied to any loose, heterogeneous and incoherent mass of soil material deposited chiefly by gravity.
Contact	The boundary between two geologic formations.
Decompose	Breaking down of rocks and minerals by the chemical weathering process.
Delta	Sediment deposited at or near the mouth of a river.
Dip	Angle at which a bed or any planar rock feature is inclined from the horizontal. The dip is at a right angle to the strike.
Displacement	Relative movement along two sides of a fault.
Earth lurches	Yielding of the earth material in the unsupported direction along a stream bank or cliff during an earthquake.
Epicenter	**Field**: The area of strongest ground shaking and usually the area of maximum damage.
	Instrumental: The exact geographical location on the surface of the earth directly above the earthquake focus.
Exfoliation	The spalling of thin layers of rock as a result of differential stresses and weathering within the rock mass.
Fault	A fracture or zone along which the rocks have been displaced on either side relative to one another.
Fault trace	The linear expression of a fault on the ground surface.
Flash flood	A local and sudden flood or torrent of relatively great volume and short duration.

Focus	The point of origin of the initial earthquake on the fault plane.
Folding	The curving or bending of a planar structure, such as rock strata.
Formation	A rock grouping or assemblage which have some characteristics in common, such as age.
Fracture	General term used for any break in a rock or rock mass due to mechanical failure by stress.
Fundamental period	Vibration characteristics of a building.
Geodimeter net	A precise method of measuring ground distances across a fault
Geotechnical	The application of scientific methods and engineering principles to the acquisition, interpretation, and use of knowledge of materials of the Earth's crust to the solution of civil engineering problems.
Glacial outwash	Stratified deposits (silt, sand and gravel) washed out from a glacier by meltwater streams
Glacio-fluvial deposits	Deposits from meltwater streams flowing from retreating glaciers
Granodiorite	A variety of crystalline granitic rock
Ground failure	Disruption of the ground surface due to liquefaction, etc.
Ground shaking	Periodic oscillation of the ground resulting from fault movement
Inclinometer	An instrument that determines the amount and direction of departure from the vertical of a borehole or well.
Indurate	Compact rock or soil hardened by pressure, cementation and/or heat
Intensity (Mercalli Scale)	A measure of the destructiveness of an earthquake, expressed in Roman Numerals ranging from I to XII. This intensity value decreases with increased distance from the earthquake source. Thus, a single earthquake can have many intensities, ranging from the high damage level of XII to the low of I (as contrasted with "magnitude", which describes the total impact of an earthquake).
Lateral spreading	Failure and lateral flow of soil caused by an earthquake
Latite	Fine-grained extrusive rock with little or no quartz
Liquefaction	A process, caused by ground shaking, by which water-saturated, cohesionless soils lose all shear strength and assume the properties of a heavy liquid

Lithology	Physical characteristics of a rock
Magnitude (Richter Scale)	A numerical value characteristic of the total strength of an earthquake as determined by numerous seismographic observations and calculations. An earthquake can have but one magnitude (as contrasted with "intensity", which varies from place to place).
Mass wasting	A term covering a wide variety of types of soil and rock movement caused by gravity, such as landslides, mudflows, etc.
Metamorphic rock	Rock formed by pressure, heat and chemical solutions, usually at considerable depth within the earth.
Moraine	Accumulation of unsorted glacial-transported rock and soil
Mudflow-breccia (lahar)	Poorly indurated volcanic flow debris containing angular rock fragments.
Normal fault	A fault in which the upper side has moved downward in relation to the lower side
Outcrop	Surface exposure of bedrock
Percolation	Movement of water under the force of gravity or hydrostatic pressure through the interstices of rock or soil
Permeability	Capability for transmitting a fluid
Pore water	The water that fills the voids between particles of a soil or rock mass
Predominant period	A number representing the time between seismic wave peaks, usually measured in seconds
Rain shadow	Area on the lee side of a mountain which generally receives noticeably less precipitation than the windward side.
Runup	The maximum on-shore elevation reached by a seismically induced water wave above the still water level at the time of the occurrence
Seiche	Periodic oscillations of a generally confined body of water, caused by an earthquake
Seismic	Pertaining to an earthquake or earth vibration
Shear zones	A planar zone of crushed and broken rock caused by repeated movement along closely-spaced subparallel fractures.

Strike	The horizontal course or bearing of a rock outcrop, measured perpendicular to the direction of the dip
Subaqueous	Deposits that are formed or situated in or under water
Subglacial streams	Streams flowing immediately beneath a glacier
Tectonic	Pertaining to rock structure and surface forms resulting from deformation of the earth's crust
Tiltmeter	An instrument that measures slight changes from the horizontal in the earth's surface
Tuff	A rock formed of compacted volcanic fragments which were ejected from a volcanic vent
Volcanic rocks	Generally fine-grained rocks deposited in a molten state at or near the earth's surface

APPENDIX D

SELECT BIBLIOGRAPHY

APPENDIX D

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APPENDIX E

NATURAL HAZARDS PLANNING GUIDE

APPENDIX E

NATURAL HAZARDS PLANNING GUIDE

Our report includes a compilation of existing data on a large scale map (1 inch = 2,000 feet). Included in this compilation is the basic geology of the Tahoe Basin, as developed by Matthews (1968) and Burnett (1967). Superimposed on the basic geological map are "Hazard Groupings of Geomorphic Units", as outlined in Geology and Geomorphology of the Lake Tahoe Region, A Guide for Planning, prepared for T.R.P.A. in 1971.

The U.S. Forest Service (1971), in cooperation with T.R.P.A., compiled a reconnaissance level Land Capability Map of the Lake Tahoe Basin (scale: 1 inch = 2 miles) based on these geomorphic units and soil characteristics. Using these data, the region was divided into seven land classes based on the relative risk of land damage, as follows:

High hazard	=	Classes 1 and 2 (90% of the Basin)
Moderate hazard	=	Classes 3 and 4 (4% of the Basin)
Low hazard	=	Classes 5 through 7 (6% of the Basin)

Areas of high, moderate and low hazard are distinguished on the Natural Hazards Map (Plates 1-A through 1-D) by degree of shading density. Natural ground stability (by geomorphic unit), seismic ground response, and areas of probable snow avalanche are therefore shown at the three levels of hazard. Areas of probable inundation from seiches, as a result of a seismic event or landslides into the lake, are shown by dark shading. This map provides a unification of data which is helpful in regional planning. By superimposing the various hazards on top of one another, the most hazardous areas are easily identified since they are the most heavily shaded. Also, specific faults and landslides are generally located and can be avoided or investigated in detail for site-specific projects.

Knowledge and location of a potential natural hazard are only the first steps in a regional planning guide; a risk factor must also be determined. This factor is generally determined by land use, type of structure, and population densities. The final report to the Legislature of the State of California by the Joint Committee on Seismic Safety outlines the following four levels of acceptable risk:

SCALE OF ACCEPTABLE RISKS

Level of Acceptable Risk	Kind of Structures
1. An "ordinary" level of risk to occupants of the structure	The vast majority of structures: most commercial and industrial buildings, small hotels and apartment buildings, and single family residences.
2. Lowest possible risk to occupants of the structure	Structures of high occupancy, or whose use after a disaster would be particularly convenient: schools, churches, theaters, large hotels, and other high-rise buildings housing large numbers of people, other places normally attracting large concentrations of people, civic buildings such as fire stations, secondary utility structures, extremely large commercial enterprises, most roads, alternative or noncritical bridges and overpasses.
3. High risk	Structures whose use is critically needed after a disaster: important utility centers; hospitals, fire, police, and emergency communication facilites; fire stations; and critical transportation elements such as bridges and overpasses; also smaller dams.
4. Extremely high risk level	Structures whose continued functioning is critical, or whose failure might be catastrophic; nuclear reactors, large dams, power intertie systems, plants manufacturing or storing explosives or toxic materials.

Knowledge of the potential natural hazard and risk level provides guidance in establishing the degree and type of investigation necessary for a particular site. Landslide and fault zones should be investigated in detail and avoided where possible. In general, the following investigation guidelines should be used for high natural hazard zones (the numbers correspond to the levels of acceptable risk listed above):

1. Current building code requirements must be met, as well as other existing State and local ordinances and regulations. Also, geologic and soil engineering investigations should be made to determine whether or not the specific site is in a fault or other specific hazard zone.

2. All of the above, plus sufficient geologic, seismic, soil and structural engineering analysis to determine suitability of the site relative to the occupancy and intended use. In some instances, it may be necessary to extend the investigations beyond the immediate confines of the proposed site in order to obtain the necessary data. Where faults are present, special investigations should be made to determine if setback requirements are necessary and, if so, the setback distance required.

3. All of the above, plus,

   A. Specific investigations to evaluate liquefaction potential.

   B. Detailed foundation investigations to evaluate and estimate differential settlement potential and suitable foundation types.

   C. Detailed fault and landslide investigations.

4. All of the above, plus dynamic ground motion analyses and structural design employing the most current "state-of-the-art" seismic design methods.

APPENDIX F

CREDITS

APPENDIX F

CREDITS

TAHOE REGIONAL PLANNING AGENCY

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James Henry, Representative, Placer County Board of Supervisors
Thomas Stewart, Representative, El Dorado County Board of Supervisors
John Wynn, Representative, City of South Lake Tahoe
Charles C. Meneley, Jr., Representative, Douglas County Board of Commissioners
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