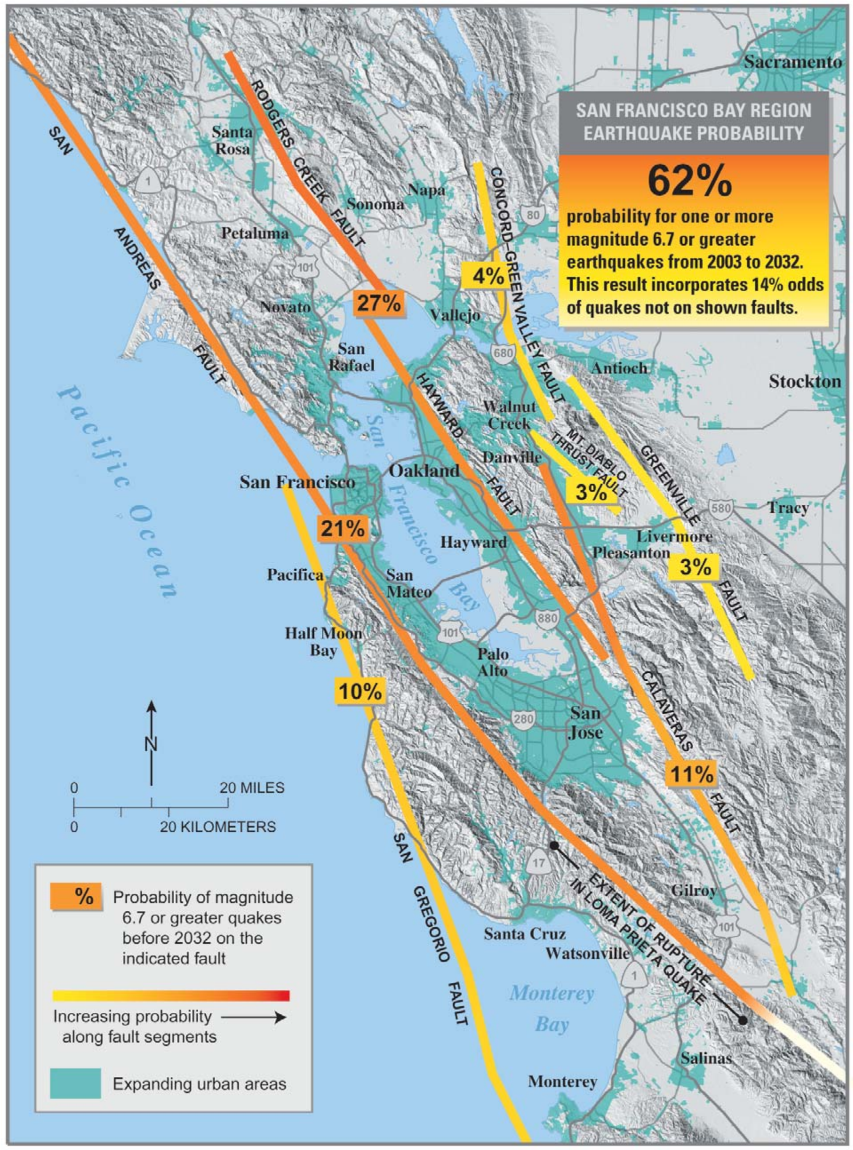
UNDERSTANDING EARTHQUAKE HAZARDS IN THE SAN FRANCISCO BAY REGION

Is a Powerful Quake Likely to Strike in the Next 30 Years?

Using newly collected data and evolving theories of earthquake occurrence, U.S. Geological Survey (USGS) and other scientists now conclude that there is a 62% probability of at least one magnitude 6.7 or greater quake, capable of causing widespread damage, striking somewhere in the San Francisco Bay region before 2032. A major quake can occur in any part of this densely populated region. Therefore, there is an ongoing need for all communities in the Bay region to continue preparing for the quakes that will strike in the future.



The threat of earthquakes extends across the entire San Francisco Bay region, and a major quake is likely before 2032. Knowing this will help people make informed decisions as they continue to prepare for future quakes.

Since the great earthquake of 1906, no major quake has been centered near a densely urbanized part of the San Francisco Bay region. Although the 1989 magnitude 6.9 Loma Prieta quake killed more than 40 people in the region's urban core, it was centered in mountainous country 50 miles south of San Francisco. In 1995, when a quake of the same magnitude struck Kobe, Japan, another bayside urban area thought to be well prepared for earthquakes, more than 6,000 people died and the damage amounted to $100 billion. Had the Loma Prieta quake been centered in San Jose, Oakland, or San Francisco, similar losses could have occurred.

Damaging earthquakes are inevitable in the Bay region, but taking actions based on the likelihood of future quakes will help save lives and protect property. Following the Loma Prieta quake, the U.S. Geological Survey's (USGS) Working Group on California Earthquake Probabilities reassessed the likelihood of large quakes striking the Bay region and issued a report in 1990.

Since then, scientists have gained new insights into Bay region earthquakes, providing a better basis for determining future quake probabilities. The USGS working group was expanded to include about 100 scientists from Federal and State of California agencies, consulting firms, industry, and universities. In 1999, results from this expanded working group were published in USGS Fact Sheet 152-99 and USGS Open-File Report 99-517. The efforts of this continuing working group, now called WG02, have produced a new assessment of Bay region earthquake probabilities that is published in this Fact Sheet and more fully in a USGS Open-File Report. WG02 determined that there is a 62% chance of at least one magnitude 6.7 or greater earthquake striking the San Francisco Bay region between 2003 and 2032.

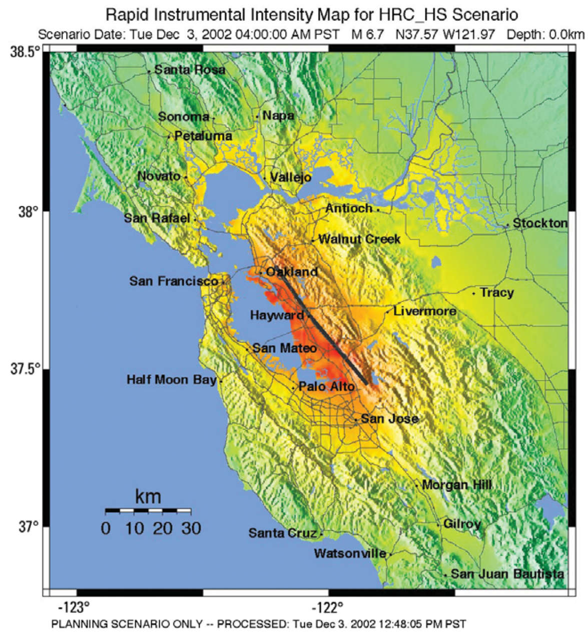
The population of this region is projected to exceed 8.2 million people by 2025—an increase of more than 1.4 million from the 2000 census level. Nearly all of this growth is expected to occur in the northern and eastern parts of the region. Solano, Napa, and Sonoma Counties are anticipated to show the highest growth, adding more than 30% to their populations. Contra Costa, Alameda, and Santa Clara Counties are projected to see a 15 to 20% increase in population.

This eastward and northward growth of the region will occur in areas of significant seismic hazard, a fact not fully appreciated until recently. The cumulative 30-year probability of an earthquake of magnitude 6.7 or greater occurring somewhere within these rapidly growing northern and eastern areas alone is nearly 50%.

Residents living near the Pacific coast in San Mateo, Santa Cruz, and Monterey Counties are sandwiched between the San Andreas and San Gregorio Faults. These two faults have a combined 34% chance of producing one or more magnitude 6.7 or greater quakes in these coastal areas before 2032.

When the 1990 USGS probability report was released, earthquake likelihood could be estimated only for the San Andreas Fault and the Hayward-Rodgers Creek Fault, although the danger posed by other faults was recognized. WG02 found that, of all the faults in the Bay region, these two and the Calaveras Fault still pose the greatest threat, because they have high quake odds and run through the region's urban core.

Since 1990, new data have allowed five additional faults to be included in the probability calculations. Furthermore, there is now a focus on events of magnitude 6.7 and greater rather than 7 and greater, because the 1994 Northridge quake in southern California was only magnitude 6.7 yet killed 57 people and caused more than $20 billion in damage. Including more faults and smaller events would be expected to increase the estimated regional probability of major quakes. This expected increase was more than compensated for, however, by two effects not included in the 1990 report: (1) gradual slip on faults in the absence of earthquakes and (2) the effect of the 1906 earthquake in reducing quake activity throughout the region.



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
MODIFIED MERCALLI INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

This "ShakeMap" shows the shaking intensities expected for a hypothetical scenario earthquake (magnitude 6.7) on the southern Hayward Fault, which last ruptured in 1868 in an event of magnitude about 6.9. Note that damaging shaking would occur over a wide tract and be especially severe around the margins of the Bay in areas underlain by bay mud. The 1868 shock destroyed a number of buildings in San Francisco. The photo below shows one wrecked building in what is now San Francisco's Financial District, mostly built on bay mud and artificial fill. (Photograph courtesy of the Karl V. Steinbrugge Collection, Earthquake Engineering Research Center, University of California, Berkeley.)

The rate of large earthquakes in the Bay region dropped abruptly after the 1906 earthquake and has only slightly increased during the last few decades. How long it will take to again reach the level of activity seen in the late 1800's is a question that WG02 carefully evaluated. The new average regional quake probability of 62% is a result of considering several earthquake theories, which produce probabilities from 37 to 87%. As earthquake science progresses, this and other uncertainties should diminish and the average probability may change.

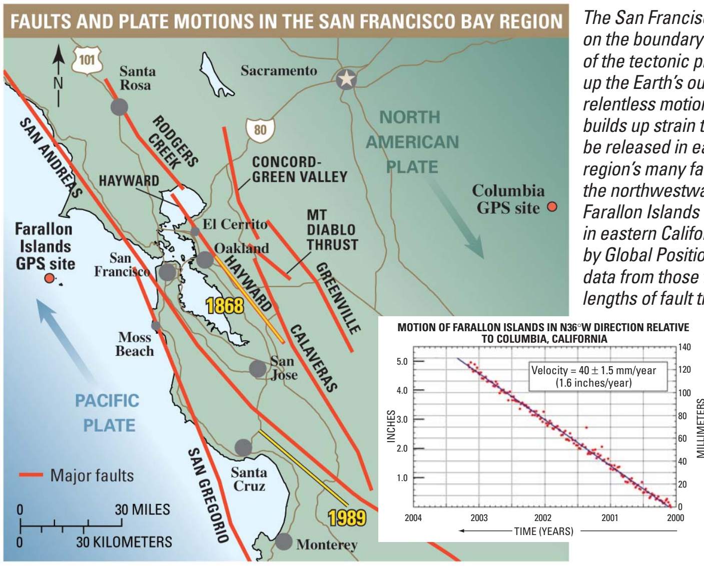
Any magnitude 6.7 or greater quake can cause damage throughout the Bay region, but even a smaller quake could have serious effects if centered in an urbanized area. WG02 found at least an 80% chance of one or more magnitude 6 to 6.6 quakes occurring in the Bay region before 2032.

Earthquake probabilities are only one component in the evaluation of earthquake hazard and risk. Local soil conditions, bedrock type, quality of construction, susceptibility to earthquake-induced ground failures or flooding (caused by dam or levee failure) can all profoundly affect the possibility of damage at a particular site in an earthquake. This was dramatically demonstrated by the 1989 Loma Prieta earthquake, which devastated vulnerable parts of Oakland and San Francisco more than 50 miles from the fault rupture.

WG02 has examined possible earthquake scenarios on all of the major Bay region faults and assigned probabilities to the occurrence of these events over the next 30 years. A next step in hazard assessment is the estimation of intensity of ground shaking from each such scenario earthquake, taking into account the location, length, and magnitude of the anticipated rupture and the ground conditions (bedrock and soil types) at various locations around the Bay region. For example, a shock on the southern Hayward Fault, which last ruptured in 1868 in an earthquake of magnitude about 6.9, would produce damaging shaking over a wide area.

The estimated distribution of shaking intensities in the Bay region from a scenario event, combined with the probability of that event happening in a given time period, yields an estimated frequency of occurrence of that dis-

FAULTS AND PLATE MOTIONS IN THE SAN FRANCISCO BAY REGION



The San Francisco Bay region lies on the boundary zone between two of the tectonic plates that make up the Earth's outer shell. The relentless motion of these plates builds up strain that will eventually be released in earthquakes on the region's many faults. Inset shows the northwestward movement of the Farallon Islands relative to Columbia in eastern California, as documented by Global Positioning System (GPS) data from those two sites. The lengths of fault that slipped in the 1868 Hayward and 1989 Loma Prieta magnitude 6.9 earthquakes are shown in yellow.

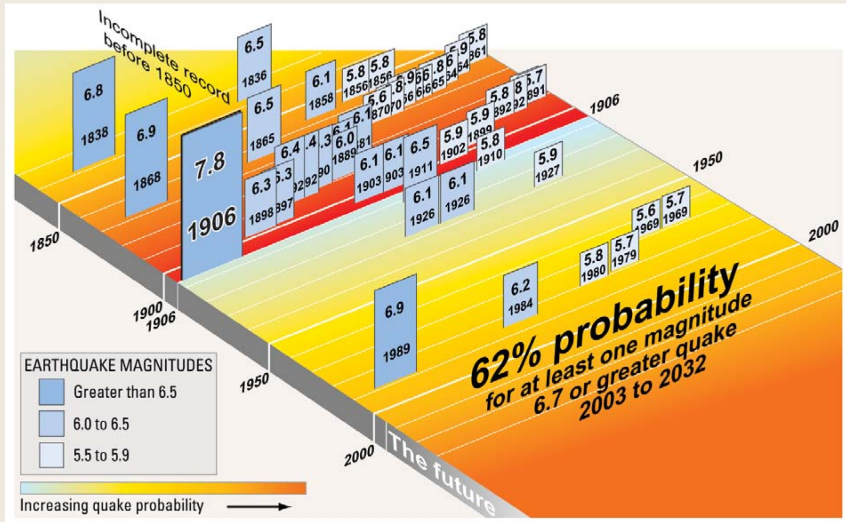
EARTHQUAKE ODDS—A BALANCING ACT

Quake probabilities for the San Francisco Bay region are derived by balancing two processes—(1) the motions of the plates that make up the Earth's outer shell and (2) the slip on faults, which occurs primarily during earthquakes. The continual northwestward motion of the Pacific Plate past the North American Plate loads strain onto the network of active faults that slice through the region. Earthquakes sporadically release and redistribute this strain.

One side of the balance is the rate at which plate motions load strain onto faults. Development of the Global Positioning System (GPS) has allowed geophysicists to make accurate measurements of how the current plate motions—totaling 1.6 inches per year across the entire Bay region—distribute strain onto individual faults. Geologic studies also contribute to this understanding by documenting long-term fault slip, which must match the strain-loading rate. For example, on the San Gregorio Fault near Moss Beach, a buried stream channel has been offset about 1,000 feet over the past 80,000 years, giving a local slip rate of about one-sixth of an inch per year.

On the other side of the balance is slip on faults, primarily during earthquakes. Data from seismograms, historical accounts, and trenches that reveal buried fault ruptures provide information about past quakes in the San Francisco Bay region. U.S. Geological Survey and other scientists reanalyzed seismograms and historical accounts and excavated many new trenches across faults as part of recent reassessments of earthquake hazards in the region. For example, a trench in El Cerrito revealed evidence of four to seven large quakes on the Hayward Fault during the past 2,200 years. Unfortunately, seismogram records only go back to about 1900, historical accounts in this region are fragmentary before 1850, and trenches are effective only in some locations.

Supplementing these data with up-to-date knowledge about how faults work, scientists are able to make better projections of the expected sizes and locations of future quakes. If Earth scientists can identify the lengths of fault segments that may rupture in an earthquake, they can estimate the magnitudes and amounts of slip for possible future quakes.



The rate of large earthquakes in the San Francisco Bay region dropped abruptly after the Great 1906 Earthquake. The San Andreas Fault slipped so much over such a great length in that quake that the strain was reduced on most faults throughout the region. Strain has been slowly building up again. However, the level of seismic activity has not yet reached that of the late 1800's.

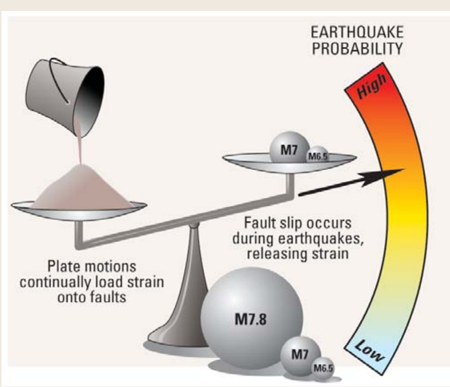
For example, the magnitude 7.8 San Francisco earthquake of 1906 ruptured 300 miles of the San Andreas Fault and produced as much as 25 feet of slip, whereas the magnitude 6.9 Loma Prieta quake in 1989 ruptured only 25 miles of fault and produced only about 6 feet of slip. Scientists identify fault segments by studying bends, intersections, and gaps in faults, past earthquake ruptures, and major changes in rock types along faults.

Reading the Balance

Over millennia the balance between plate motions and slip on faults must even out, and therefore average long-term earthquake probabilities can be reliably calculated. However, calculating accurate odds for a short time period such as 30 years is more difficult, and alternative models lead to different results. For example, the rate of large quakes in the Bay region was high in the late 1800's but dropped abruptly after the 1906 San Francisco earthquake. Scientists believe that this rate dropped because the San Andreas Fault slipped so much over such a great length in 1906 that the strain was reduced on most faults throughout the region. Because plate motions are continuous, strain has been slowly building up again, and strong earthquakes began to reoccur in the 1980's. However, the level of seismic activity in the Bay region has not yet reached that of the late 1800's. Some earthquake models forecast that this relatively low level of activity should continue for some time and that earthquake probabilities therefore will be lower than average. Other models, in which earthquakes on different faults recur on somewhat regular schedules, yield higher than average probabilities for the next few decades.

At some point, the rate of earthquakes in the Bay region must increase so that the balance will once again even out. Earth scientists do not agree on how soon this may happen, because they do not yet sufficiently understand the process by which strain reductions are imposed by large earthquakes and are removed by plate motions and the slow deformation of the Earth. We know what is on the two sides of the balance, but do not know all the details of how the balance really works.

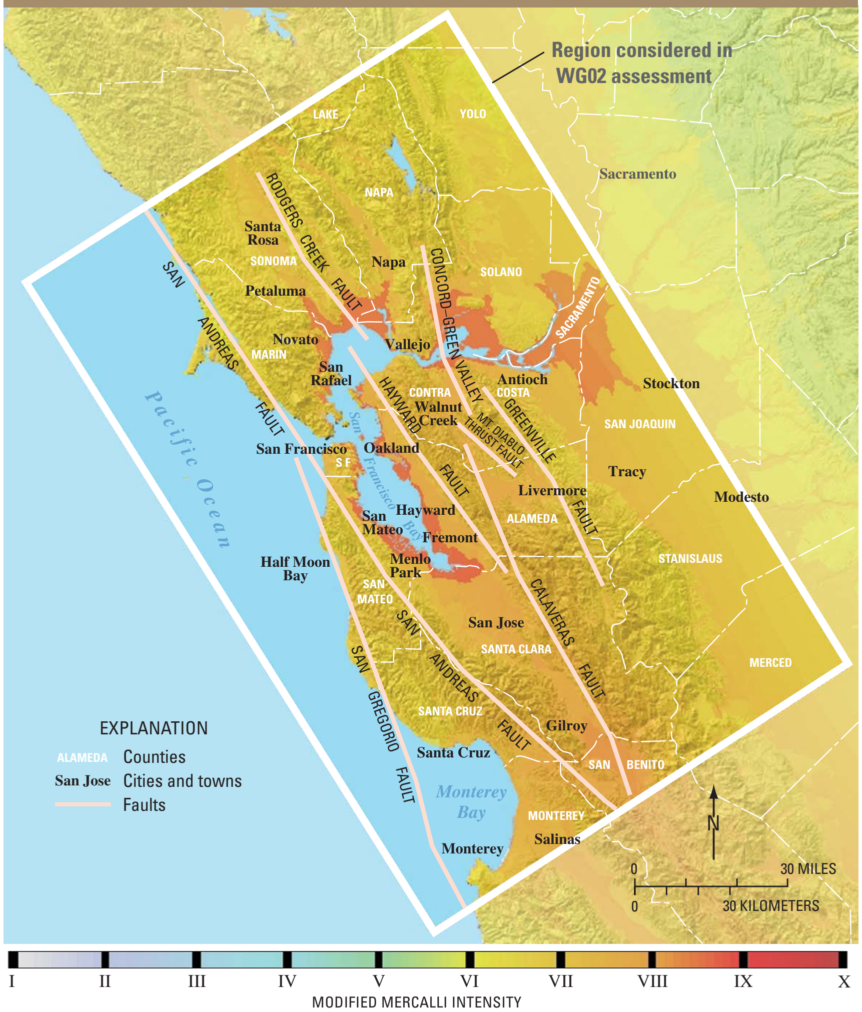
Given the uncertainty in how to model future earthquake behavior, determining earthquake probabilities involves making many decisions, such as defining fault segments and choosing among alternative statistical models. Because such decisions are uncertain, recent reassessments of Bay region earthquake probabilities have assigned weights to the various choices so that all were included in the overall calculations. These weights led to an average result of 62%, but this value could be as low as 37% or as high as 87%, given the uncertainties in these choices. Regardless, the San Francisco Bay region has substantial earthquake hazard.



Quake probabilities are derived by balancing two processes—(1) the continual motions of the plates that make up the Earth's outer shell (represented by pouring sand onto the left tray) and (2) the slip on faults, which occurs primarily during earthquakes (equivalent to adding balls to the right tray). The slip on faults over time must balance the strain built up by the plate motions. The total amount of slip during an earthquake, shown here by the proportional volumes of the spheres, depends on its magnitude (M). The larger the quake, the more strain released.

Knowledge of past earthquakes is essential for estimating the odds of future temblors. This knowledge comes from historical damage accounts, fault ruptures exposed in trenches, and seismographic records.

SHAKING INTENSITIES WITH 50% CHANCE OF BEING EXCEEDED IN THE NEXT 30 YEARS



This map, derived by combining the predicted frequencies and intensities of shaking from all likely earthquake scenarios in the San Francisco Bay region, shows levels of shaking that have a 50% chance of being exceeded over the next 30 years. Most populated areas of the region have even odds of experiencing shaking of intensity VII or greater on the Modified Mercalli Intensity (MMI) scale, sufficient to cause moderate damage. Areas on soft soil, such as on the edges of the Bay, have even odds of experiencing MMI intensity VIII or greater, capable of causing serious structural damage.

tribution of shaking intensities. By using such information from all anticipated scenario ruptures in the region, an overall probability can be calculated that a location will experience at least a given level of shaking within a specific time period, say the expected lifetime of a building—a probability of considerable interest to building designers and structural engineers.

The final layer in the assessment of risk involves combining the level of hazard with the quantity and vulnerability of structures exposed to the hazard. The earthquake hazard has been shown to extend throughout the entire Bay region, but the local risk and potential loss depend on the exposure. A densely built urban area with an expectation of high shaking intensity is clearly at greater risk than an agricultural area with the same expected level of shaking. An analysis of potential earthquake losses in the Bay region conducted by the USGS and the California Geological Survey indicates that areas along the Hayward Fault have the highest likely proportional loss of any parts of the region. This high potential loss is the result of dense development directly along and adjacent to the Hayward Fault and the fact that earthquakes on the Hayward, though smaller than those on the San Andreas Fault, occur more frequently.

Large earthquakes in the San Francisco Bay region can produce sudden and tremendous loss of life and property, threatening the region's social and economic fabric.

Although quakes cannot be prevented, the damage they do can be greatly reduced through prudent planning and preparedness. Much preparation has already been done, but because a large quake is likely and could happen at any moment, further preparations should not be delayed.

WG02's reassessment of earthquake probabilities in the Bay region reaffirms that the earthquake hazard is both high and widely spread. This reassessment will help business, government, and the public make informed choices as they continue their earthquake preparations. Using the new knowledge on the level of earthquake hazard and the degree of exposure and vulnerability in different parts of the Bay region, USGS and other scientists are working with decisionmakers to help plan and prioritize mitigation efforts and strategies. The ongoing work of USGS and other scientists in evaluating earthquake probabilities for the San Francisco Bay region is part of the National Earthquake Hazard Reduction Program's efforts to safeguard lives and property from the future quakes that are certain to strike in northern California and elsewhere in the United States.

SIMPLE STEPS TO EARTHQUAKE PREPAREDNESS

Before the next quake, learn:

- **What to do during a quake,**
- **What supplies to have on hand, and**
- **How to make sure your home, office, and schools are safe.**

Some good places to get preparedness information are the front of telephone directories, libraries, Red Cross (http://www.bayarea-redcross.org/), California Governor's Office of Emergency Services (510-286-0873; http://www.oes.ca.gov/), Association of Bay Area Governments (http//www.abag.ca.gov/), and U.S Geological Survey (http://earthquake.usgs.gov).

Andrew J. Michael, Stephanie L. Ross, Robert W. Simpson, Mary Lou Zoback, David P. Schwartz, Michael L. Blanpied, and Working Group 2002

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COOPERATING ORGANIZATIONS
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California Geological Survey
California Governor's Office of Emergency Services
Federal Emergency Management Agency
Lawrence Livermore National Laboratory
Geomatrix Consultants Inc.
Pacific Gas and Electric Company
University of California at Berkeley
William Lettis & Associates
Many other institutions, organizations, and firms

For more information contact:
Earthquake information Hotline (650) 329-4085
U.S. Geological Survey, Mail Stop 977
345 Middlefield Road, Menlo Park, CA 94025
http://earthquake.usgs.gov

See also *The USGS Earthquake Hazards Program in NEHRP—Investing in a Safer Future* (USGS Fact Sheet 017-03), *"ShakeMaps"—Instant Maps of Earthquake Shaking* (USGS Fact Sheet 103-00), *When Will the Next Great Quake Strike Northern California?* (USGS Fact Sheet 094-96), and *Hazard Maps Help Save Lives and Property* (USGS Fact Sheet 183-96)
This fact sheet and any updates to it are available online at:
http://geopubs.wr.usgs.gov/fact-sheet/fs039-03

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