Liquefaction Maps

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ATC TechBrief

Background

This technical brief inventories and describes the available regional liquefaction hazard maps in the United States and gives information on how to obtain them. The types of maps are explained, as well as the methods for determining liquefaction susceptibility. The present regional coverage of liquefaction hazard maps in the United States is shown in Figure 1. Details on the maps and their availability are given in Table 2.

Liquefaction, a process in which loose, granular soils below the ground water table temporarily lose strength during strong earthquake shaking, has been the cause of considerable damage during earthquakes. To provide a microzonation of this hazard, maps have been prepared for various subregions of the United States. These maps have been prepared under the auspices of the National Earthquake Hazards Reduction Program (NEHRP) by scientists and engineers within the U.S. Geological Survey, organizations sponsored by the USGS NEHRP External Research Program, and state government agencies. The maps aid the design professional by

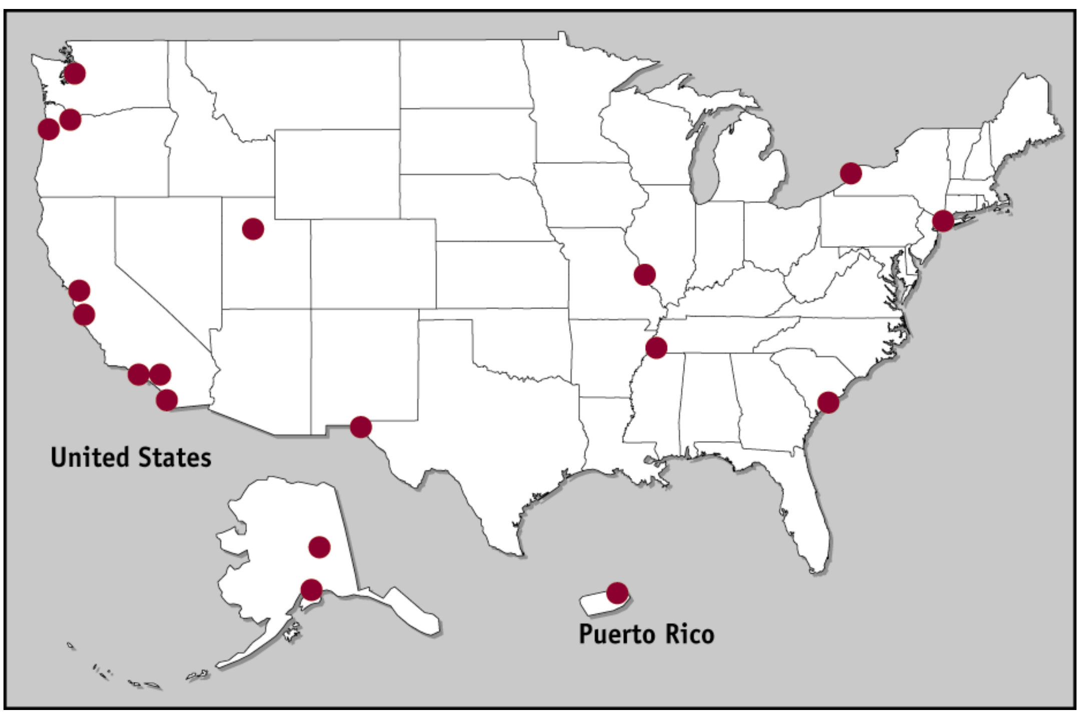

Figure 1: Locations in the United States covered by liquefaction maps listed in Table 2.

delineating areas where liquefaction could pose a significant hazard and should therefore be considered during facilities design. The maps can also be used by local officials and public policy-makers for land-use planning and emergency response planning.

Applicability

For structural engineers and geotechnical engineers, liquefaction hazard maps serve to identify areas where the potential for and consequences of liquefaction should be evaluated when designing new facilities and retrofitting existing facilities. In general, liquefaction hazard maps prepared to larger scales, typically 1:24,000, or USGS-7.5-minute quadrangle sheet scale, are based on a more detailed examination of geologic and subsurface soil and groundwater data and provide a more definitive characterization of liquefaction potential. As a general guideline, building projects located in areas described as having moderate or high liquefaction hazard require site-specific liquefaction hazard investigations, and those located in areas described as having low liquefaction hazard do not. However, because of variations in the definitions of liquefaction susceptibility or liquefaction potential shown on different maps, and also because the significance of liquefaction depends on the type of structure and the local setting, some building projects located in areas of moderate liquefaction hazard may not require specific liquefaction hazard investigations; other building projects located in areas of low liquefaction hazard may need such investigations. Therefore, a geotechnical professional experienced in liquefaction potential assessments should be consulted regarding the implications of the zonation presented on a liquefaction hazard map for a specific building project.

Types of Maps

Two types of liquefaction hazard maps are considered in this technical brief. The first type, a historic liquefaction map, shows where liquefaction has occurred during historic earthquakes. The second type, a liquefaction hazard map, divides a region into areas having different degrees of liquefaction hazard. Figure 2 shows a portion of a sample liquefaction hazard map.

The relatively few available historic maps are summarized in Table 1. Maps of historic liquefaction are useful for identifying potentially hazardous areas because soils with a history of liquefaction may liquefy again during future earthquakes. Note that liquefaction has occurred in most moderate-to-large historic earthquakes in the United States. Accounts of liquefaction damage can be found in postearthquake reports, but the reports have not always been compiled into a comprehensive liquefaction map.

Table 2 summarizes available liquefaction hazard maps. There are three types of liquefaction hazard maps. The first type is a *liquefaction susceptibility* map. This type of map indicates the inherent relative susceptibility of the soils to liquefaction. The determination can be based on several types of data including geologic mapping (G), historical information on liquefaction in the area (HIS), groundwater depth (GW), soil boring data (B), analysis of standard penetration test (SPT) blow counts, and analysis of cone penetration test (CPT) resistances. Generally, susceptibility maps indicate areas of low, moderate, and high susceptibility to liquefaction. Some maps show additional categories such as very low or very high. A special type of susceptibility map is being pre-

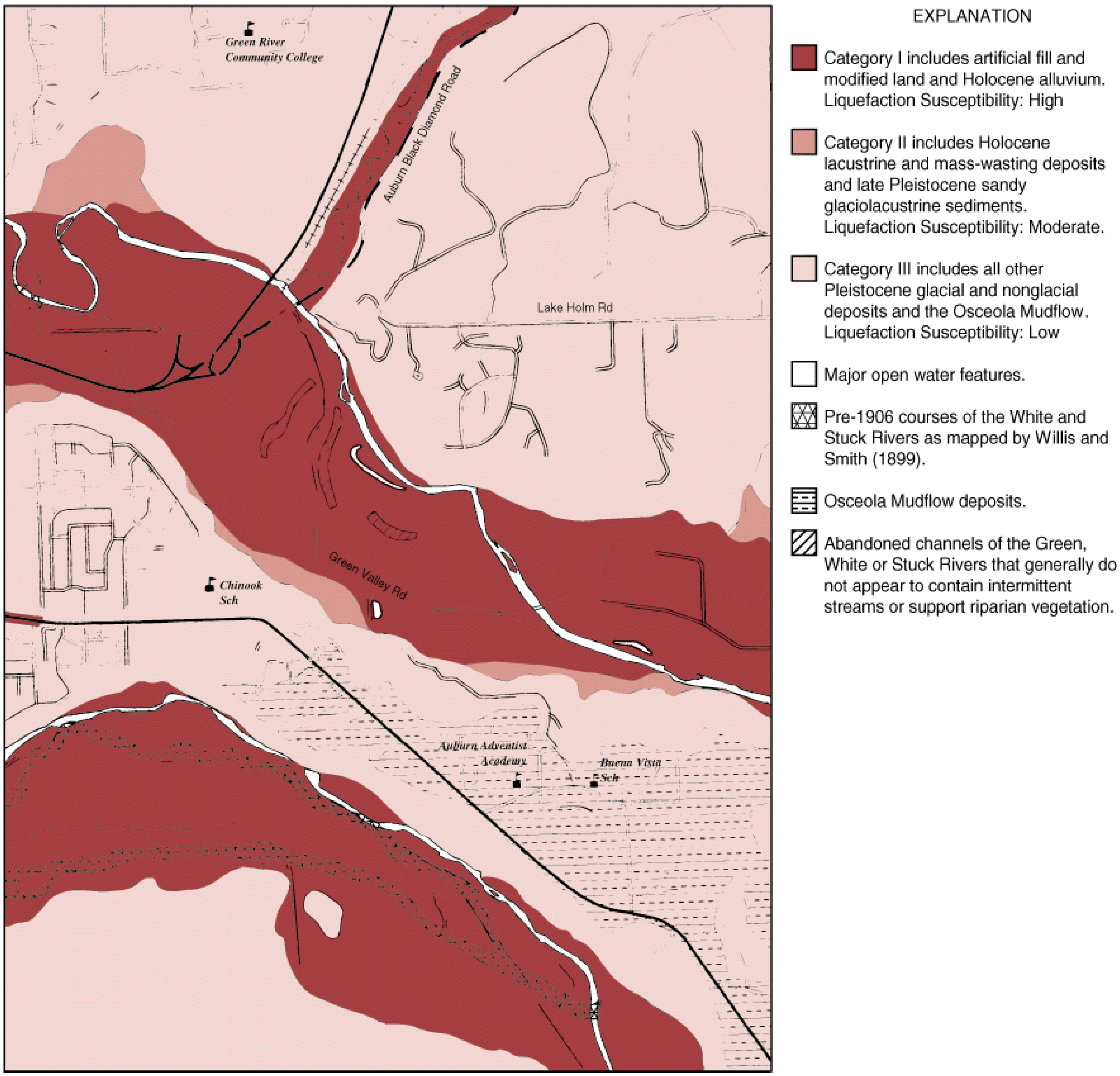

Figure 2: Portion of a sample liquefaction hazard map (Palmer, S.P., Walsh, T.J., Logan, R.L., and Gerstel, W.J., 1995, Liquefaction susceptibility for the Auburn and Poverty Bay 7.5-minute Quadrangles, Washington: Washington Division of Geology and Earth Resources, Geologic Map GM-43, Olympia, Washington).

Table 1: Historic Liquefaction Maps

Earthquake Name	*Area Covered and Scale*	*Authors and Reference*
1811–1812 New Madrid, Missouri earthquake	Arkansas, Kentucky, Missouri, and Tennessee 1:5,000,000	Obermeier, S.F., 1989, *The New Madrid earthquakes: An engineering-geologic interpretation of relict liquefaction features*, U.S. Geological Survey Professional Paper 1336-B, 114 pp. and 11 plates.
1906 San Francisco, California earthquake	Northern California 1:24,000 to 1:500,000	Youd, T.L., and S.N. Hoose, 1978, *Historic ground failures in northern California triggered by earthquakes.* U.S. Geological Survey Professional Paper 993, 175 pp. (5 plates).
1949 and 1965 Puget Sound, Washington earthquakes	Puget Sound, Washington 1:100,000	Chleborad, A.F. and R.L. Schuster, 1990, Ground failure associated with the Puget Sound region earthquakes on April 13, 1949 and April 29, 1965: U.S. Geological Survey Open-file Report 90-687, 136 pp.
1979 Imperial Valley, California earthquake	Southern Imperial Valley, California 1:250,000	Youd, T.L., and G.F. Wieczorek, 1982, Liquefaction and secondary ground failure, in *The Imperial Valley, California, Earthquake of October 15, 1979*, eds. C.E. Johnson, C. Rojahn, and R.V. Sharp, U.S. Geological Survey Professional Paper 1254, pp. 223–246, plate 4.
1983 Borah Peak, Idaho earthquake	Big Lost River Valley, Idaho 1:690,000	Youd, T.L., E.L. Harp, D.K. Keefer, and R.C. Wilson, 1985, Liquefaction generated by the 1983 Borah Peak, Idaho earthquake, in *Proceedings of Workshop XXVIII on the Borah Peak, Idaho Earthquake*, R.S. Stein and R.C. Bucknam, eds., U.S. Geological Survey Open-file Report 85-290, pp. 625–644.
1989 Loma Prieta, California earthquake	San Francisco and Monterey Bay Regions, California 1:125,000	Tinsley, J.C., III, J.A. Egan, R.E. Kayen, M.J. Bennett, A. Kropp, and T.L. Holzer, in press, Maps and description of liquefaction and associated effects—the Loma Prieta, California, earthquake of October 17, 1989, in *The Loma Prieta, California, earthquake of October 17, 1989—Liquefaction,* ed. T.L. Holzer, U.S. Geological Survey Professional Paper 1551-B, 2 tables, 2 maps.

pared by the California Division of Mines and Geology (CDMG), which delineates zones in which site-specific liquefaction potential investigations are required by law for new construction. To date, CDMG has prepared five maps for portions of the greater Los Angeles area and a map for San Francisco. Eventually, all major urban areas in seismically active regions of California will be covered by this mapping program.

A second type of liquefaction hazard map is a *liquefaction potential* map, which incorporates considerations of both the susceptibility of the soils and the earthquake potential in a region. One kind of liquefaction potential map expresses the likelihood of liquefaction in the various geologic deposits for one or more selected regional scenario earthquakes. A second kind of potential map expresses either the likelihood of liquefaction of the geological deposits during a certain time period (for example, 10% probability of liquefaction in 50 years) or a return period for liquefaction (for example, average 500-year return period for liquefaction occurrence).

A third type of liquefaction hazard map is a *liquefaction-induced ground failure* map. These maps attempt to characterize permanent ground displacements associated with liquefaction. Conceptually, these maps may be either of the scenario earthquake type or the probabilistic type, similar to the liquefaction potential maps summarized above. The most common type prepared to date is called a Liquefaction Severity Index (LSI) map, which expresses estimated maximum amounts of ground displacement due to lateral spreading in gently sloping, highly liquefaction-susceptible deposits for selected probabilities of exceedance and time periods.

Notice: Please notify ATC of other liquefaction hazard maps you may be aware of for possible inclusion in future revisions of this TechBrief.

Table 2: Liquefaction Hazard Maps (listed alphabetically by state)

Area Covered and Scale	*Type of Map*	*Susceptibility Basis (page 2)*	*Notes*	*Authors and References*
Anchorage, Alaska 1,600 km^2 1:25,000 and 1:63,360	Susceptibility	G, HIS, GW, B	Zones of different ground failure susceptibility are mapped, considering failure mechanisms of weakening of sensitive clay as well as liquefaction of sands.	Harding-Lawson Associates, 1979, Geotechnical hazard assessment, municipality of Anchorage, Anchorage, Alaska, report to municipality of Anchorage. *Available from:* Dept. Community Planning & Development, Municipality of Anchorage, Alaska (907) 343-4224.
Anchorage, Alaska No map—urban-area-wide geologic units evaluated	Potential (probability)	B, GW, SPT	Liquefaction susceptibility of regional geologic units was evaluated and then the probability of their liquefaction for different time periods was computed.	Moriwaki, Y. and I.M. Idriss, 1987, Evaluation of ground failure susceptibility, opportunity, and potential in the urban area of Anchorage, Alaska, Report to U.S. Geological Survey, NEHRP external program, Contract No. 14-08-0001-22031, by Woodward-Clyde Consultants, Santa Ana, California *Available from:* USGS Reston, VA, library (703) 648-4302.
Fairbanks-Nenana Area, Alaska 10,000 km^2 1:250,000	Susceptibility	G, HIS	Areas of very high, high, medium, low, and very low susceptibility are mapped.	Combellick, R.A., 1984, Potential for earthquake-induced liquefaction in the Fairbanks-Nenana Area, Alaska: Alaska Division of Geological and Geophysical Survey Report of Investigations 84-85. *Available from:* Department of Natural Resources, Division of Geological and Geophysical Surveys, Fairbanks, Alaska (907) 451-5000.
San Diego, California Urban Area 450 km^2 1:21,750	Susceptibility	G, GW, B, SPT	Areas of high, moderate, low, and very low liquefaction susceptibility are mapped.	Power, M.S., A.W. Dawson, D.W. Streiff, R.C. Perman, and V. Berger, 1982, Evaluation of liquefaction susceptibility in the San Diego, California, urban area, Vols. I and II, Report to U.S. Geological Survey, Contract No. 14-08-0001-19110, by Woodward-Clyde Consultants, San Diego, California. *Available from:* USGS Menlo Park, CA, library, (415) 329-5027.
San Diego, California, Urban Area 450 km^2 No map—followup study to Power et al., 1982	Potential (probability)	G, GW, B, SPT	Study assesses the probability of liquefaction of soils having moderate to high liquefaction susceptibility as mapped by Power, et al., 1982.	Power, M.S., V. Berger, R.R. Youngs, K.J. Coppersmith, and D.W. Streiff, 1986, Evaluation of liquefaction opportunity and liquefaction potential in the San Diego, California urban area, Report to U.S. Geological Survey, Contract No. 14-08-0001-20607, by Woodward-Clyde Consultants, San Diego, California. *Available from:* USGS Menlo Park, CA, library (415) 329-5027.
Simi Valley, California 160 km^2 1:24,000	Susceptibility	G, HIS, GW, B, SPT	Maps denote areas of potential liquefaction where site-specific investigations must be conducted.	CDMG, 1996, Seismic hazard zones, Simi Valley East Quadrangle: California Division of Mines and Geology Seismic Hazard Zone Map, 1:24,000, *Available from:* BPS Reprographic Services (415) 512-6550 and Universal Reprographics, Inc., (213) 365-7750.

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Area Covered and Scale	*Type of Map*	*Susceptibility Basis (page 2)*	*Notes*	*Authors and References*
Simi Valley, California 160 km^2 1:24,000	Susceptibility	G, HIS, GW, B, SPT	Maps denote areas of potential liquefaction where site-specific investigations must be conducted.	CDMG, 1996, Seismic hazard zones, Simi Valley West Quadrangle: California Division of Mines and Geology Seismic Hazard Zone Map, 1:24,000, *Available from:* BPS Reprographic Services (415) 512-6550 and Universal Reprographics, Inc., (213) 365-7750.
Orange County, California 160 km^2 1:24,000	Susceptibility	G, HIS, GW, B, SPT	Maps denote areas of potential liquefaction where site-specific investigations must be conducted.	CDMG, 1996, Seismic hazard zones, Anaheim Quadrangle: California Division of Mines and Geology Seismic Hazard Zone Map, 1:24,000, *Available from:* BPS Reprographic Services (415) 512-6550 and Universal Reprographics, Inc., (213) 365-7750.

Table 2: Liquefaction Hazard Maps (continued)

Area Covered and Scale	*Type of Map*	*Susceptibility Basis (page 2)*	*Notes*	*Authors and References*
Orange County, California 160 km^2 1:24,000	Susceptibility	G, HIS, GW, B, SPT	Maps denote areas of potential liquefaction where site-specific investigations must be conducted.	CDMG, 1996, Seismic hazard zones, Newport Beach Quadrangle: California Division of Mines and Geology Seismic Hazard Zone Map, 1:24,000, *Available from:* BPS Reprographic Services (415) 512-6550 and Universal Reprographics, Inc., (213) 365-7750.
Los Angeles, California 160 km^2 1:24,000	Susceptibility	G, HIS, GW, B, SPT	Maps denote areas of potential liquefaction where site-specific investigations must be conducted.	CDMG, 1996, Seismic hazard zones, Topanga Quadrangle: California Division of Mines and Geology Seismic Hazard Zone Map, 1:24,000, *Available from:* BPS Reprographic Services (415) 512-6550 and Universal Reprographics, Inc., (213) 365-7750.
Greater Los Angeles, California area 8000 km^2 From 1:210,000 to 1:290,000	Potential (scenario earthquake)	G, GW, SPT	Scenario earthquakes are a nearby magnitude 6.5 and a San Andreas magnitude 8 earthquake.	Tinsley, J.C., T.L. Youd, D.M. Perkins, and A.T.F. Chen, 1985, Evaluating liquefaction potential, in Ziony, J., ed., Evaluating Earthquake Hazards in the Los Angeles Region—An Earth Science Perspective: Professional Paper 1360, U.S. Geological Survey pp. 263-315. *Available from:* USGS Information Services (800) 435-7627.
Greater San Bernardino, California area 700 km^2 1:48,000	Potential (scenario earthquake)	G, GW, SPT	Maps of potential liquefaction areas were prepared for 3 scenario earthquakes—M8 on San Andreas, M7 on San Jacinto, and M6.75 on Cucamonga faults.	Matti, J.C. and S.E. Carson, 1991, Liquefaction susceptibility in the San Bernardino Valley and vicinity, southern California: a regional evaluation: U.S. Geological Survey Bulletin 1898, 53 pp., 5 sheets, 1:48,000. *Available from:* USGS Information Services (800) 435-7627.
San Fernando Valley, California 2,000 km^2 1:317,000	Susceptibility and potential (probability)	G, GW, B, SPT	Return periods for liquefaction were assessed for deposits mapped as having high susceptibility to liquefaction.	Youd, T.L., J.C. Tinsley, D.M. Perkins, E.J. King, and R.F. Preston, 1978, Liquefaction potential map of San Fernando Valley, California: Proceedings of the Second International Conference on Microzonation, San Francisco, California, pp. 267–278.
Southern California 130,000 km^2 1:6,000,000	Ground failure (probability)	—	Liquefaction Severity Index (LSI, see text) is mapped for 10% probability of exceedance in time periods of 10, 50, and 250 years.	Youd, T.L., and D.M. Perkins, 1987, Mapping of liquefaction severity index: Journal of Geotechnical Engineering, ASCE, v. 113, no. 11, pp. 1374–1393.

Table 2: Liquefaction Hazard Maps (continued)

Area Covered and Scale	*Type of Map*	*Susceptibility Basis (page 2)*	*Notes*	*Authors and References*
Northern Monterey County, California 400 km^2 1:24,000	Potential (scenario earthquake)	G, HIS, GW, SPT	Scenario earthquake is a repeat of 1906 San Francisco, California, earthquake.	Dupré, W.R., 1990, Maps showing geology and liquefaction susceptibility of Quaternary deposits in the Monterey, Seaside, Spreckels, and Carmel Valley Quadrangles, Monterey, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-2096, 2 sheets, 1:24,000. *Available from:* USGS Information Services (800) 435-7627.
Northern Monterey and Southern Santa Cruz Counties, California 940 km^2 1:62,500	Potential (scenario earthquake)	G, HIS, SPT	Scenario earthquake is repeat of 1906 San Francisco, California earthquake.	Dupré, W.R., and J.C. Tinsley, III, 1980, Maps showing geology and liquefaction potential of northern Monterey and southern Santa Cruz Counties, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-1199, 2 sheets, 1:62,500. *Available from:* USGS Information Services (800) 435-7627.
Santa Cruz County, California 1100 km^2 1:62, 500	Susceptibility	G	Surficial geologic units were classified by relative liquefaction susceptibility.	Dupré, W.R., 1975, Maps showing geology and liquefaction potential of Quaternary deposits in Santa Cruz County, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-648, 2 sheets, 1:62,500. *Available from:* USGS Information Services (800) 435-7627.
San Jose, California 700 km^2 1:24,000	Susceptibility and potential (probability)	G, HIS, GW, B, SPT, CPT	Areas of high, moderate, low and very low liquefaction susceptibility are mapped; probability of liquefaction is evaluated for areas of high and moderate liquefaction susceptibility.	Power, M.S., J.W. Wesling, R.C. Perman, R.R. Youngs, and L.A. DiSilvestro, 1992, Evaluation of liquefaction potential in San Jose, California, Report to U.S. Geological Survey, Award No. 14-08-0001-G1359, by Geomatrix Consultants, San Francisco, California. *Available from:* City of San Jose Department of Public Works Development Services Division (408) 277-5161; USGS Menlo Park, CA, library (415) 329-5027.
Margins of Southern San Francisco Bay, California 1,400 km^2 1:380,000	Potential (scenario earthquake)	G, HIS, GW, SPT	Scenario earthquakes are a moderate earthquake (0.2g/10 cycles) and a major earthquake (repeat of 1906 San Francisco earthquake).	Youd, T.L., E.J. Helley, D.R. Nichols, and K.R. Lajoie, 1975, Liquefaction potential, in Borcherdt, R.L., ed., Studies for Seismic Zonation of the San Francisco Bay Region: U.S. Geological Survey Professional Paper 941-A, pp. 68–74 *Available from:* USGS Information Services (800) 435-7627.
San Mateo County, California 1200 km^2 1:62,500	Susceptibility	G, HIS, GW, SPT	Eight categories of liquefaction susceptibility are mapped.	Youd, T.L. and J.B. Perkins, 1987, Map showing liquefaction susceptibility of San Mateo County, California: U.S. Geological Survey Miscellaneous Investigation Series Map I-1257-G, 1:62,500. *Available from:* USGS Information Services (800) 435-7627.
San Francisco, California 100 km^2 1:24,000	Susceptibility	G, HIS, GW, B, SPT	Maps denote areas of potential liquefaction where site-specific investigations must be conducted to assess the hazard.	CDMG, 1996, Seismic hazard zones, South half of San Francisco North and North part of the Oakland West Quadrangles: California Division of Mines and Geology Seismic Hazard Zone Map, 1:24,000. *Available from:* BPS Reprographic Services (415) 512-6550 and Universal Reprographics, Inc., (213) 365-7750.
Downtown San Francisco, California 14 km^2 1:24,000	Susceptibility; Potential (probability)	G, HIS, GW, B, SPT	Soil deposits having similar susceptibility to liquefaction are mapped and characterized. The probability of liquefaction of mapped deposits is estimated for ground motions of different intensities and return periods.	Kavazanjian, E., R.A. Roth, and H. Echezuria, 1985, Liquefaction potential mapping for San Francisco: Journal of Geotechnical Engineering, ASCE, v. 111, no. 1, pp. 54–76; Roth, R.A., and Kavazanjian, E., 1984, Liquefaction susceptibility mapping for San Francisco, California: Bulletin of the Association of Engineering Geologists, v. XXI, no. 4, pp. 459–478; Report to U.S. Geological Survey, Contract No. 14-08-0001-2059, by John A. Blume, Earthquake Engineering Center Report No. 52, Stanford University, 1983.

Table 2: Liquefaction Hazard Maps (continued)

Area Covered and Scale	*Type of Map*	*Susceptibility Basis (page 2)*	*Notes*	*Authors and References*
San Francisco, California Mission District (7.3 km^2); South of Market (11.6 km^2) Mission District (1:8,000); SOMA (1:10,000)	Ground failure (scenario earthquake)	HIS, GW, B, SPT, CPT	Predicts lateral spreading displacements for a 1906 San Francisco, California, earthquake based on correlation of actual 1906 displacements with fill thickness.	Pease, J.W., and T.D. O'Rourke, 1994, Liquefaction hazards in the Mission District and South of Market areas, San Francisco, California: Report to U.S. Geological Survey, Grant No. 14-08-0001-G2128, 194 pp. *Available from:* USGS Menlo Park, CA, library (415) 329-5027.
San Francisco Bay Counties, California 18,000 km^2 1:250,000	Potential (scenario earthquake)	G, HIS, GW, SPT	Scenario earthquake is a nearby magnitude 6.	ABAG, 1980, Liquefaction susceptibility, San Francisco Bay region: Association of Bay Area Governments, CA, 1:250,000. *Available from:* ABAG, Oakland, CA, (510) 464-7900.
San Francisco, California 1:100,000 Sheet 4,000 km^2 1:100,000	Susceptibility	G, HIS, GW	Seven categories of liquefaction susceptibility are mapped ranging from very high to very low.	Knudsen, K.L., J.S. Noller, J.M. Sowers, and W.R. Lettis, 1996, Maps showing Quaternary geology and liquefaction susceptibility in the San Francisco, California 1:100,000 sheet, Report to U.S. Geological Survey, Award No. 1434-94-G-2499 by William Lettis & Associates, Oakland, California (in press), to be published as U.S. Geological Survey Open-File Report. *Available from:* USGS Information Services (800) 435-7627.
Napa, California 1:100,000 Sheet 4,250 km^2 1:100,000	Susceptibility	G, HIS, GW	Seven categories of liquefaction susceptibility are mapped ranging from very high to very low.	Sowers, J.M., J.S. Noller, and W.R. Lettis, 1994, Maps showing Quaternary geology and liquefaction susceptibility in Napa, California, 1:100,000 sheet, Report to U.S. Geological Survey, Award No. 14-08-0001-G2129 by William Lettis & Associates, Oakland, California; U.S. Geological Survey Open-File Report 95-205. *Available from:* USGS Information Services (800) 435-7627.
Greater St. Louis area, Missouri 65km^2 1:50,000 (Journal article)	Potential (scenario earthquake)	G, GW, B	Scenario earthquake is an earthquake in the New Madrid seismic zone.	Higgins, J.D. and J.D. Rockaway, 1986, A graphics system for seismic response mapping: Bulletin of the Association of Engineering Geologists, v. XXIII, no. 1, pp. 77–91; Stephenson, R.W. and J.D. Rockaway, 1982, Soil response microzonation of St. Louis: Proceedings of the Third International Earthquake Microzonation Conference, Seattle, Washington, pp. 1429–1438; Stephenson, R.W. and J.D. Rockway, 1990, Seismic mapping of St. Louis County, Report to U.S. Geological Survey, Contract No. 14-08-0001-G-518. *Available from:* USGS Menlo Park, CA, library (415) 329-5027 (report).
Upper Manhattan and Central Buffalo, New York Upper Manhattan (15 km^2); Central Buffalo (28 km^2) 1:9,600	Potential (scenario earthquake)	GW, B, SPT	Scenario earthquake is magnitude 7.5 and peak ground acceleration of 0.15g.	Budhu, M., V. Vijayakumar, R.F. Giese, and L. Baumgras, 1993, Liquefaction potential of soils in portions of Upper Manhattan and Buffalo: Proceedings of National Earthquake Conference: Earthquake Hazard Reduction in the Central and Eastern United States: A Time for Examination and Action, Memphis, Tennessee. *Available from:* National Center for Earthquake Engineering Research, State University of New York at Buffalo (716) 645-3377 (report).
Portland Quadrangle (Multomah and Washington Counties, Oregon, and Clark County, Washington) 130 km^2, 1:24,000	Potential and ground failure (scenario earthquakes)	G, GW, B, SPT	Scenario earthquakes are a moment magnitude 8.5 earthquake at a distance of 100 km and a moment magnitude 6.5 earthquake at a distance of 10 km. Ground failure is characterized by amounts of lateral ground displacement.	Youd, T.L. and C.F. Jones, 1993, Liquefaction hazard maps for the Portland Quadrangle, Oregon: Earthquake Hazard Maps of the Portland Quadrangle, Multnomah and Washington Counties, Oregon, and Clark County, Washington, by Mabey, M.A., I.P. Madin, T.L. Youd, and C.F. Jones, Oregon Department of Geological and Mineral Industries GMS-79 Map Series, funded in part by U.S. Geological Survey, Award Nos. 14-08-0001-G1985, -G2132, and -G2324. *Available from:* State of Oregon, Department of Geology and Mineral Industries, Portland, Oregon, (503) 872-2750.

Table 2: Liquefaction Hazard Maps (continued)

Area Covered and Scale	*Type of Map*	*Susceptibility Basis (page 2)*	*Notes*	*Authors and References*
Mount Tabor Quadrangle (Multnomah County, Oregon and Clark County, Washington) 50 km^2 1:55,000	Potential (scenario earthquake)	G, GW, B, SPT	Four liquefaction hazard categories are defined based on thickness of liquefiable material and depth to groundwater.	Mabey, M.A., D.B. Meir, and S.P. Palmer, 1995, Relative earthquake hazard map of the Mount Tabor Quadrangle, Multnomah County, Oregon and Clark County, Washington: Oregon Department of Geology and Mineral Industries Geological Map Series, GMS-89, research supported by U.S. Geological Survey, Award Nos. 1434-93-G-2318, 1434-93-G-2324, and 14-08-0001-A0512. *Available from:* Oregon Department of Geology and Mineral Industries, Portland, Oregon, (503) 872-2750.
Beaverton Quadrangle, Clackamas and Washington Counties, Oregon 50 km^2 1:55,000	Potential (scenario earthquake)	G, GW, B, SPT	Four liquefaction hazard categories are defined based on thickness of liquefiable material and depth to groundwater.	Mabey, M.A., I.P Madin, and D.B. Meier, 1995, Relative earthquake hazard map of the Beaverton Quadrangle, Clackamas and Washington Counties, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-90, research supported by U.S. Geological Survey, Award Nos. 1434-93-G-2324 and 14-08-0001-A0512. *Available from:* Oregon Department of Geology and Mineral Industries, Portland, Oregon (503) 872-2750.
Lake Oswego Quadrangle, Clackamas and Multnomah Counties, Oregon 50 km^2 1:55,000	Potential (scenario earthquake)	G, GW, B, SPT	Four liquefaction hazard categories are defined based on thickness of liquefiable material and depth to groundwater.	Mabey, M.A., I.P Madin, and D.B. Meier, 1995, Relative earthquake hazard map of the Lake Oswego Quadrangle, Clackamas and Multnomah Counties, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-91, research supported by U.S. Geological Survey, Award Nos. 1434-93-G-2324 and 14-08-0001-A0512. *Available from:* Oregon Department of Geology and Mineral Industries, Portland, Oregon (503) 872-2750.
Gladstone Quadrangle, Clackamas and Multnomah Counties, Oregon 50 km^2 1:55,000	Potential (scenario earthquake)	G, GW, B, SPT	Four liquefaction hazard categories are defined based on thickness of liquefiable material and depth to groundwater.	Mabey, M.A., I.P Madin, and D.B. Meier, 1995, Relative earthquake hazard map of the Gladstone Quadrangle, Clackamas and Multnomah Counties, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-92, research supported by U.S. Geological Survey, Award Nos. 1434-93-G-2324 and 14-08-0001-A0512. *Available from:* Oregon Department of Geology and Mineral Industries, Portland, Oregon (503) 872-2750.
Siletz Bay Area, Coastal Lincoln County, Oregon 30 km^2 1:24,000	Potential (scenario earthquake)	G, GW, B, SPT, CPT	Four liquefaction hazard categories are defined based on thickness of liquefiable material for a magnitude 8.5 earthquake and a peak ground acceleration of 0.35 g.	Wang, Y. and W.J. Leonard, 1995, Liquefaction susceptibility map of the Siletz Bay Area, Coastal Lincoln County, Oregon, in Relative Earthquake Hazard Maps of the Siletz Bay Area, Coastal Lincoln County, Oregon, by Y. Wang and G.R. Priest: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-93. *Available from:* Oregon Department of Geology and Mineral Industries, Portland, Oregon (503) 872-2750.
Salem East and Salem West Quadrangles, Marion and Polk Counties, Oregon 270 km^2 1:24,000	Potential (scenario earthquake)	G, GW, B, SPT, CPT	Six categories of liquefaction susceptibility are defined based on thickness of liquefiable material for a magnitude 8.5 earthquake and a peak ground acceleration of 0.3 g.	Wang, Y. and W.J. Leonard, 1995, Relative earthquake hazard maps of the Salem East and Salem West Quadrangles, Marion and Polk Counties, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-105. *Available from:* Oregon Department of Geology and Mineral Industries, Portland, Oregon (503) 872-2750.

Table 2: Liquefaction Hazard Maps (continued)

Area Covered and Scale	*Type of Map*	*Susceptibility Basis (page 2)*	*Notes*	*Authors and References*
San Juan, Puerto Rico, Metropolitan area 37 km^2 1:40,000	Susceptibility	G, GW	Areas of high, moderate, and low liquefaction susceptibility are mapped.	Molinelli, J., 1987, Earthquake study for the metropolitan area of San Juan, Puerto Rico, in W.W. Hays and P.L. Gori, eds., Workshop on Assessment of Geologic Hazards and Risk in Puerto Rico: U.S. Geological Survey Open-File Report 87-008, pp. 49-113. *Available from:* USGS Information Services (800) 435-7627.
Charleston, South Carolina 12 km^2 1:63,000	Potential (probability)	GW, B, SPT	City is zoned into areas having similar probabilities of liquefaction. Note: Hadj-Hamou, Goni, and Elton, in Proceedings of the 1993 National Earthquake Conference: Earthquake Hazard Reduction in the Central and Eastern United States, Memphis, Tennessee, May 1993, present revised probabilities of liquefaction.	Elton, D.J. and T. Hadj-Hamou, 1990, Liquefaction potential map for Charleston, South Carolina: Journal of Geotechnical Engineering, ASCE, v. 116, no. 2, pp. 244–265; Hadj-Hamou, T. and D.J. Elton, 1988, Liquefaction Potential Map for Charleston, S.C., Report GT-88-1, Dept. of Civil Engineering, Tulane University, New Orleans, LA; U.S. Geological Survey, Award No. 14-08-0001-G1345. *Available from:* USGS Menlo Park, CA, library (415) 329-5027 (report).
Memphis, Tennessee 500 km^2 1:250,000	Potential (scenario earthquake)	GW, B, SPT	Scenario earthquake is a magnitude 6.4 earthquake at a distance of 50 km. Liquefaction potential was evaluated for only those soil deposits for which boring data existed.	Sharma, S. and W.D. Kovacs, 1982, Preliminary microzonation of the Memphis, Tennessee area: Bulletin of the Seismological Society of America, v. 72, no. 3, pp. 1011–1024; Sharma, S. and W.D. Kovacs, 1980, Microzonation of the Memphis, Tennessee area, Report to U.S. Geological Survey, Contract No. 14-08-0001-17752, U.S. Geological Survey Open-File Report No. 80-914. *Available from:* USGS Information Services (800) 435-7627.
Memphis and Shelby County, Tennessee 2,000 km^2 1:500,000	Potential (scenario earthquake)	GW, B, SPT	Scenario earthquake is moment magnitude 7.5 on the New Madrid seismic zone.	Hwang, H. and C.S. Lee, 1992, Evaluation of Liquefaction Potential in Memphis Area, USA: Proceedings of the Tenth World Conference on Earthquake Engineering, Madrid, Spain, pp. 1457–1460; National Center for Earthquake Engineering Research Contract No. NCEER-90-3009 (NSF Grant No. ECE-86-07591).
El Paso, Texas 1,250 km^2 1:48,000	Susceptibility	G, GW, B, SPT	Hazards of surface fault rupture, tectonic deformation, and landsliding evaluated in addition to liquefaction hazard.	Keaton, J.R., 1993, Maps of potential earthquake hazards in the urban area of El Paso, Texas, Report to U.S. Geological Survey, Contract No. 1434-92-G-2171, by SHB AGRA, Inc., El Paso, Texas. *Available from:* USGS Denver, CO, library (303) 236-1000.
Northern Wasatch Front, Utah (portions of Cache, Weber, and Box Elder Counties) 3,400 km^2 1:48,000	Potential (probability)	G, GW, B, SPT, CPT	Liquefaction potential categories are based on the probability of liquefaction in 100 years: High (> 50%), Moderate (50-10%), Low (10-5%), Very Low (< 5%).	Anderson, L.R., J.R. Keaton, and J.A. Bay, 1990, Liquefaction potential map for the northern Wasatch Front, Utah: Utah Geological Survey Complete Technical Report No. 94-6, Report to U.S. Geological Survey, Contract No. 14-08-0001-22015, by Department of Civil and Environmental Engineering, Utah State University, Logan, Utah. *Available from:* Utah Geological Survey, Salt Lake City, Utah (801) 537-3320.
Central Utah (portions of Summit, Wasatch, Juab, Sampete, Millard, and Sevier Counties) 12,000 km^2 1:48,000	Potential (probability)	G, GW, B, SPT, CPT	Liquefaction potential categories are based on the probability of liquefaction in 100 years: High (>50%), Moderate (50-10%), Low (10-5%), Very Low (< 5%).	Anderson, L.R., J.R. Keaton, and J.D. Rice, 1990, Liquefaction potential map for central Utah: Utah Geological Survey Complete Technical Report No. 94-10, Report to U.S. Geological Survey, Contract No. 14-08-0001-G1384, by Department of Civil and Environmental Engineering, Utah State University, Logan, Utah. *Available from:* Utah Geological Survey, Salt Lake City, Utah (801) 537-3320.

Table 2: Liquefaction Hazard Maps (continued)

Area Covered and Scale	*Type of Map*	*Susceptibility Basis (page 2)*	*Notes*	*Authors and References*
Davis County, Utah 680 km^2 1:48,000	Potential (probability)	G, GW, B, SPT	Liquefaction potential categories are based on the probability of liquefaction in 100 years: High (> 50%), Moderate (50-10%), Low (10-5%), Very Low (<5%).	Anderson, L.R., J.R. Keaton, K. Aubrey, and S. Ellis, 1982, Liquefaction potential map for Davis County, Utah: Utah Geological Survey Complete Technical Report No. 94-7, Report to U.S. Geological Survey, Contract No. 14-08-0001-19127, by Department of Civil and Environmental Engineering, Utah State University, Logan, Utah, and Dames & Moore, Salt Lake City, Utah. *Available from:* Utah Geological Survey, Salt Lake City, Utah (801) 537-3320.
Utah County, Utah 2,700 km^2 1:48,000	Potential (probability)	G, GW, B, SPT, CPT	Liquefaction potential categories are based on the probability of liquefaction in 100 years: High (> 50%), Moderate (50-10%), Low (10-5%), Very Low (< 5%).	Anderson, L.R., J.R. Keaton, and J.E. Bischoff, 1994, Liquefaction potential map for Utah County, Utah: Utah Geological Survey Complete Technical Report No. 94-8, Report to U.S. Geological Survey, Contract No. 14-08-0001-21359 by Department of Civil and Environmental Engineering, Utah State University, Logan, Utah, and Dames & Moore, Salt Lake City, Utah. *Available from:* Utah Geological Survey, Salt Lake City, Utah (801) 537-3320.
Salt Lake County, Utah 1,750 km^2 1:48,000	Potential (probability)	G, GW, B, SPT, CPT	Liquefaction potential categories are based on the probability of liquefaction in 100 years: High (> 50%), Moderate (50-10%), Low (10-5%), Very Low (< 5%).	Anderson, L.R., J.R. Keaton, J.E. Spitzley, and A.C. Allen, 1986, Liquefaction potential map for Salt Lake County, Utah: Utah Geological Survey Complete Technical Report No. 94-9, Report to U.S. Geological Survey, Contract No. 14-08-0001-19910, by Department of Civil and Environmental Engineering, Utah State University, Logan, Utah, and Dames & Moore Consulting Engineers, Salt Lake City, Utah. *Available from:* Utah Geological Survey, Salt Lake City, Utah (801) 537-3320.
State of Utah 220,000 km^2 1:3,000,000	Ground failure (probability)	—	Liquefaction Severity Index (LSI) (see text) is mapped for 10% probability of exceedance in time periods of 10, 50, 250, and 1000 years.	Mabey, M.A. and T.L. Youd, 1989, Probabilistic liquefaction severity index maps of the State of Utah: Utah Geological and Mineral Survey Open-File Report No. 159, Salt Lake City, Utah. *Available from:* Utah Geological Survey, Salt Lake City, Utah (801) 537-3320.
Des Moines and Renton 7.5-minute Quadrangles, Washington 235 km^2 1:24,000	Susceptibility	G, HIS, GW, B, SPT	Areas of high, low-to-high, low, and low-to-nil liquefaction susceptibility are mapped.	Palmer, S.P., H.W. Schasse, and D.K. Norman, 1994, Liquefaction susceptibility for the Des Moines and Renton 7.5-minute Quadrangles, Washington: Washington Division of Geology and Earth Resources, Geologic Map GM-41, Olympia, Washington, funded by U.S. Geological Survey Cooperative Agreement No. 14-08-001-A0509 and Federal Emergency Management Agency. *Available from:* Washington State Department of Natural Resources, Division of Geology and Earth Resources, Olympia, Washington (360) 902-1450.
Auburn and Poverty Bay 7.5-minute Quadrangles, Washington 255 km^2 1:24,000	Susceptibility	G, HIS, GW, B, SPT	Areas of high, moderate, and low liquefaction susceptibility are mapped.	Palmer, S.P., T.J. Walsh, R.L. Logan, and W.J. Gerstel, 1995, Liquefaction susceptibility for the Auburn and Poverty Bay 7.5-minute Quadrangles, Washington: Washington Division of Geology and Earth Resources, Geologic Map GM-43, Olympia, Washington, partially funded by U.S. Geological Survey Cooperative Agreement No. 14-08-001-A0509 and Federal Emergency Management Agency. *Available from:* Washington State Department of Natural Resources, Division of Geology and Earth Resources, Olympia, Washington (360) 902-1450.

Table 2: Liquefaction Hazard Maps (continued)

Area Covered and Scale	*Type of Map*	*Susceptibility Basis (page 2)*	*Notes*	*Authors and References*
Sumner 7.5-minute Quadrangle, Washington 125 km^2 1:24,000	Susceptibility	G, HIS, GW, B, SPT, CPT	Areas of high, low-to-moderate, and low liquefaction susceptibility are mapped.	Dragovich, J.D. and P.T. Pringle, 1995, Liquefaction susceptibility for the Sumner 7.5-minute Quadrangle, Washington: Washington Division of Geology and Earth Resources, Geologic Map GM-44, Olympia, Washington, partially funded by Federal Emergency Management Agency. *Available from:* Washington State Department of Natural Resources, Division of Geology and Earth Resources, Olympia, Washington (360) 902-1450.
Seattle, Washington 230 km^2 1:24,000	Potential (scenario earthquake)	G, HIS, GW, B, SPT	Scenario earthquake is a magnitude 7.5 earthquake causing a peak ground acceleration of 0.30g.	Grant, W.P., W.J. Perkins, and T.L. Youd, 1992, Evaluation of liquefaction potential, Seattle, Washington: U.S. Geological Survey Open-File Report 91-441-T, Report to U.S. Geological Survey by Shannon & Wilson, Inc., Seattle, Washington. *Available from:* USGS Information Services (800) 435-7627.
Tacoma, Washington 500 km^2 1:100,000	Potential (scenario earthquake)	G, HIS, GW, B, SPT	Scenario earthquake is a magnitude 7.5 earthquake causing a peak ground acceleration of 0.30g.	Grant, W.P., 1993, Evaluation of liquefaction potential, Tacoma, Washington, Report to U.S. Geological Survey, Award No. 14-08-0001-G-1978, by Shannon & Wilson, Inc., Seattle, Washington. *Available from:* USGS, Menlo Park, CA, library (415) 329-5027.
Central United States—Arkansas, Illinois, Indiana, Kentucky, Missouri, Mississippi, Tennessee 160,000 km^2 1:1,000,000	Potential (scenario earthquake)	G	Area mapped is within area of Modified Mercalli Intensity ŠIX of the 1811–12 earthquakes in New Madrid seismic zone.	Obermeier, S.F. and N. Wingard, 1985, Potential for liquefaction in areas with Modified Mercalli Intensity IX and greater, *in* M.G. Hopper, ed., Estimation of Earthquake Effects Associated with Large Earthquakes in the New Madrid Seismic Zone: U.S. Geological Survey Open-File Report 85-457, pp. 92–99. *Available from:* USGS Information Services (800) 435-7627.
National Map 4,800,000 km^2 1:23,000,000	Ground failure (probability)	—	National map presents Liquefaction Severity Index (LSI) contours (see text) for selected probabilities of exceedance as a function of regional earthquake recurrence.	Turner, W.G. and T.L. Youd, 1987, National map of liquefaction hazard, Report to U.S. Geological Survey, Grant No. 14-08-0001-G1187, by Department of Civil and Environmental Engineering, Brigham Young University, Provo, Utah. *Available from:* USGS Menlo Park, CA, library (415) 329-5027.

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